Route knowledge in Germany: A simulator study

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Abstract. Train drivers are only permitted to drive on a public railway infrastructure if they have the required knowledge of the route, which means that they are familiar with all specifics and characteristics of the route. Route knowledge is usually obtained by accompanying an experienced driver. Today`s approaches for obtaining route knowledge are organisationally difficult and time consuming. This paper presents an experiment which has researched if modern media is as good as existing methods for teaching route knowledge.

Keywords. User experience, measuring, case study, questionnaire.

1. Motivation

The European Union wants to harmonize the European railway sector (Eisenbahn-Bundesamt (2016)). It is planned to adapt the technical standards and to develop common safety method as well as to set common safety goals which are one day applicable to the whole European railway (European Parliament (2004)). For the safety and the interoperability of European railway operations not only technical aspects are relevant, but also non-technical issues like, e.g. the training and the required knowledge of train drivers have to be discussed and in some way – taking into account today's conditions – harmonized. An example for this is the aspect of route knowledge which exists in most countries but the concrete conditions and the importance varies widely.

In Germany, a train driver obtains route knowledge by studying operational documents and by experiencing the route – e.g. as a train driver accompanied by an experienced train driver or by accompanying another train driver (Eisenbahn-Bundesamt (2016)).

For vertical integrated railway companies where train drivers regularly drive on larger parts of the network, training route knowledge should not be too difficult (Pachl (2003)). However, in the last decade many small railway companies have entered the market. In contrast to larger companies and to how it used to be, their train drivers drive on very different parts of a network and often on short notice. For these smaller companies always having train drivers with the necessary route knowledge available is difficult.

In this situation, a first approach to make it easier for train drivers to obtain route knowledge is to simplify the current approach for training it. Modern media, e.g. films or computer simulations, can be very helpful in reaching that goal. In this paper, we present the results of a PhD project which compared different approaches for training route knowledge. Based on the results of a literature study and a questionnaire three scenarios were chosen and evaluated with a simulator study.

2. What is route knowledge in Germany?

Route knowledge is a prerequisite before a train driver can start travelling. In the Triebfahrzeugführschein-Verordnung (2016) route knowledge is defined as "…by looking at the route and studying the operational documents obtained knowledge of such characteristics of a route that a train driver needs additionally to signal information and timetable information to drive safely, on schedule and economically."

In the VDV-Schrift 755 (2016) is also gives an open list of what aspects can be important for route knowledge. Listed examples are

- Operating procedures, e.g. where procedures change,
- Signals and signalling systems, e.g. position of signals, end of switch area,
- Route infrastructure, e.g. route topography, train radio, stopping place,
- Knowledge about stations, e.g. speed, possible routes.

The given aspects in VDV-Schrift 755 (2016) are of general nature only. Due to missing a clear and complete definition of the term "route knowledge", the discussion about the necessity of route knowledge and its effects on train operation is difficult and no conclusion has been reached yet. Therefore, instead of discussing if route knowledge is needed or not, it seems sensible to assess as a first step how to make obtaining route knowledge easier and less complicated. This would support an overall successful railway system while at the same time guaranteeing safety.

In VDV-Schrift 755 (2016) the general options for obtaining route knowledge in Germany are listed:

- The train driver drives accompanied by a person with route knowledge.
- The train driver accompanies another train driver in the cab.
- The train driver studies films which show the original route.
- The train driver drives with a simulator on an original simulation of the route.
- The train driver walks along the infrastructure.

Based on this general classification every railway organisation can decide for themselves how exactly the train drivers are trained. Usually train drivers drive accompanied by experienced train drivers or train drivers accompanying experienced train drivers. This approach has several advantages and disadvantages.

A huge advantage is that train drivers are trained based on actual practical experience. This will include official information but can also mean soft factors which are not part of any official guideline. Also, information presented by an actual train driver might be better accepted than information given in a classroom by a teacher. Besides these advantages, there are also significant disadvantages. The communicated information depends on the person of the experienced driver. Human factors (e.g. fatigue, personal relationship) will influence the resulting route knowledge. Also, every teaching driver will focus on different aspects so there will not be the same level of route knowledge amongst train drivers.

