PMC

Lars Schnieder

COMMUNICATIONS-BASED TRAIN CONTROL (CBTC)

Components – Functions – Operations

ABSTRACT

eBOOK INSIDE

Content

1 Motivation and Background

More and more people are moving to the cities. At the same time, transport demand is steadily increasing. Where there is a lack of public transport systems, there is substantial pressure that they should be built. Where existing systems are reaching the limits of their capacity, it is necessary for this to be increased through comprehensive technical and operational measures. This chapter describes first the evolution of urban mobility that can be observed worldwide (section 1.1). The resulting challenges can be addressed through the benefits of automated urban rail transport systems, which are also described in this introductory chapter (section 1.2).

1.1 Development of Urban Mobility

For the first time in human history, the majority of the world's population lives in cities. In the future, this trend is expected to continue. By the middle of the 21st century, more than two-thirds of earth's inhabitants are expected to live in urban centres (United Nations 2015). This process is also called *urbanisation*. In order to satisfy their needs of everyday life (e. g. education, work, leisure, accommodation), people need to be able to move around in their city. Leaving the increasing demand for mobility to motorised private transport would be ecologically and economically devastating. The development of sustainable mobility concepts is therefore important, for the protection of natural resources. It is also of high priority in order to successfully combat climate change.

In the industrialised countries, parallel to the urbanisation described above, there is also suburbanisation (suburban – on the edge of the city). *Suburbanisation* refers to the exodus of urban population or urban functions (industry, services) from the core to the periphery of the city. This migration generally leads to an increase in commuter traffic. It also results in a significantly higher traffic volume on transport infrastructure, especially in the morning and evening rush hours.

Urbanisation and suburbanisation require an increasing efficiency of urban transport infrastructure and the services that run on it. This requires a holistic approach to system design as much urban transport infrastructure has already reached or probably even exceeded its capacity limits. Automatic train control systems play a central role in the development of additional capacity (see Ishikawa diagram in Figure 1.1).

In particular for overall optimisation of line capacity the following levers can be used:

– *Optimisation of vehicle characteristics.* The vehicles used can be optimised with regard to the achievable capacities. For example, vehicles can be driven for a longer time at the maximum possible line speed, using a higher rate of acceleration or shorter braking distances between the stations. Furthermore, reducing station times addresses a significant disturbance in the operation of urban rail transport systems. In order to shorten the station time required for the joining and alighting of passengers, the number and width of the doors can be increased (though this will mean fewer seats). Sometimes there happen to be platforms on both sides of the train, so both sets of doors can be used. The hope of public transport operators in this case is that station stop times can be reduced, as passengers enter on one side and leave on the other. In practice this should be accompanied with a precise announcement to the passengers on board the train to avoid unnecessary confusion during the station stops caused by passengers both entering or leaving the train by the 'wrong side'.

2 System Components and Surrounding Systems of Automatic Train Control Systems

Automatic train control systems may be integrated into an ecosystem of neighbouring technical systems. For new lines being built, proper system integration is easier to accomplish. In this case, the CBTC system as well as the system environment are designed and built nearly at the same time. For existing installations, integration is much more difficult, since the automatic train control system must be integrated into existing ecosystem(s). This chapter explains the components of automatic train control systems (see section 2.1). Subsequently, the interfaces to surrounding systems are explained (see section 2.2). These dependencies must be taken into account by the operator when creating specifications for future automatic train control systems.

2.1 System Components of Automatic Train Control Systems

Automatic train control systems consist of various components (see Figure 2.1). The different system constituents are explained in the following sections.

