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Benefits of Automatic Train Operation

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Abstract

Railway traffic is experiencing notable growth, but also competition from other modes of transport with considerable technological developments. An alternative for rail is through train operation optimization, both at the management level and at the train level. At the train level, the implementation of Automatic Train Operation (ATO) can be employed. This ATO facilitates efficient operation and serves as a decision-support or decision-making component depending on the level of automation. This study explores the benefits of Automatic Train Operation (ATO) technology as presented in the literature. Employing thematic content analysis and grounded theory, the study delves into peer-reviewed articles to synthesize knowledge on ATO benefits, including resource optimization, improved passenger experience, operational efficiency, and safety and reliability. These findings will offer valuable insights for stakeholders considering the implementation of ATO technology on non-metro rail lines, potentially encouraging wider adoption of this technology. While ATO also has costs and potential disadvantages, this study focus on benefits mentioned in literature.

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Keywords: automatic train operation; grades of automation; railway digitalization; levels of automation;

1. Introduction

Railway traffic is experiencing notable growth due to the rapid pace of urbanization, economic growth, and advancements in railway technologies, to name a few. This heightened demand for efficient and reliable transportation options within and between cities. Additionally, the push for sustainable transportation solutions aimed at mitigating environmental impact has made railways more attractive to passengers[1], as it has a lower environmental impact than other modes of land transport[2]. Railway transport systems, being eco-friendlier and more capable of carrying greater weight than other land transport modes, have the potential to gain increased advocacy from governments and policymakers. This also contributes to the current rise in railway traffic and is expected to fuel further growth.

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However, for rail to be able to fulfil its role, it is also need for continuous efficiency improvements, supported by digitalization.
To address the issue of growing traffic, responsible authorities must invest heavily in infrastructure, either by expanding the existing one or building new ones, which is costly and time-consuming approach[1-3]. The other option is to optimize train operations through different approaches, focusing on the traffic management system and train control [2, 3]. Firstly, optimization occurs at the management level, focusing on the traffic management system. This involves a broad range of operational information, including dynamic data like real-time train movements along the tracks, the status of the interlocking system, and track occupancy, alongside static data such as timetables and infrastructure details. This comprehensive operational information enables the dispatch control center to execute the dispatching process effectively. The optimization efforts at this level aim to enhance the decision-making processes of dispatchers, providing them with decision support that offers an overview of the entire traffic network system[3]. Secondly, optimization at the train level involves improving the train control system. Train drivers receive information from onboard equipment and wayside systems, guiding them in executing commands based on their expertise. The aim at this level is to achieve precise and efficient train control movements, minimizing operational discrepancies or errors caused by the drivers. Automatic Train Operation (ATO) can support drivers and provide consistent and efficient operations. ATO serves as decision support for drivers at lower levels of automation and becomes the core decision-making component at higher levels of automation[3].

ATO is a railway technology that helps the train driver to execute tasks or even takes over all the driver's tasks, i.e., Autonomous trains[4]. ATO is well-established in the urban metro systems as it was implemented over 50 years ago[5]. The efficacy of ATO versus non-ATO urban metro systems are well documented by various studies[6]. However, implementation of ATO in non-metro lines has been slow due to factors such as heterogeneous service, different stopping patterns, multiple operators, minimal grade separation, different signaling vendors, uneven demographic and topographic nature of the places catered by these lines[7]. Despite these complexities, ongoing efforts are being made to introduce ATO in different non-metro lines to replicate the efficacy observed in metro systems. Therefore, it is interesting to assess the advantages of ATO through comprehensive literature reviews drawn from various studies. These findings will offer valuable insights for stakeholders considering the implementation of ATO technology on non-metro rail lines, potentially encouraging wider adoption of this technology. With this in mind, the objective of this study is to explore the benefits of ATO from different sources, irrespective of the grade of automation implemented. The study is related to the flagship project FP2 R2DATO under the Europe's Rail Joint Undertaking.

The structure of the remainder of the article is as follows: Chapter 2 outlines the methodology employed in this study. Chapter 3 presents the results and discussion; Chapter 4 concludes the article.