More flexible ways of training route knowledge are allowed by the regulation but hardly ever used. In Germany, films were produced and used when a new line was built because many train drivers had to be trained in a short time. But modern media is not necessary a good or even better solution than the traditional trainings. Advantages are that, e.g. when using films, these can be updated with additional information like photos or figures. It is easier to control which information are given as the media are generally developed under the guidance of a railway company. This also allows highlighting aspects which are considered important, e.g. relating to service or safety culture. Training route knowledge becomes more flexible because the learning driver can choose when and probably where he wants to watch the films. The presentations can be stopped or repeated as often as possible. Last but not least, benchmarking is possible, e.g. by including tests which allow to actually prove that a driver has a certain level of knowledge. But there are also disadvantages. If questions arise the train driver cannot just ask someone directly. Often it is said by train drivers that route knowledge is more than knowledge but also a certain feel for the route and the driving experience (Lorenz (2017)). This also helps to remember. This is missing when training with digital media. Also, an official document will always only include official information. Aspects, which are rather informal but help a driver, will probably not be included in the documents.

3. Research project

There exists hardly any literature which discusses the different aspects of (German) route knowledge. Some research was down in the UK, but due to the general differences in, e.g. the signalling system these results cannot be easily transferred.

The research project consists of two parts. First, a questionnaire was designed and widely distributed to gather information about the train drivers` view of route knowledge. The results of this part of the project were published by Lorenz and Milius (2016). Based on the results of this questionnaire the general research question was detailed and the experiment was planned and performed. The simulator study, which was done at the TU Braunschweig lab, is the first one in Germany evaluating the different options of training route knowledge. The following questions are to be answered by the research:

- Is modern media just as suitable as the traditional methods for training route knowledge?
- Is it sufficient to drive with limited route knowledge (as defined in Germany`s standards, where the train driver has studied operational documents but has not seen the route)?

4. Training of route knowledge: Comparison of different approaches

As already stated with the general research question, the main idea is the comparison of traditional methods of route knowledge training with more modern approaches. Therefore, the following three groups (i.e. three stages) of the independent variable “Method to obtain route knowledge” were designed:

- Training of route knowledge by studying operational documents only (e.g. schedule, signalling plans) (group is called ”Limited”)
- Training of route knowledge by accompanying a driver first and driving accompanied afterwards (group is called ”Driving”)
- Training of route knowledge by using a computer-based training course (group is called “CBT”)

The following hypotheses were developed and evaluated in the experiment:

- Hypotheses A: Driving after obtaining route knowledge by accompanied driving is more successful than driving with limited route knowledge.
- Hypotheses B: Driving after obtaining route knowledge by CBT is more successful than

driving with limited route knowledge.

- Hypotheses C: Driving after obtaining route knowledge by accompanied driving is just as successful as driving after obtaining route knowledge by CBT.

To assess the hypotheses, the term "successful" needs to be defined. The Triebfahrzeugführschein-Verordnung (2016) states that a train driver has to drive safely, on time and economically. For the experiment, these three qualities were operationalized, that means that variables were defined and it was decided which data (eye tracking or performance data) had to be recorded during the experiment. Additionally, the aspect of well-being of the train driver was evaluated by collecting subjective statements by an interview.

5. Method

The experiment was performed between September 29th and October 29th 2015. The train drivers for the experiment were recruited from the participants of the questionnaire. At the end of the questionnaire train drivers could mark their interest to be included in the study. These persons were later contacted and 31 train drivers participated. The set consisted of male drivers with an average age of 39. For each train driver, the experiment lasted about two hours in which the introduction, a first ride to practice the handling of the simulator and driving/braking with the vehicle type as well as the experimental rides and an interview happened.

The route to be travelled was designed in close cooperation with the developer of the simulation software, taking into account the results of the questionnaire. It was decided beforehand that it would not be sensible to use a route from the German railway network because the research interest made it necessary that certain elements and conditions had to be included in the chosen infrastructure. It would have been very hard to find a route exactly like that. Nevertheless, the designed route was close to known examples from the real world. The chosen infrastructure included a tunnel as well as a long rising gradient. Both elements were chosen because they required special attention from the train drivers and a route knowledge-based effect was expected.

