



IMPACT OF OPERATIONAL DISRUPTIONS ON QUALITY INDICATORS IN SOFIA METRO UNDER DIFFERENT LEVELS OF AUTOMATION

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Abstract - Ensuring accurate and failure free movement of trains in the metro attracts a larger passenger flow and thus reduces environmental pollution by limiting passenger car transportation. Ensuring movement in the Sofia metro, as well as the systematization and analysis of various cases of its disruptions, will help in the implementation of new systems using artificial intelligence (AI), or in the development of more effective procedures for action. The main objective of the study is to identify and classify these specific operational disruptions that occur due to failures in occurring during the movement trains. In this way, an analytical basis is created for subsequent modeling of their quantitative impact on the key performance indicators (KPI) in service. The work consistently presents the technological ways to ensure movement on the lines and determines the levels of automation of GoA. KPIs under normal operating conditions are determined and the possible causes leading to disruption of the train schedule are analyzed. The structured analysis performed deduces the cause-and-effect relationships between operational disruptions and KPIs, assisting in future simulation or mathematical modeling of the transport process.

Keywords – levels of automation GoA, Train Schedule (TS), KPI, operational disruptions,

1. INTRODUCTION

The effective functioning of urban mass rail transport systems is a key factor for the sustainable development of modern megacities. Among them, the metro occupies a leading position due to its high throughput, speed and independence from street traffic. Ensuring reliable and continuous train movement requires a complex synergy between modern signaling, automation and dispatching control systems. In modern engineering practice, the degree of autonomy and the distribution of functions between the human factor and automated systems are defined by the internationally recognized Levels of Grade of Automation – GoA, according to the IEC 62290-1 standard. They range from partially automated control with a driver (GoA1/GoA2) to fully unmanned systems (GoA3/GoA4), with each level defining a specific approach to traffic control, speed regulation and train door management.

In real operating conditions, however, regardless of the degree of automation, the train schedule is subject to constant stochastic disturbances at the “passenger-

train” or “passenger-platform” interface. The nature of these disturbances directly depends on the technological generation of the line – from technical failures in the drive of the doors of the railcars to critical overcrowding of the platforms during mass events, which on older lines threatens safety with falling objects and people, and on lines with PSD slows down the synchronization process when closing. Therefore, it is necessary to systematize in detail the various cases of traffic disruption in the Sofia Metropolitan, viewed through the prism of the existing levels of automation of the Centralized Traffic Control (CTC) on the different lines. The main objective of the development is to identify, classify and analyze the mechanism of these specific operational violations, which will subsequently allow, through mathematical or simulation modeling of traffic, to establish and quantitatively assess their direct impact on the project KPIs for passenger service set out in the Nexus project[1].

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2. THE ANALYSIS OF DISPATCH MANAGEMENT IN METROS

Two different CTCs are used for traffic management in MetroS, respectively on metro lines 1 and 2, which started operating from 1998 year and including all new stations on these lines, and metro line 3, was put into operation from 2020 year.

2.1. Train Traffic Management System DISIM

The CTC "DISIM" used in managing train traffic on lines 1, 2 and 4 [2] must provide: -control over the devices for management of the position and occupancy of the switches, the occupancy of the tracks at the stations and the adjacent inter-station sections, as well as the repetition of the traffic lights at stations with track branches; -control from one place of the switches and signals at the stations and the possibility of transferring the control to local one of the switches and signals; -fulfillment of the requirements set for electrical centralization and auto-blocking systems; -automatic recording of the train movement schedule and a system for transmitting the train number.

Through DISIM, the train dispatchers on duty: monitor, control and manage the movement of trains, each for the route for which they are responsible, respectively for Line 1 and Line 2. The basic information about the status of the entire facility is displayed on the Light Information Board (LIB). This system also performs control and signaling functions, which is convenient for the train dispatcher [3]. The movement of all trains is visualized, as well as the location of the various vehicles (stationed, service) along the entire controlled route. The system is highly intelligent, with special software for managing train traffic, where in real time the train dispatcher receives information about the location of each metro train, number, route, rail circuit, delay, the status of security equipment and plenty of other information ensuring the security and safety of the train movement. The system allows for multiple functions and stores the complete information and all operations made by train dispatchers. The functional capabilities of the system are divided into the following main groups: train movement control functions, functions for managing the operation of the system itself, internal diagnostics, and functions related to information visualization, archiving, automatic forecasting, generation and presentation of relevant alarm messages /classified as functions/[4].