2. Methods

This study employed a theoretical literature review of peer-reviewed articles to address the specified objective. A theoretical literature review involves systematically examining, summarizing, and critically analyzing the theories, frameworks, and fundamental concepts relevant to a specific topic or field of study[8]. This type of review focuses on synthesizing and evaluating the body of theoretical knowledge rather than empirical data, aiming to identify key concepts and develop different models.

2.1. Searching strategy

The initial step in the methodology section comprises selecting electronic databases for the search, setting search strings, and identifying the articles relevant to the research objective while applying specific inclusion and exclusion criteria. To guarantee reproducibility, the study employed structured and systematic search strategies. With the help of the Peer Review of Electronic Search Strategies (PRESS) checklist, the developed search strings comprehensively reflect the research objective.

Choosing search databases and setting the search terms

To ensure a comprehensive search coverage, two databases were used, following the recommendation by Ewald *et al.*[9], that using multiple databases can significantly reduce the risk of missing relevant articles. For this purpose, Scopus and Web of Science were chosen due to their status as the most widely used bibliometric information sources. In setting the search terms, the research objective was broken into two main groups: technology and the benefits of the technology. Synonyms and related terms were incorporated into each category for better recall and precision. The two primary Boolean Operators utilized: "AND" to connect two main groups and "OR" to connect relevant terms within the groups, with the addition of the wildcard asterisk (*) to include variations of the same root word.

Identifying the articles

A total of 2755 articles were identified across both databases, 2156 from Scopus and 599 from Web of Science. Inclusion and exclusion criteria were applied directly within the databases to ensure the retrieval of the most relevant and comprehensive articles. Using these criteria (detailed in the table below), 398 articles remained for further analysis. Additionally, some articles were identified through the snowball technique.

Table 1: Inclusion and Exclusion Criteria

Parameters	Criteria	Rationale
Subject area	Engineering; Transportation; Engineering multidisciplinary	Careful search efforts were made in both Scopus and Web of Science databases to collect knowledge from a specific area, using set criteria despite their different ways of categorizing information.
Document Type	Journal articles	Articles that have passed through a rigorous peer review process.
Language	English	Authors use the English language for academic purposes

2.2. Screening and Evaluation

The 398 identified papers were then imported to Rayyan software for screening and evaluation. Rayyan is a web-based application designed to streamline the process of conducting systematic reviews and other knowledge synthesis projects. It provides a platform to detect and remove duplicates, collaboratively screen, and include or exclude articles for reviews. Initial screening was conducted on titles and keywords, excluding some irrelevant articles. Further screening was carried out on abstracts and through full-text reading, followed by a critical appraisal of the methodology, findings, and conclusions of each document as depicted on Figure 1.

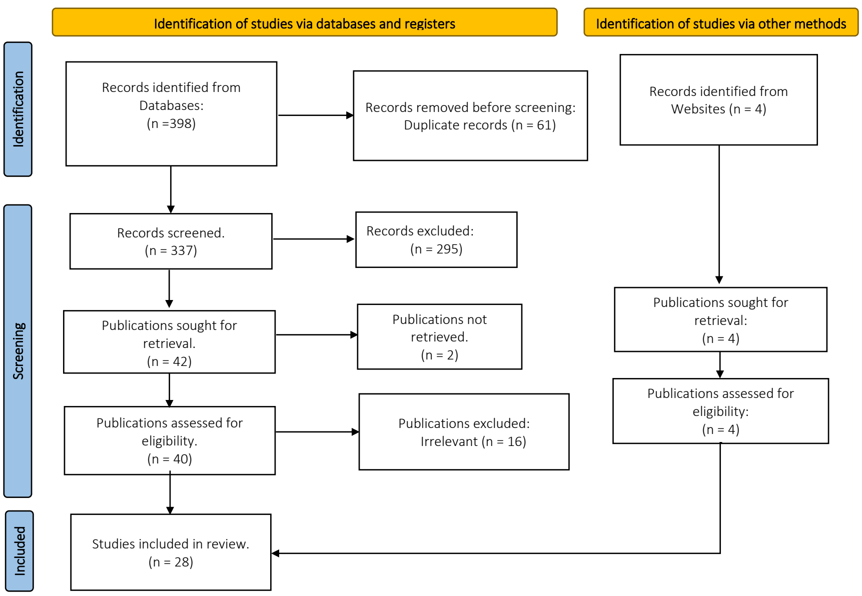

Figure 1: PRISMA flow diagram as applied in this study.

