Computer-aided train operation: CATO

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Abstract

The aim of the CATO project is to lay a foundation for development of a system for optimal driving of trains. It is based on data communication between the train and the Traffic Control Centre (TCC) in combination with a centralised system for the calculation of optimal train movements. This paper gives a brief overview of the system concept, as well as a description of the benefits it could bring to efficient railway operation.

The name CATO (Computer Aided Train Operation) has been chosen as a parallel to the concept CATD (Computer Aided Train Dispatching). CATO also comes close to ATO (Automatic Train Operation), even though it is conceived as a non-vital system. Shortly speaking, CATO is an optimising traffic management layer on top of the existing signalling and safety system.

1 Introduction

Developments within the areas of information technology and telecommunication have reached a point making it possible to integrate several of the more advanced computer based techniques with the current systems for train traffic control.

Within the railway area, one research focus has been on development of systems that support optimal computer aided train dispatching (CATD). Another focus has been on research into the theory and practice of energy-efficient train control, with the aim of developing systems providing train drivers with advice on energy-efficient driving. A third focus has been on the control of power supply substations loads in electrified railway systems.

Investments are done to improve traffic capacity of the railway lines. Standards and commercial development of new harmonised signalling, safety and traffic management systems (ETCS/ERTMS) are ongoing in Europe as well as development of a new digital two-way train radio system (GSM-R). The new systems and the research projects create a good platform for the development
and introduction of better systems for traffic management, control and train operation. CATO is conceived as an optimising traffic management layer on top of the existing or new signalling and safety systems.

The trains are today basically driven on the drivers’ knowledge of the line, current train parameters, and of course on the information they obtain through the signalling system. The basic idea of the CATO system is to give the drivers better information on the traffic situation, thereby enhancing their ability to run the trains in a more “optimal” way, taking consideration to traffic and system aspects on a higher level than possible today.

Systems to optimise train driving can be installed either in the train itself and/or be centralised to a TCC. A train borne system, see Howlett et al [1][2], may be quite efficient on a line with few trains and little external influence on the driving of each train. A centralised system can handle more complex situations, but is more complex and requires a fairly efficient communication between the TCC and the train. The CATO system described in this paper is of the centralised type.

Various ideas on systems as the one described in this paper have been studied in Sweden in the past. So far, the problem has been that no efficient means of communication between train and TCC has been available. Today, the new European GSM-R radio system is under installation in Sweden. This provides a perfect communication link, and thus a renewed interest in the development of a CATO-system.

The current study - mainly financed by Banverket, the Swedish National Railway Administration - is performed by the Swedish rail system consulting company Transrail Sweden AB in co-operation with some Swedish universities.

2 General principles of a CATO system

The general principles of the proposed CATO system are described below and indicated in Figure 1:

1. Digital radio communication (GSM-R) between the trains and the TCC.
2. Every train regularly sends data to the TCC on its current position, speed and acceleration/deceleration as well as on current train parameters (performance data, weight and length).
3. The optimal running profiles for the trains during the next time interval are calculated in the TCC. See chapter 4.
4. The TCC sends the preferred running profile to each of the trains. This information may be used as guidance to the drivers or be used for full ATO-control of the train(s).

The general features of the CATO installation in the train are described in Figure 2. CATO is installed as a system independent of the ATP and traction/brake control systems of the vehicle. Its only interface is the driver HMI. Actually, the figure also indicates, by dotted lines, connections if the CATO system is to be used as an ATO overlay on the existing ATP.
3 Advantages with a CATO system

One fundamental idea in the CATO structure is to utilise, in a controlled manner, the time margins (slacks) that by necessity exist in the timetable as well as appears in the practical traffic operation. These slacks can be used in a CATO control scheme to improve line capacity and punctuality, to minimise e.g. energy consumption and/or to optimise other parameters. Train data (traction/braking performance, length, weight, max speed, faults etc), necessary for an efficient traffic management, e.g. by a CATD system, can be provided on a day-to-day or even on an almost minute-to-minute basis. Such information is of ultimate importance to an efficient traffic management system.

CATO may be of specific interest on a railway network such as the Swedish one, with a substantial part single tracked (80%) and being almost fully electrified. Efficient control of train meetings is essential for the efficiency of the whole system. Current development, with an increasing difference in passenger and freight train speeds, has also made it necessary to frequently do overtakings on
both single and double tracked lines. Improved traffic management methods, such as CATO, are becoming ever more important.