To ensure the movement of trains on Lines 1, 2 and 4, they are equipped with station devices: automated train control system, electrical centralization of switches and signals, and dispatcher centralization. Section devices include:

- autoblocking – the road is fenced off by traffic

lights, and their signals change automatically when the train moves in these sections,

- Automatic locomotive signaling with automatic speed regulation/ automatic regulation of the speed (ALS-ARS) – movement is carried out according to code signals transmitted to the driver's cabin.

The ALS-ARS system provides:

- Continuous monitoring of compliance with the maximum permissible speeds and automatic stopping when the train exceeds these speeds. In ALS-ARS, the speed of movement is continuously controlled;
- Automatic deactivation of the train braking after reducing the speed to the maximum permissible one and after confirming the driver's vigilance by pressing the brake acceptance button (BAB) or the safety pedal (SP);
- Indications of ALS signals on the remote control in the driver's cabin;
- Fixing the train braking to prevent the train from moving on a slope.

The maximum throughput is achieved by equipping with a complex ALS-ARS system, as the ARS contains a subsystem for the safety of the devices and the automatic control of the trains. The automatic block system refers to the devices of the railway automation. After turning off the AB, it is switched to the ALS-ARS system, which is fast-acting.

2.2. Dispatch Centralization Communication-Based Train Control (CBTC)

CBTC on line 3 - manufactured by Siemens for Sofia is based on technology using high-resolution train location determination, independent of the establishment of track clearance; continuous and highly efficient two-way data communication between the train and the trackside devices; on-board and trackside processors that can perform primary functions [5,6]. Fig. 1 shows CBTC elements.

Automatic Train Supervision (ATS). ATS of Control Guide OCS or simply ATS, manages and monitors the railway system thus that trains run according to the timetable and organization of the movement of the vehicles. This is related to the optimization of railway operations and service reliability, as well as minimizing the consequences of abnormal system conditions and equipment failures. ATS also provides a graphical interface for multiple users with different responsibilities and offers automatic train control, schedule management and calculation of schedule deviations.

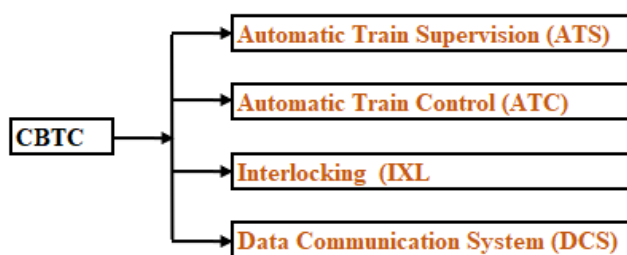


Fig.1. Communication-Based Train Control

Automatic Train Control (ATC) Automatic train and door control subsystem, ensuring train safety and guiding train operations. ATC includes automatic train protection (ATP) and automatic train operation (ATO). ATO is a component of the automatic train control system that provides functions such as speed control, programmed braking, door control, control of the level of technical parameters, etc. ATP is the other component of the automatic train control system that maintains fail-safe protection against collision, overspeed and other dangerous conditions through a combination of train detection, train separation and centralization, etc.

Interlocking (IXL) uses Clearguard ACM 200 and Trackguard Westrace Mk II (Siemens Mobility). As a secondary (backup) system for monitoring the track clearance, a Clearguard ACM 200 axle counting system is used. Trackguard Westrace Mk II is a modern computerized centralization/interlocking through which: remote control and management of switches, routing and issuing of train movement permits are carried out while observing all safety conditions.

Data Communication System (DCS). It provides high-resolution train location determination, regardless of the establishment of track clearance, continuous and highly efficient two-way data communication between the train and the trackside devices. The movement of trains is carried out in automatic mode, with the presence of a driver being provided for managing the system in case of emergencies and accidents.