2.3. Data extraction and synthesis approach

In this section, thematic content analysis was employed, integrated with the grounded theory approach, which Glaser and Strauss introduced in the 1960s[10]. Grounded theory is a methodology that involves constructing theories through systematic gathering and analysis of data, see Figure 2. It is a widely recognized qualitative research method designed to create theories by codifying and categorizing data that explain processes, actions, origins, interactions, or relationships among various elements[10-12]. Through full-text reading and using a three-phase coding strategy, initial codes were developed from the literature in the first level of coding, known as open coding. Then, in the second coding level, axial coding, the developed codes were sifted, refined, and categorized to generate meaningful categories. Selective coding, the third level, involves integrating various categories to construct cohesive themes, thus facilitating the formulation of a theory. The NVivo software was utilized to facilitate the coding process.

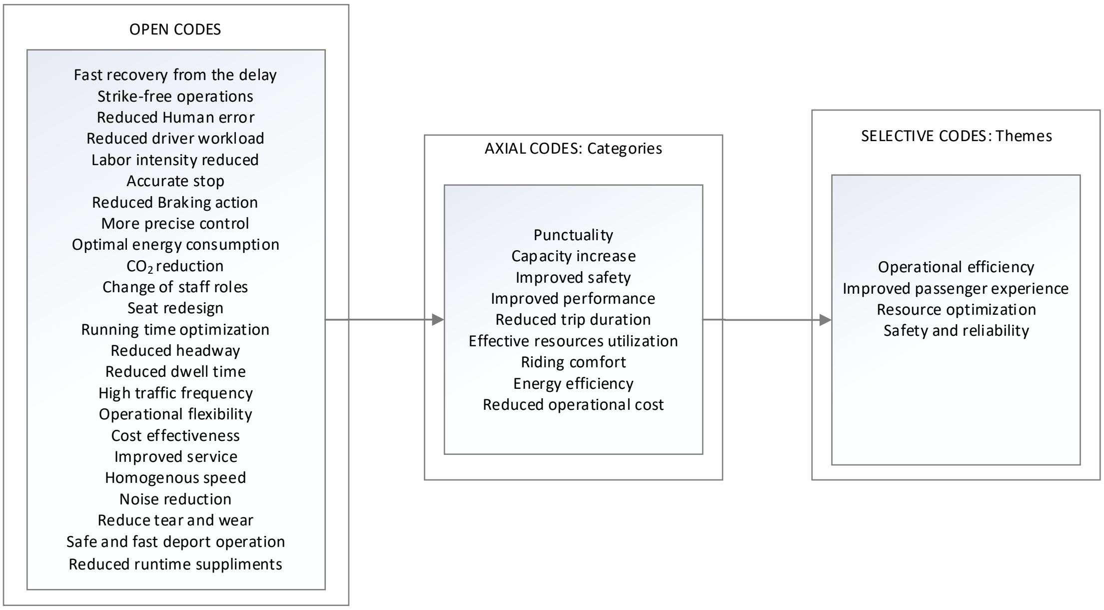

Figure 2: Ground theory coding as applied in this study.

3. Results and Discussion

Following the content analysis, this section presents the results derived from various literature sources regarding the benefits of ATO. In this study, the advantages of ATO, as highlighted in the reviewed literature, are categorized into overall effects, which include secondary effects, further derived from the primary effects of ATO.