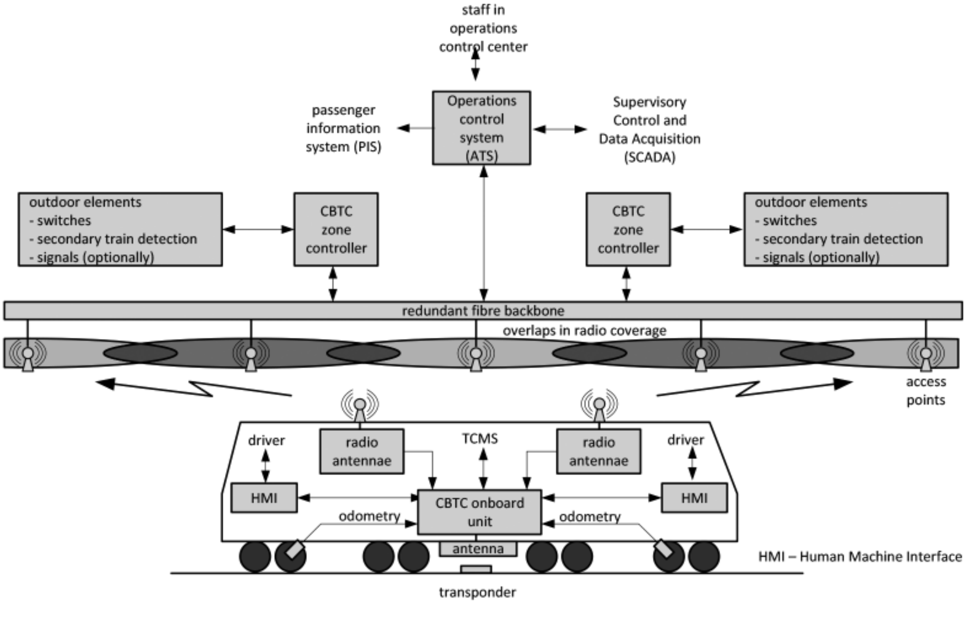

Figure 2.1: CBTC system overview based on Brückner 2017

5.2 Drive the Train

The function of driving of the vehicle consists of the basic functions of calculating the optimum speed profile and of controlling the trains depending on the identified optimum speed profile.

Basic function: Calculation of optimum speed profile

The Automatic Train Supervision (ATS) can assist in optimising the speed of a train. The operations control system knows the current operating situation of the line and can make superordinate strategy decisions for optimum driving. Basically, the strategy options include time-optimised driving and energy-optimised driving. The two strategic options are described below:

– *Time-optimised driving.* In the event of delays, the travel time of the train can be influenced by a specific variation, for example, of dwell times at stations or a variation of travel times between the stations (as a function of acceleration, deceleration and/or speed of the vehicle). Driving recommendations are displayed to the driver in manual train operations. In case of train operations in higher grades of automation (semi-automatic train operations or higher) the driving recommendation is automatically transferred into commands to the vehicle control by the ATO component (ATO, automatic train operation). The implementation of the time-optimised driving strategy is shown in Figure 5.9. Here, the upper half of the graph indicates the permissible speed along the line. A computer-based controller can optimally follow the solid line (speed indication). A human driver will usually stay below the speed limit and drive the vehicle just below the target with a characteristic “sawtooth” motion. It becomes clear that with a computer-based controller a reduction of travel times becomes possible.