The track was about 16 km long and equipped with mechanical as well as light signals and a PZB (Punktförmige Zugbeeinflussung). The allowed speed was 140 km/h. A 154 m long passenger train was used with a maximum allowed speed of 160 km/h. A passenger train was chosen to include stopping at stations as part of the experiment. We do expect that the results for a (heavy) freight train can differ and strongly suggest repeating the experiment with varying conditions. The timetable was developed for the experiment. The regular time for the trip was 16 minutes. Each trip included three stops. Two groups ("Driving" and "CBT") got detailed information to develop route knowledge. To ensure that this information were close to what the train drivers would learn in real life, two experienced train drivers were consulted. Together, a set of route knowledge relevant aspect was defined and later on used as a basis for the oral briefing as well as the design of the computer based training.

The development of the CBT was an important part of the experiment and would probably influence the results significantly. On the other hand, the resources were limited. Therefore, the chosen design had to take these limitations into account. The general layout is based on an existing CBT (Bahnkonzept (2016)) and shown in figure 1 (left). On the screen, the track and the environment as well as timetable information were given. All aspects which were relevant to route knowledge were colour-coded, verbally explained as well as defined in a text box below the track. The train drivers could stop the video at any point.

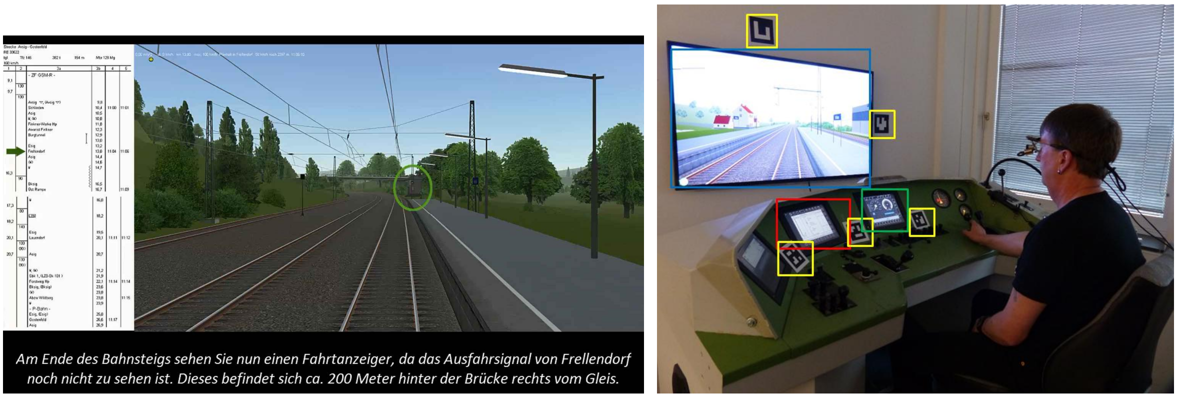

Figure 1: (left) Screenshot of the computer edited video; (right) Participant of the experiment with the eye tracking glass and the markers (Arendholz (2016))

The experiment was done using a train driving simulator which consisted of parts of a real train (Control car of type Bxf 796) and the simulation software Zusi. The train driving simulator belongs to the Institute of Railway Systems Engineering and Transport Safety of the TU Braunschweig and was used free of charge. Zusi was also used to record the driving data, whereas the eye tracking was done using the Dikablis system. Information regarding the subjective situation was gained by an interview. Figure 1 (right) shows the general setup for the experiment including the markers used for the eye tracking. The focus of the eye tracking was on the track (yellow markers), the electronic timetable with list of low speed sections (EBuLa, red marker) and the display (modular train cab display, green marker).