A CATO system as described in the previous chapter is likely to bring the following major advantages compared to the present situation of railway traffic operation:

1. More efficient traffic management, better punctuality and less traffic disturbances.
2. Improved capacity of the railway line.
3. Reduced energy consumption.
4. Reduced peak power levels on power supply substations.
5. Reduced wear of the trains’ braking systems and wheels.
6. Improved comfort for passengers and public.

3.1 Traffic management – fine-tuning train meetings

This section describes situations where a CATO control system can, among other things, assist in reducing train delays and thus improve the capacity of a railway line. The following example illustrates the advantages using a CATO control scheme to fine-tune train arrivals at a meeting station on a single track line. A corresponding control system may be used for trains overtaking each other at a station on a single or double track line.

A typical meeting station on the Swedish railway network has a design as shown in figure 3. The delays of the trains at the meeting station depend in a wide range on their relative arrival times ($\Delta t$) to the station (see figure 4). There is normally a lot of slack built into the timetable. If, for example, train 2 has priority and must not be delayed by the meeting, train 1 must be scheduled to arrive $80+20+60=140$ seconds before train 2. 80 seconds are necessary to avoid a restrictive signal to train 2 (see figure 4), 20 seconds is the scheduled allowance for a maximum length of train 1 and 60 seconds is the scheduled allowance for a delay of train 1. If the schedule shall also allow for a delayed arrival of train 2, the departure of train 1 should be scheduled with a further 60 seconds delay at the station. Slacks for either of the trains will also occur in the daily operation depending on early or late arrivals, daily variations of train parameters etc. A field study within this project shows that especially freight trains often have a slack, which is in the order of several minutes.

Figure 3: The installation of a typical meeting station on the Swedish single track railway network. Trains arriving to the pre-signals with a time difference $\Delta t$. 
Figure 4: Example of train delays at a meeting station depending on the difference of the relative arrival times (Δt) of the trains.

Figure 5: Reduction of energy consumption and mechanical brake energy vs prolonged running time when stopping a typical freight train from 95 km/h.

A CATO system should have the capability to control the trains’ arrival times to a meeting station or overtaking so that either one gets a minimum delay and/or so that unnecessary expenditure of energy and wear from mechanical braking can be avoided. Available slack may also be used e.g. to let the trains...
coast before the station or to use only non-wear electric brake. Such improvements are, in this example, illustrated by figure 5.

3.2 Traffic management – fine-tuning “follow-the-leader” situations

Another common situation where a CATO system would enhance capacity and punctuality is illustrated in figure 6. This example shows the current peak time traffic on the southern entry to Stockholm Central station. The traffic on this double track line is rather dense with a mix of suburban and interregional trains. The current signalling system allows for a schedule with 2 suburban and 1 interregional train passing during a time interval of 360 seconds.

The same number of trains would be able to pass in a 300 sec time period if a CATO control scheme is used. This corresponds to a capacity increase of 17%. In this situation the CATO control should make it possible to adjust the running speed profile of the interregional train so that:

1. it enters this line section in exactly the correct slot relative to the suburban trains,
2. its speed profile matches the speed profiles of the suburban trains on this line section.

Figure 6: Current paths for suburban and interregional trains entering Stockholm Central station from the south at peak traffic. Gray bands show suburban trains and the black band an interregional train. Shaded areas show stopping distances of the trains, and the black dotted lines the back end of the trains with a 30 sec allowance for train delays.
3.3 Reduction of energy and power consumption

In section 3.1 has been described how a CATO system can be used to reduce energy consumption in a situation when two trains are meeting each other at a meeting station. As a matter of fact, the same control strategy can be used whenever a train is approaching a restrictive signal. In such situations the train’s speed profile should be adjusted so that it will not arrive earlier than necessary. This is perhaps one of the most important control principles for a CATO system.

However, depending on the actual situation a CATO system should make it possible to make optimal use of possibly existing slack time at any suitable situation before reaching a restrictive signal. The control should be able to consider parameters and energy saving options such as:

1. Reduced speed before a downhill slope, thus eliminating use of mechanical brakes to keep the train within its permissible maximum speed.
2. Reduced tractive effort and/or regenerative braking when electric power is needed for another train with higher priority.
3. Minimisation of substation power peaks.
5. Reduced overall maximum speed of a train.