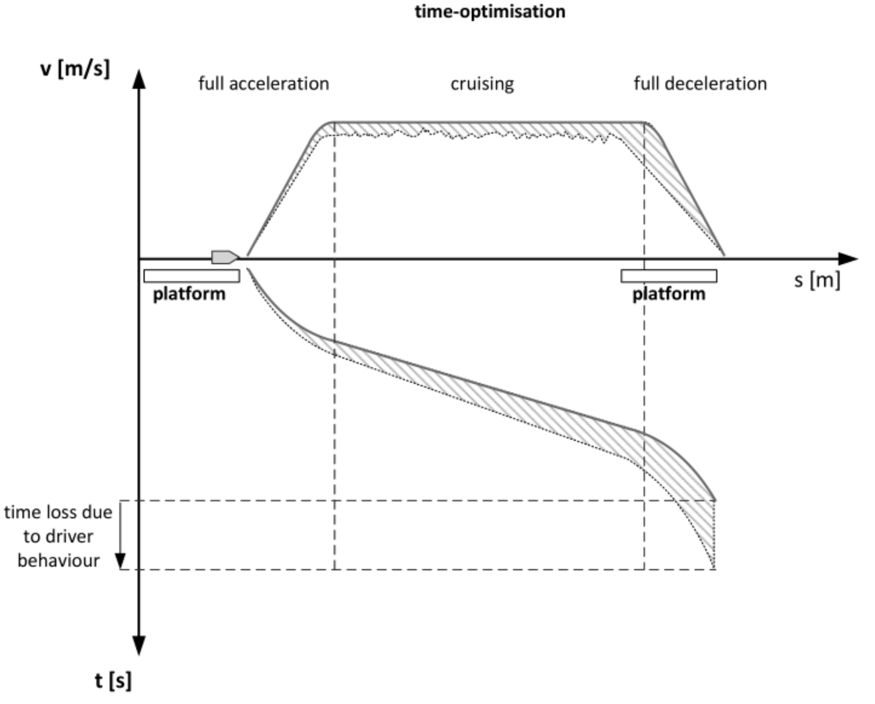

Figure 5.9: Implementation of a time-optimised driving style by the ATO (automatic train operation)

7 Migration and Test Strategies for Urban Rail Transport Systems

The right choice for the renewal strategy is one of the most important success factors, especially for projects that are not realised in a green field sense. There are many specific limitations that must be considered when defining the appropriate renewal strategy. The decision is further complicated by the fact that the chosen strategy has a huge effect on costs. Different strategies vary according to the existing limitations as well as their advantages and disadvantages. The renewal of signalling system will become more and more important in Europe in the next few years, as much of the existing infrastructure of subway systems in major cities is more than 45 years old (de Silvestre 2005). Many operators are facing replacements for the following reasons:

- *Obsolescence.* Spare parts for existing systems are no longer available. This poses a major challenge (McCullough 2008).
- *Capacity.* With the existing systems, the growing demand for transport can no longer be met. Denser train sequences are no longer feasible with the existing signalling systems (McCullough 2008).

To ensure that the conversion of signalling systems from conventional to CBTC is successful, the right migration strategy must be developed. This is discussed in Section 7.1. In addition, an effective test management must be established to prove the correct and successful functioning of the systems. This is explained in section 7.2.

7.1 Definition of the Migration Strategy

The right choice of renewal strategy is one of the most important success factors, especially for projects that are not realised as a “green field project”. There are many influences to consider and specific limitations that must be taken into consideration when defining what is appropriate. The decision is further complicated by the fact that the chosen renewal strategy has a huge cost effect. Different strategies are described according to their existing limitations, as well as their advantages and disadvantages.

The following objectives apply regardless of the chosen renewal strategy:

- *Minimum impairment of passenger operations.* Particularly during the construction phase, passenger operations should be affected as little as possible. This concerns both track possessions and the vehicle fleet:
  - *Minimum track possessions during construction.* There are various strategies. Here, the alternative of a possible full closure of the track for an optimum construction process needs to be carefully weighed against the option of a longer installation phase of nighttime track closures (usually three to four hours) with the lowest possible impact for the passengers.
  - *Retrofitting of vehicles.* The number of vehicles needs to be considered. In order to equip them, they must be taken temporarily out of service. This usually reduces the operator’s vehicle reserve and maybe even the number of vehicles available for passenger operations. The renewal strategy must therefore be coordinated at an early stage with the division responsible for the vehicles.
- *Minimisation of technical and operational risks during the migration phase.* The impact of changes in the overall system must be assessed. For example, in the case of later

8 Outlook

Many cities around the world have already introduced new systems with communication-based train control in recent years. This trend will continue into the future. In the next decade, there will be a worldwide increase in urban rail transport systems with unmanned train operations (UTO). Forecasts based on already confirmed projects show that the total length of metro systems with UTO will more than triple in length from 1,026 km in the year 2018 to more than 3,800 km in the next 10 years (see Figure 8.1). The largest share will be attributed to the expected opening of new lines. The vast majority of these are generally in Asia, and especially in China (Schnieder 2019). A smaller share (7 % of the route length) will be allocated to European modernisation projects. In Germany, too, this trend seems to have arrived. In Nuremberg, the operator can now look back on almost ten years of operating experience with a driverless system. In Vienna, work has begun on the introduction of a subway line with unmanned train operations (U5) (Heinrich, Stuchlik and Schnieder 2019). Other operators in German-speaking countries are specifically concerned with system selection and are preparing replacement investment in their networks. CBTC systems will therefore also be used in Germany in the foreseeable future.

