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The Resignalling Challenge: Investigating the Possibilities and Limitations of a New CBTC Signalling System on the Copenhagen Metro

Fabrizio Cerreto, fac@m.dk
The Copenhagen Metro
Michele Prisma, Pau Romero
Trenolab

Background and Objective

The Copenhagen Metro lines M1 and M2 are approaching the end of their expected operational life, despite a previous life extension following a condition assessment. Concurrently, the increasing passenger demand is straining the transportation capacity of the system, particularly during the morning rush hour in the central section between Christianshavn and Nørreport.

Currently, the metro system aims to achieve scheduled headway as low as 90 seconds, a target that remains in pursuit. However, projections indicate that the growing demand will push the system to its capacity limit by 2035. Although other projects, such as the newly approved M5 line (approved at the end of March 2025), are expected to alleviate some of the demand from the central section, M5 is not anticipated to open until 2036. Thus, the demand will continue to rise in the foreseeable future.

In response to these challenges, Metroselskabet is exploring ways to increase transport supply by reducing the scheduled headway during peak morning hours. This will be achieved by replacing the current signalling system, which relies on fixed blocking sections and track circuits, with a Communications-Based Train Control (CBTC) system, potentially utilizing a moving block approach.

This preliminary analysis aims to investigate the possibilities offered by such a system. The findings will be instrumental in defining the requirement specifications for a future phase of tendering. The objective is to establish ambitious yet achievable requirements and to focus on system modifications that yield tangible improvements across various aspects of the metro system.

Method and Analysis

This project is based on railway traffic simulation, which involves creating detailed models of railway operations to analyze and predict system performance under various scenarios. Railway traffic simulation helps in understanding the impact of different variables on train schedules, passenger flow, and overall system efficiency.

The tool utilized for this project is Trenissimo, developed by Trenolab. Trenissimo is a microscopic simulation software designed specifically for railway systems. It allows for the modeling of infrastructure, rolling stock, and operational scenarios to assess performance and optimize operations.

Details about the simulation project:

- **Reference Scenario Model:** A reference scenario model of the current infrastructure was built using technical drawings of the alignment and signalling system, along with the characteristics of the rolling stock. The dynamic performance of the trains was calibrated against speed profiles recorded from actual operations. The general performance of the system was calibrated using realized operations data, focusing on headway and running time performance from the Automatic Train Control (ATC) logs. Dwell times were modeled as scheduled times plus a random component, both derived from statistical analysis of realized dwell times.
- **Alternative Scenario:** An alternative scenario was created to represent a hypothetical CBTC system with moving block technology. Several assumptions were made, and individual elements were modified to assess their impact on system performance:
  - **Technical Dwell Time:** Reduced by 4 seconds based on the performance difference between the current M1-M2 system and the newer M3-M4 system, which is an updated version from the same supplier.
  - **Rolling Stock Variants:** Modeled in three variants with different power levels: current, current +1/6, and current +1/3. This assumes that one axle or one whole bogie could be motorized with the same equipment as the remainder, improving acceleration capabilities and maintaining higher acceleration over a broader range of speeds.
  - **Speed Limit Increase:** Investigated in three scenarios: current speed (max 80 km/h), max 90 km/h, and max 100 km/h. The current speed limit is constrained by the signalling system and design choices from the initial phase, where 80 km/h was the highest achievable. The line speed was increased where allowed by the alignment, or where not limited by any other system than the signalling.
  - **Different Schedules:** Created to assess system capabilities with headways of 95 seconds (current), 90 seconds, 85 seconds, 80 seconds, and 75 seconds.

Comparison Aspects:

- Realized headway and running times
- Recovery time after incidents
- Operational stability
- Transport capacity
- Amount of rolling stock necessary (system-independent but dictated by the schedule)
- Power consumption

Limitations: Other changes in the system were not considered, such as increasing parking capacity at pocket tracks. This could reduce ramp-up/down time and therefore the number of empty runs needed to adjust headway during the day.

Results

The results show an improvement in different aspects of the metro operations under a hypothetical CBTC system, but not all.

The operational stability is considerably improved as the route reservation ahead of the trains is shorter and consumes less capacity. However, a major benefit is also supported by the reduction of technical dwell times, which introduces an even larger timetable margin in the form of dwell times buffer.

Higher stability is visible mainly in the shorter time to recover from medium-larger disruptions, whereas the small variations from daily operations are already very well absorbed in the current system and see a marginal improvement.

Othe results include scientifically relevant findings, where the operational stability in shorter planned headways resembles the traffic flow in continuous and free-flow systems. In these cases, the realized headway even improves when the scheduled headway is reduced. As opposed to that, the running times explode in this scenario because the trains queue very densely, being able to keep a minimum headway, but running much slower. This can be interpreted as the effect of much reduced operational flexibility, but also much worse stability, as would be expected by any saturated system, even in uncontrolled density.

The increase of the line speed limit does not contribute to a reasonable running time reduction, due to the reduced distance between stations.

On the other hand, improving the traction power of trains shows some potential improvement in the stability in a CBTC scenario. This is supposedly due to the availability of more slack between trains (capacity) to allow for recoveries, which also need the capability of the trains to actually quickly reach a faster speed to catch up from their delays.
In conclusion, the introduction of a higher-capacity Schultz system provides several improvements, some of which are realizable immediately, where others are only potential, and actually need some other changes to other subsystems to be realized.
Further work will address power consumption in different scenarios, dimensioning of the rolling stock, optimization of the technical dwell time at stations, and other changes that can reduce the running time, increase the capacity, and improve the overall passenger experience.