Table 1: Summary of experiment process

Experiment process	Description		
	Group „Limited“	Group „Driving“	Group „CBT“
Practical driving	Practice handling with the simulator and driving/ braking with the vehicle type		
Preparation, part 1	operational documents, e.g. timetable		
Interview, part 1	Questions 6 and 7		
Preparation, part 2	- -	First, accompanying the train driver who is familiar with the route. Second, driving accompanied by the train driver who is familiar with the route	Watching computer-edited videos of the route twice
Interview, part 2	-	Question 8	
Experiment	First measurement drive		
Interview, part 3	Questions 13 to 16	-	-
Experiment	Second measurement drive		
	Third measurement drive	-	
Interview, part 4	Questions 9 to 12 and questions 17 to 20	Questions 13 to 20	

The participants of the experiment were divided into three groups according to the three scenarios as explained above (group 1: limited route knowledge driving, group 2: accompanied driving, group 3: CBT-based driving). The details of how each group was prepared and trained can be seen in table 1.

Table 2 shows which data was collected to assess "successful driving" as well as the relation to the dependent variables (DV). The DV are explained below the table.

Table 2: Relation of the dependent variables to assess the "success of driving"

Measuring data	Goals train driver	Dependent variables (DV)
Eye tracking data	Safety	DV 1: Percentage of views
		DV 2: Grade of fixation of signals which are difficult to see
Performance data	Punctuality	DV 3: Mean of the braking time until still stand in railway stations
		DV 4: Mean of driving time
	Economy	DV 5: Mean of energy consumption
		DV 6: Number of unnecessary usages of the braking lever
Subjective data	Subjective well-being	DV 7: Mean of the feeling of being prepared
		DV 8: Mean of confidence on driving the route
		DV 9: Mean of the feeling of the effort during driving

- DV 1: Percentage of the views on the track and in the timetable: data is provided by the eye tracker. It was assumed that with better route knowledge, the train driver looks more on the track ahead and less into the time table.
- DV 2: Fixation of signals which were difficult to see: data was obtained by eye tracker. It was assumed that a train driver with good route knowledge knows which signals are difficult to see and will focus the attention on them early.
- DV 3: Average braking time to the stop in the station: data was obtained by Zusi. It was assumed that a train driver with good route knowledge has shorter braking times because he will be braking more precise.
- DV 4: Average driving time: data was obtained by Zusi. It was assumed that a train driver with good route knowledge drives faster, but also close to the timetable as he knows the route and has therefore more confidence in his driving.
- DV 5: Average of energy consumption: data was obtained by Zusi. It was assumed that a train driver with good route knowledge has a better energy consumption of his train as he knows the route and can drive anticipating the different track sections.
- DV 6: Number of unnecessary usages of the braking lever: data was obtained by Zusi. It was assumed that a train driver with good route knowledge uses the braking lever less often and therefore drives more smoothly.
- DV 7: Average of the feeling of being prepared: data was obtained by questionnaire. A train driver with route knowledge was expected to feel better prepared.

- DV 8: Average of the feeling of confidence in driving on the specific track: data was obtained by questionnaire. A train driver with route knowledge was expected to feel more confident in driving on the track.
- DV 9: Average of the feeling of effort: data was obtained by questionnaire. A train driver with route knowledge was expected to feel the need for less effort than a train driver without route knowledge.

Besides the variables as discussed above, some questions were used to get general information about the participants and to clarify information. More details about the questions and the assessment of the results can be found in Lorenz (2017).

6. Results

All data was evaluated. The complete results can be found in Lorenz (2017) and are discussed in general in the next chapter. In this chapter, we give an example how the data was assessed. This is done using the variable "Average of driving time". The variable was used to assess the effect of route knowledge on the punctuality of driving. Figure 3 shows the results of the evaluation. For each group, the mean of the driving time was calculated and the standard derivation is given.[1] The table as well as the box plot shows clearly that the group "Limited" was the slowest group with the largest standard derivation. The better result regarding driving time of the group "Driving" might have been strongly influenced by two drivers being significantly faster than all others.