3. KPIS FOR RAIL PASSENGER SERVICES

A significant number of KPIs have been adopted to assess passenger service and safety during metro transportation [1], but we will focus on the following indicators: Average train journey time (ATJT), representing the average time from the initial to the final destination; Average station waiting time (ATWT), including the time from entering the station to boarding the train; Average station dwell time (ASDT) including the time that trains spend at each station. Regularity of train (RT) movements measured in the interval between consecutive trains. Events leading to a reduction in the level of passenger safety related to station overcrowding (peak hours).

KPI	Times
ATJT	30 min
ATWT	depends on the size of the interval between trains and is defined as half of it
ASDT	30 seconds
RT	5 min
Safety	min

Tabl.1 KPI from Sofia metro

4. REASONS FOR TRAIN DELAYS

In cases of major events in the territory of Sofia or due to a strike of all other types of public transport, i.e. the movement of passengers in Sofia is carried out only by MetroS, a scenario arises in which there is a shortage of trains and the passenger flow during peak hours cannot be adequately transported, although additional trains have been assigned - there were passengers who could not board and were left for the next train. then the safety of passengers is compromised due to the large number of people on the platforms and the train movement times increase due to the increase in the waiting times on the stations. Other cases that lead to disruptions of train movement:

- ensuring the movement for both the network and the station

Problem with the opening of one of the train doors: The passengers usually decide to move to the adjacent doors to get on and off the carriage (vehicle), which leads to an increase in the train's stay at the stations. In such a case, the train arrives at the final station, then is sent to the depot, which is moved between regular train movement according to the train schedule. In the place of the train with the failure in the doors, another train from the final station is used, which is standing as a reserve;

Falling of an object on the track in stations without barrier doors – this is a variant of an object, obstructing the movement of trains, when it is necessary to remove it by the traffic controller. The delay can be from 5 to 15 minutes;

Problem with the platform screen doors/ barrier doors– assistance from the traffic controller – delay from 2 to 10 minutes.

- ensuring movement on the network

For metro line 3 at GoA3: delocalization of the train – it switches to manual mode and moves by the driver until it is localized – this can lead to delays from the train schedule [6];

Damage to the vehicle: passengers are dropped off at the next station, the vehicle continues to the depot, and the another train, from the reserve, is included in the schedule;

Unfortunately, more severe cases of unwanted events occur: interruption of the movement of trains

for an extended period of time, for example 2 or 3 hours (for example, in the event of a suicide at station 208) - depending on the location of the station, the movement is organized by making nearby stations with railway points as last stations and movement is reversing direction there, or if there are no stations with railway points there, a single train is launched as a shuttle (Fig.2).



Fig.2. Organization of train traffic

3. CONCLUSION

CTC "DISCIM" ensures the movement of trains when they are controlled by the driver. He drives the train, stops and starts from stations, opens and closes the doors, performs and monitors all accompanying operations. The special thing is that the speed of the train is controlled, that is, the driver cannot increase the speed higher than the specified one and in case of problems the locomotive is stopped automatically without the driver's participation. Therefore, DISCIM is between Go1 and Go2, but in terms of functions it does not reach Go2. The CBTC system for Metro Line 3 of Sofia underground complies with GoA3, as defined by the IEC 62290-1 standard, and with the IEEE1474.1 standard. An upgrade to GoA4 automation level is planned through a software update. The difference between GoA3 and GoA4 is that in GoA3 the train operating staff manages and controls the operation of the train during faults (e.g. malfunction of train doors), worsened performance and emergency situations.

In order to assess the quality of passenger service, key performance indicators (KPIs) have been introduced, such as: average train travel time, average station waiting time, average station dwell time and train regularity. In addition, for lines 1, 2 and 4 (except for stations equipped with vertical doors with a barrier mechanism), a safety metric is applied, defined as the total duration of traffic interruption when a person or object falls onto the tracks (such events trigger immediate emergency protocols). These KPIs have been determined under normal operating conditions of the Sofia Metro. With the implementation of this study, individual cases of train movement disruptions have been successfully classified and systematized. This classification serves as a key and mandatory prerequisite for future train movement modeling, allowing researchers to accurately determine and

measure the direct impact of these interruptions on the established KPIs. The data and structures collected in this study will serve as the main conceptual framework for developing these predictive models and optimizing future dispatching operations in the Sofia Metro network in accordance with the objectives of the Nexus project.

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