3.1. Improved passenger experience.

Passenger experience can be evaluated through a comfort indicator, which assesses the level of comfort individuals experience during specific tasks. In the context of transportation, this indicator measures the comfort level experienced by passengers while utilizing various modes of transport. It can be qualitatively or quantitatively assessed. Factors such as riding comfort, improved service, and reduced trip duration—further explained below—all contribute to achieving a better value for the comfort indicator[13]. Implementing ATO in trains can potentially enhance these factors.

Riding comfort: ATO manages traction, coasting, and braking of the operating train[6, 14, 15], ensuring streamlined operations and less variability in driving behavior[4, 7]. Riding comfort is influenced by the rate of change of acceleration, where sudden changes negatively impact riding comfort and vice versa[13, 14, 16]. Additionally, vibration, noise level, and inconsistent speed negatively affect riding comfort, all of which ATO aims to improve[6, 17].

Improved service: In higher levels of ATO, there is no driver onboard; instead, there is an attendant or unattended operation. The individual previously responsible for driving can focus on passenger-oriented service rather than train operation, thus improving the service[6, 15, 17, 18].

Running time optimization: ATO can minimizes the deviation between train speed and target speed[3, 7]. Additionally, it can reduce the dwell time by eliminating driver reaction time delays, improving signal response, automating door operations, and supports integration of different platform safety features such as Platform Screen Doors (PSD) with train stopping[6, 18]. Consequently, this reduces trip duration, which potentially improves the passenger experience.

3.2. Resource Optimization.

As mentioned, railway traffic is rapidly increasing, necessitating measures to effectively manage this growth. Therefore, proper and efficient resource optimization is needed, and Automatic Train Operation (ATO) has potential to provide a robust solution[19-21]. It can enhance resource optimization by increasing capacity, extending operating periods[18] improving speed and energy efficiency[6, 19-21].

Capacity increase: An efficient way to increase capacity without expanding infrastructure is through operational optimization[2, 3]. ATO is effective in allowing more trains to run on the same tracks by precisely adhering to the permitted speed limit at the closest curve possible[4], minimizing headway to as little as 2 minutes, which is not feasible by the human driver[6, 18], runtime supplements[7], and dwell time[6, 18], thereby increasing the capacity[20]. Additionally, trains with a higher level of ATO no longer require a driver or a cabin[22]. This allows for the redesign of seating arrangements, thereby increasing the carrying capacity of the wagon[17].

Energy efficiency: Energy consumption is a critical aspect of railway operations, with traction systems accounting for 80% of the energy used, while auxiliary systems consume the remaining 20%[23]. Given that ATO controls traction, coasting, and braking based on built-in algorithms[24, 25], its implementation reduces energy consumption by traction systems[6, 7, 21] as it calculates the optimal speed profile to reach the next station[4]. Additionally, energy efficiency contributes to reducing CO2 emissions[6, 15], aligning with the latest environmental goals advocated for all transportation systems. This reduction in energy use and emissions supports sustainable and eco-friendly transportation initiatives[7, 15, 18].

However, there is to a certain extent a tradeoff between capacity increase and energy efficiency, as optimization of one of the aspects comes at the expense of the other.

3.3. Operational efficiency.

The train equipped with ATO brings advantages by cutting several costs linked to its operation, which are part of the train operation cost structure. This cost structure encompasses several expenditures such as staffing, energy, maintenance, infrastructure user fees, terminal expenses, and others[26]. With ATO, there is potential to reduce staffing expenses, which constitute 20-25% of all operation costs[26] by reallocating drivers to other tasks. It also decreases energy costs through energy-efficient driving methods[6, 7, 21], and cut maintenance costs by mitigating wear and tear[17, 19] resulting in reduced disturbances during maintenance as they occur at less frequent intervals[4]. Therefore, a train equipped with ATO potentially assure operational efficiency through cost-effective operations[7, 27], reduced labor intensity[6, 14, 18, 28], enhanced operational flexibility through operating over extended periods without concerns from worker union associations, and even new or abandoned stations can now be served[27, 29].