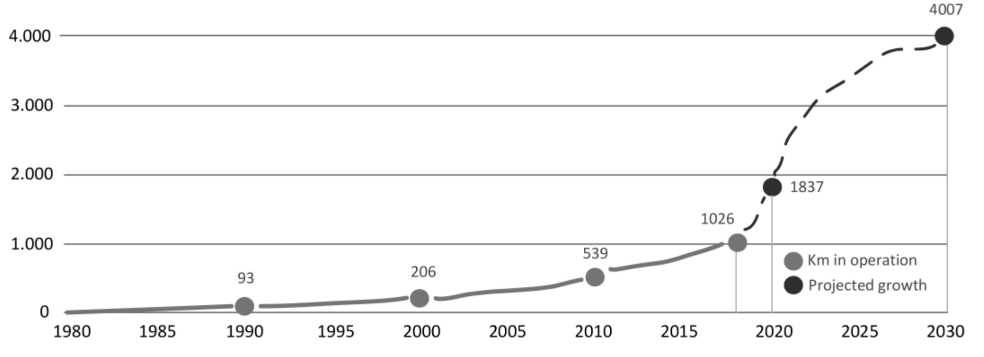

Figure 8.1: Growth of UTO operated route length in km **(UITP 2019)**

So far, the CBTC system solutions are exclusively proprietary. Because of the great heterogeneity of mass transit systems and despite the efforts of some selected operators of large subway systems, it is not likely that this situation will change in the foreseeable future. Thus, the operators are tied to a manufacturer with their investment decision over the entire life cycle of the signalling system. This is due to the lack of interoperability and interchangeability of components.

- *Interoperability* refers to the possibility that, within the network of an operator, the vehicle equipped with CBTC onboard equipment of one manufacturer can interact properly with wayside equipment delivered by another supplier. To achieve such interoperability, CBTC systems would need to be logically and physically standardised at the interface between onboard equipment and wayside equipment (McCullough 2008).
- *Interchangeability* means the ability to exchange elements of the CBTC system of one supplier with subsystems or components of another manufacturer. It should be possible to exchange individual elements of the CBTC system without having to replace the entire system. Interchangeability requires standardised CBTC system architectures with well-defined interfaces. Among other things, this requires a uniform allocation of functions to system components (McCullough 2008).

Abbreviations

A

ATC **A**utomatic **T**rain **C**ontrol
ATO **A**utomatic **T**rain **O**peration
ATP **A**utomatic **T**rain **P**rotection
ATS **A**utomatic **T**rain **S**upervision

C

CAPEX **Cap**ital **Ex**penditures
CBTC **C**ommunications-**B**ased **T**rain **C**ontrol

D

DTO **D**riverless **T**rain **O**peration

G

GoA **G**rade **o**f **A**utomation

H

HMI **H**uman **M**achine **I**nterface

I

IP **I**nternet **P**rotocol
ISMS **I**nformation **S**ecurity **M**anagement **S**ystem

L

LCC **L**ife **C**ycle **C**osts
LRU **L**ine **R**eplaceable **U**nit
LTE **L**ong **T**erm **E**volution

M

MDT **M**ean **D**own **T**ime
MTBF **M**ean **T**ime **B**etween **F**ailures
MUT **M**ean **U**p **T**ime

N

NTO **N**on-automated **T**rain **O**perations

What you can take with you from this ABSTRACT

- Definitions of automatic train control systems
- Basic safety functions of automatic train control systems
- Definition of grades of automation of automatic train control systems
- Operating modes of automatic train control systems and transitions between them
- Performance criteria of automatic train control systems
- Migration and test strategies for automatic train control systems

Bonus for free: The e-book is available upon registration. Users of devices with a pdf reader (PC, tablet, smartphone) will have electronic access to all the terms and references through a search function.

ISBN 978-3-96245-200-1

9 783962 452001