Various studies have been done in order to evaluate possible energy saving running regimes. Using the estimates of a study by Leander [3], regenerative braking could give an overall energy reduction of 7-12% in the Swedish railway traffic operation of today. The lower value refers to a blended (mechanical-electrical) braking system. The higher value refers to usage of regenerative braking only, which should be a possible braking strategy with a CATO system.

Another Swedish study by Fors [4] indicates that energy consumption can be reduced by approximately 10% if coasting is used to reduce speed before downhill slopes. Drivers already use this kind of “soft” driving technique to a certain extent, but cannot fully utilise its potential. They do not have enough information on the consequences of such driving for the total traffic scheme, and it is difficult or even impossible for them to estimate where to start coasting. Other studies give similar results, see e.g. Howlett [1][2]. A CATO system should make it possible to utilise this energy-saving driving method.

Within this area there also exists methods for minimisation of load on power supply substations. A study by Zheng [5] utilises slack time to reduce substation peak loads. His study compared three situations:

1. Trains drawing power irrespective of line voltage (“uncontrolled”)
2. Trains reducing power when line voltage drops below 90% of nominal value (“train-borne regulators”)
3. Centralised control based on a simulator using a simplex method in continuous time. The control set to a maximum substation power of 5,6 MW.

Some results from his study is shown in figure 7, which shows the efficiency of the centralised control system. In fact, the centralised system did not affect train running times as much as the train-borne system of today.
Figure 7 Examples of power loads on substation according to study of Zheng [5]. Train headways 10-12 min.

3.4 Passenger and public comfort

From a comfort point of view it is not an advantage to run a passenger train fast, especially not in curves or on tracks with bad positioning. This is the case even if the train is fitted with a tilting system in order to negotiate the curves at increased speeds. CATO can be used to improve the comfort of passengers by keeping train speeds, especially speeds in curves, as low as possible taking available slack time and other constraints into consideration.

Another comfort issue is a reduced usage of mechanical brakes, as outlined above. This will give reduced noise levels inside the cars and noise in the surrounding of the railway, especially in the braking of freight trains.

4 The CATO system

The general ideas of a CATO-system were presented in chapter 2. Perhaps needless to say, such system should as far as possible be based on and follow the European ETCS/ERTMS and GSM-R specifications, see [6]. However, CATO will also involve the central (TCC) computer system and the HMI-units in the TCC as well as in the drivers’ cabins. These systems are briefly discussed below.

4.1 The CATO system in the Traffic Control Centre

The CATO system in the TCC is anticipated to have a general structure according to the description in Figure 8.

The calculation of optimal running profiles for the trains is conceived to be done in the following three steps:

1. A TPC-program calculates the expected running profiles for the trains for the next control time interval.
running profiles (time, position, speed, acceleration) for the trains
current position, speed, acceleration and performance data of the trains
GSM-R Radio-unit
Central computer

1. Calculation of "as is" running profile for each train during the next time interval

2. Calculation of optimal train schedules (including decisions on meeting/overtaking stations, train priorities etc) "CATD"

3. Calculation of optimised running profile for each train during the next time interval

Figure 8: Structure of CATO-system in the Traffic Control Centre

2. Meeting stations etc during the next control interval are decided by the dispatcher using some type of CATD system, see among others Higgins [7], Jovanovic [8], Mills [9].

3. Finally, the optimal running profiles for the trains are calculated. These are the profiles meeting the aspects raised in chapter 3 and using various types of optimisation algorithms, such as those proposed by Howlett [1][2], Fors [4] and Zheng [5] as mentioned above.

4.2 The CATO system in the trains

A fact is that today the train driver, for several practical reasons, uses the direct communication link (phone) with the TCC only to a lesser extent, see e.g. Hellström[10]. The basic idea of a CATO system is to give assistance to train drivers, thereby enhancing their ability to run the trains in a more “optimal” way. This is obtained by giving the driver more and better information on how to drive the train.

The CATO system onboard the trains was roughly described by Figure 2. Of specific interest will be to find a suitable method to present the running profile calculated by the TCC to the driver. The ETCS HMI specification [11] foresees that external systems shall be possible to incorporate. However, the question is how to best present the CATO information to the driver.
5 Conclusions

A generic system for Computer Aided Train Operation (CATO) has been presented in this paper. The short description can help us to understand its potentials as well as its complexity.

The results obtained so far indicates that a CATO system will make it possible to improve traffic capacity and punctuality and to reduce energy consumption, rolling stock wear and passenger/public inconvenience.

Finally, it is important that a complex system like this is designed to be flexible and allow for modifications and new techniques and methods to be readily built in.

References