DV 4: mean of driving time		
M [s]		
Limited (*n* = 9)	Driving (*n* = 9)	CBT (*n* = 11)
1138	1073	1104
SD [s]		
Limited (*n* = 9)	Driving (*n* = 9)	CBT (*n* = 9)
100	48	53

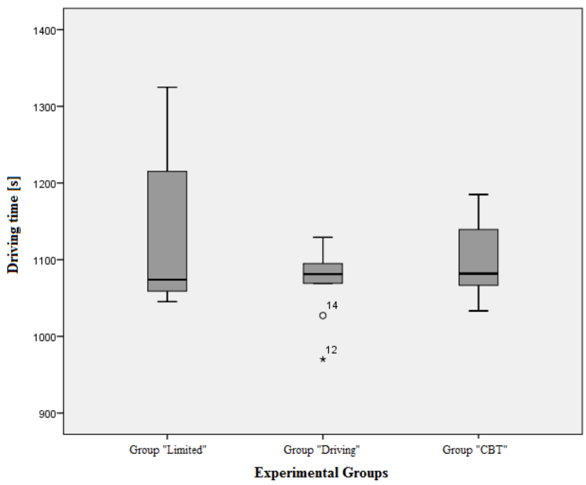

Figure 2: Descriptive statistical result and box plot – DV 4, Driving time

To check the relevance of the results, statistics were applied. The Levene test was used to evaluate the variances. It shows that the differences of the variances of the groups were significant. Therefore, as a second step, the Kruskal-Wallis-H-test was used to evaluate the driving time which could not prove significant effects between any two groups.
In another evaluation, the area of interest was limited to the tunnel and the long gradient because we expected that in these areas the effect of route knowledge would be stronger. The results for these two parts of the track are shown in table 3 and box plot figure 4.

[1] The group "Limited" drove three times. For the evaluation, we used the data of the first ride. Otherwise, the train drivers of this group had more than just the route knowledge from the operational documents.

Table 3: Descriptive statistical result – DV 4, tunnel and gradient

DV 4: mean of driving time	*M* [s]			*SD* [s]		
	Limited (n = 10)	Driving (n_{Tunnel} = 9 $n_{gradient}$ = 10)	CBT (n = 11)	Limited (n = 10)	Driving (n_{Tunnel} = 9 $n_{gradient}$ = 10)	CBT (n = 11)
tunnel	125	106	105	31	13	18
gradient	87	81	82	5	2	3

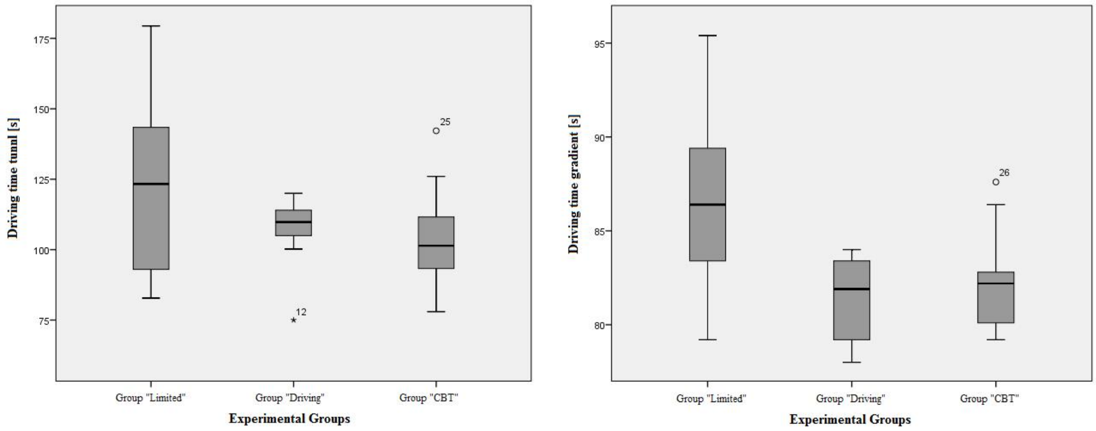

Figure 2: Box plot – DV4, Driving time in tunnel and on gradient

Again, on average the train drivers from group “Limited” drove slower than the train drivers from the other groups. The differences were not significant for driving on the tunnel but could be proven as significant for driving on the gradient. The difference was highly significant between group “Limited” and “Driving” and high significant between group “Limited” and group “CBT”. The groups “Driving” and “CBT” did not differ significantly.