Furthermore, the change in staff roles, particularly drivers, allows them to participate in other passenger-oriented tasks such as customer service and ticket inspection[5, 17]. Additionally, for freight trains, the extended transportation period and drivers' waiting times can be minimized during the unloading of the shipment for the last-mile operation.

Despite the potential for high train frequency influenced by ATO to initially increase operational costs, this may not be the case when travel demand is considered[26].

3.4. Safety and reliability.

Safety and reliability are critical aspects of rail transport, and ATO has the potential to improve them[4]. According to the Globalement Aussi Equivalent (GAME) principle, which translates from French as "Globally as Equivalent", the new technical system (ATO) should match or exceed the performance of the old system (driver) on a global scale[30]. The GAME principle is used to ensure that a system replacing a human operator should have a safety integrity level that is equivalent to or better than the human operator’s capability[30]. While ATO is not classified as a safety-critical system, it possesses safety integrity level SIL 2, considered acceptable as compared to the driver onboard, and it is supported by a safety-critical system (ATP) rated at the highest level, SIL 4[3, 25, 31].

In traditional driving, the driver, being subjected to the monotonous task, is prone to fatigue, which can affect efficiency[32]. Thus, ATO reduces errors caused by human fatigue and negligence[17, 18, 33]. Additionally, ATO alleviates the workload on the driver, thus enhancing the driver's efficiency and improving safety[13, 21, 33]. Accurate stop, reduced braking action, and reduced tear and wear are other benefits of ATO that improve train safety[14, 28, 34].

Automatic Train Operation enhances the reliability of train service through punctuality and improved performance[16]. Punctuality is the ability to operate on schedule as indicated on the timetable. In the Beijing subway, trains equipped with ATO demonstrate superior punctuality, with a rate of 99.99%, compared to 99.5% for non-ATO trains under normal circumstances[6]. Furthermore, trains with ATO can recover more quickly from delays, which various operational factors can cause[17]. Another benefit of ATO that improves reliability is the potential for strike-free operations due to the reduction or even elimination of personnel involved in driving activities[29, 34].

In summary ATO offers numerous advantages, as illustrated in Figure 3, which depicts the general benefits of ATO irrespective of the grade implemented. However, the extent to which these benefits are realized varies depending on the grade of ATO in use.

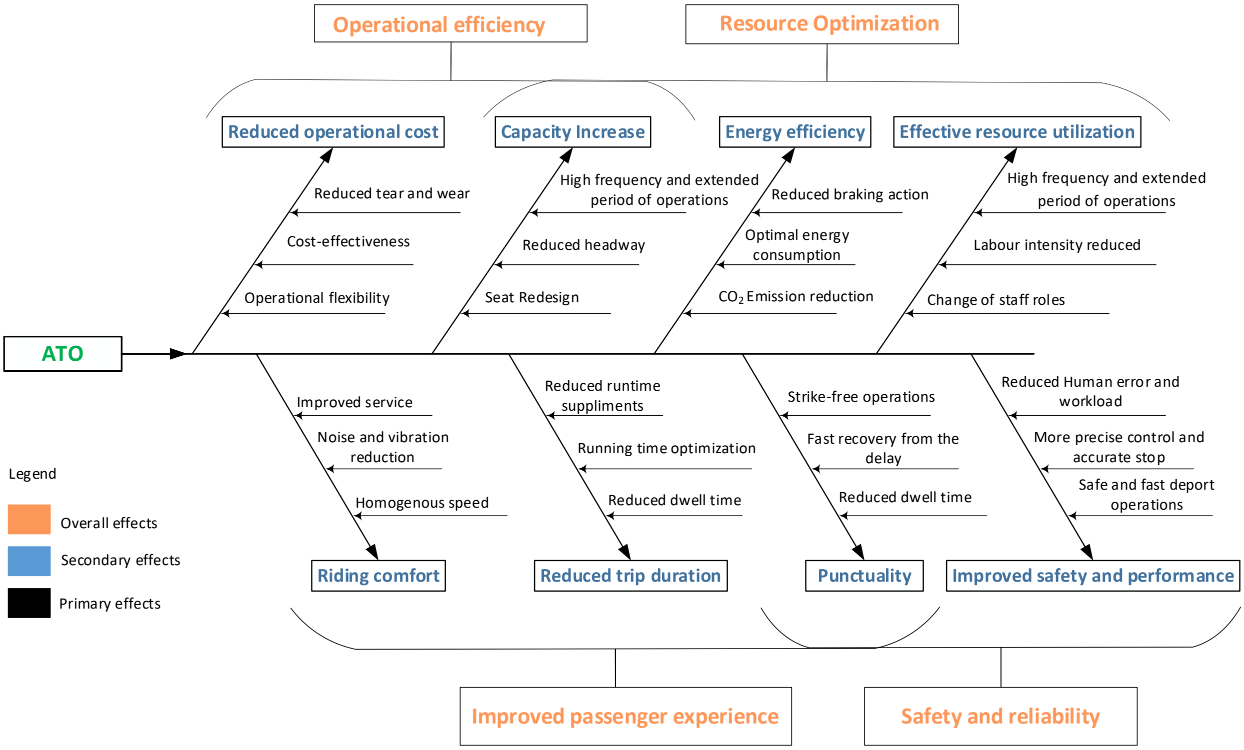

Figure 3: Modified Ishikawa diagram illustrating ATO benefits.

4. Conclusion

Automatic Train Operation (ATO) presents an approach to modernizing railway operations. The literature review conducted in this study indicates that ATO provides benefits, as depicted in the open coding section, and these are considered the primary effects of ATO. These primary effects are then grouped into similar categories in the axial coding section, representing the secondary effects. These categories culminate in the selective codes, where the themes are developed, representing the overall effects. With these themes, the theory *"automatic train operation serves as an important technological system that facilitates the optimization of operational processes at the train level"* developed as depicted in the figure below. This theory indicates the role of ATO technology in optimizing train operations. However, while ATO can potentially enhance train operations, optimizing the train operations would also hinge on other factors ranging from management to train levels.

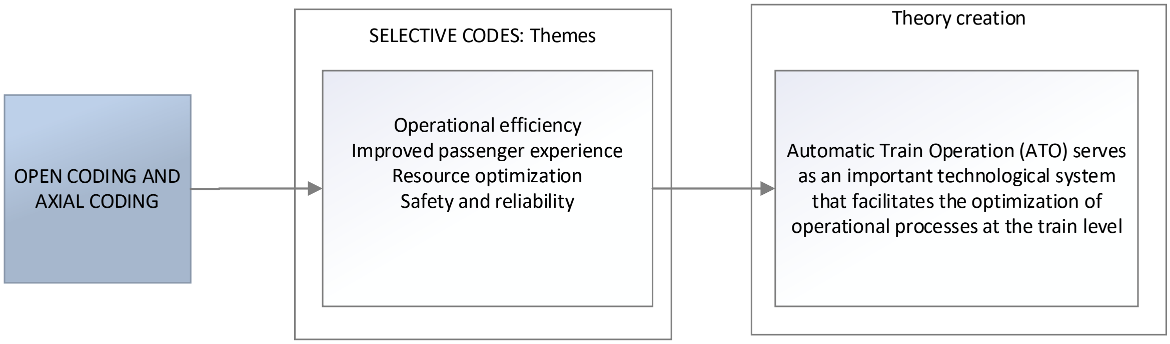

Figure 4: Theory creation.

Despite the benefits offered by ATO, there are challenges to fully replacing drivers. The study by Jansson et al.[35] highlighted the driver's responsibilities during disruptions in driverless and unattended train operations. Tasks previously handled by the driver—such as detecting issues, reporting problems, inspecting and adjusting equipment, managing passengers, and responding to train orders—now need to be managed through automation, remotely, or by sending an external person onto the train. Additionally, implementing ATO in non-metro environments, the associated costs, and concerns about new roles for railway staff present further hurdles. Nevertheless, the potential advantages underscore the need for continued efforts to overcome these challenges.

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