7. Discussion

Table 5 gives an overview of the results for all hypotheses.
For the criterion safety all three hypotheses could not be confirmed in general. The gaze behaviour did not vary between the train drivers of the different groups. Looking at the data in more detail, the gaze behaviour regarding the timetable did vary between the three groups. Train drivers of the group “limited route knowledge” looked more often into the time table than drivers from the other groups. These means that when route knowledge is missing the train driver has less time for other tasks, e.g. talking on radio or watching out for irregularities.

Regarding dependent variable 2, fixation of signals which are difficult to see, train drivers with limited route knowledge did not fixate the signals as strongly as the other train drivers. However, the evaluation was hindered by the fact that the determination of the exact moment of the first fixation was very difficult and sometimes impossible. It was therefore not possible to generally confirm the hypotheses.

Table 3: Evaluation of the hypotheses based on DV 1 to 9

	Goals train driver	DV	Confirmation of the hypotheses
Eye tracking data	Safety	DV 1: Percentage of views	(✓)
		DV 2: Grade of fixation of signals which are difficult to see	(✓)
Performance data	Punctuality	DV 3: Mean of the braking time until still stand in railway stations	✗
		DV 4: Mean of driving time	(✓)
	Economy	DV 5: Mean of energy consumption	✗
		DV 6: Number of unnecessary usage of the braking lever	✗
Subjective data	Subjective well-being	DV 7: Mean of the feeling after preparation	✓
		DV 8: Mean of confidence on driving the route	✓
		DV 9: Mean of the feeling of the effort during driving	✗

Remark: ✓ Hypotheses confirmed; (✓) Hypotheses partly confirmed; ✗ Hypotheses not confirmed

Regarding punctuality, no general conclusion was possible but the results of the group with limited route knowledge showed a larger variance than the other groups. Also, when looking only at the part of the track with the gradient, for this area the hypotheses were confirmed. As the variance gave a first impression and some results were promising, we expect that a larger sample of train drivers might produce more significant results. However, we assume that route knowledge is only one of several influences. For example, an additional evaluation looking at the relation between the learning effect and the driving time was successful (details in Lorenz (2017)).

The method of route knowledge training seems to have no influence on economical driving. It was possible to show that the work experience of the train drivers had a more determining effect than route knowledge training. Trains which were driven by train drivers with less work experience consumed more energy while driving than trains driven by more experienced train drivers.

As expected, the train drivers felt better and more confident when they had route knowledge. These were the train drivers of the groups "Driving" and "CBT". The same difference between the groups could not be confirmed significantly or subjective feeling of effort. Using methods of descriptive statistics it could be shown that the group "limited route knowledge" had to use more effort than the drivers from the other groups. Also, the variance for this group was larger than the variances from the other groups. In conclusion, we assume that a larger sample would produce significant results. However, it should be taken into account that we saw that the perceived effort seems to correlate also to the work experience of the train drivers. Having more work experience has the effect that the train drivers perceive driving as less strenuous.

An interesting effect was observed when evaluating the eye tracking data. The signals of the infrastructure included a signal showing the direction a train will take at the next switch. The signal is indicated in the timetable and should therefore have been known to all train drivers. However, the data lead to the conclusion that some train drivers from the group with limited route knowledge did not see this signal what lead to slower and less confident driving. Also, under some circumstances this can have safety-relevant effects. We assume that these train drivers without route knowledge were busy with all the information that they just missed this data. In contrast, the train drivers with CBT and the ones which had actually already travelled on the route were more likely to fixate the signal

8. Conclusions

The simulator study has shown that it is possible to compare and evaluate different methods of training route knowledge. We are able to answer the questions raised in section 3 as follows: Regarding the first question, evaluation of the visual data, the observation of the driving time trends and the driver's statements regarding subjective well-being all suggest that both researched methods to obtain route knowledge (modern media and the traditional methods) are equally well suited. Regarding the second question, the tendencies in the results for punctuality and the driver's statements regarding subjective well-being hint to the fact that it is better to drive with full route knowledge than with limited route knowledge only. The criterion "safety" cannot be conclusively assessed because not all safety-related aspects are known but there are tendencies which point to the conclusion that driving with route knowledge is safer compared to driving with restricted route knowledge without speed restrictions.

We expect to perform further experiments to get more results and come to a final conclusion.

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