Predictive Support for Stopping and Parking: Technologies, Evaluation Methods, and Gaps for Remote Train Driving

by

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Introduction

Stopping and parking manoeuvres are critical phases of vehicle operation, requiring precise control, accurate distance estimation, and continuous perception–action coupling (Takahashi, 2013). In many transportation systems, failures or inefficiencies during these manoeuvres can negatively impact safety, comfort, and operational performance. These challenges are amplified in contexts where sensory information is restricted or delayed, such as in remote or automated operation (Dybvik et al., 2021).

To address these challenges, a variety of predictive and assistive technologies have been proposed, including Head-Up displays (HUDs), augmented reality (AR) overlays, visual guidance lines, and other driver assistance interfaces. While individual studies have investigated the effectiveness of such technologies, the literature remains dispersed across transportation domains, methodological traditions, and evaluation metrics. As a result, there is limited shared understanding of which technologies have been explored, how they have been evaluated, and where critical research gaps remain. The present paper addresses this gap by providing a structured review of predictive technologies designed to support stopping and parking manoeuvres in ground transportation.

Aim and research question

By synthesising both technological approaches and evaluation methods, the review aims to inform future research and design efforts, particularly in remote train driving, where evidence is scarces. This review is guided by the following research questions:

RQ1: What predictive technologies have been used to assist stopping and parking manoeuvres in ground transportation?

*R*Q2: *Which methods have been used to evaluate the effect on parking performance and perception of the technologies?*

Method

The review followed the PRISMA and PRISMA-S guidelines to ensure transparency, reproducibility, and bias control. Searches were conducted in Scopus, the ACM Digital Library, and TRID. The following query was applied across the databases:

" ("train driving" OR "rail teleoperation" OR "remote train driving" OR "train simulator" OR "ATO" OR "car" OR "bus" OR "tram" OR "boat" OR "ship" OR "transportation system") AND

("predictive display" OR "augmented reality" OR "AR" OR "head-up display" OR "HUD" OR "guidance lines" OR "parking aid" OR "driver assistance system" OR "visual aid" OR "assistive interface" OR "ADAS") AND

("user experience" OR "usability" OR "UX" OR "trust" OR "workload" OR "cognitive demand" OR "performance" OR "stopping distance" OR "time to collision" OR "TTC" OR "reaction time" OR "NASA-TLX" OR "UEQ" OR "Stopping Accuracy").

Studies included followed the characteristics defined using the PICO framework: (i) Population: human operators performing stopping or parking maneuvers on ground transportation systems; (ii) Intervention: technological systems supporting parking/stopping maneuvers; (iii) Comparator: use versus non-use of support or predictive technology, comparisons across the same and different systems in different conditions, and comparison between guidance lines and other technologies; (iv) Outcome: objective performance measures and subjective experience evaluations. Apart from these criteria, studies included were peer-reviewed journal or conference papers, in English, published from 2010 onward, conducted in simulator, prototype, or real-world settings, with evaluation involving human–system interaction.

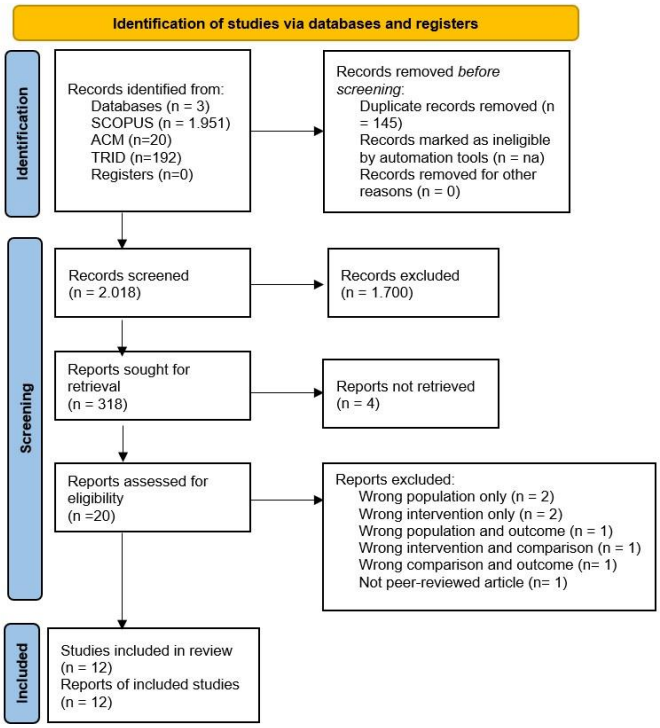

Figure 1. *Prisma Flow Diagram*

Results

Technologies and Transportation Contexts

The reviewed studies predominantly focus on automotive contexts, with head-up displays and augmented reality visualisations being the most common technologies for parking, stopping and following manoeuvres. No study was found to involve train driving, and only one study addressed remote operation.

Evaluation Measures

The most representative objective variables were those related to time (e.g., reaction time, time to park, time to collision), those related to distance (e.g., first braking distance, distance from the obstacle), and those related to speed (e.g., acceleration, velocity). Instead, the most representative subjective variables were those related to user experience (e.g., utility, satisfaction), those related to technology acceptance, and those related to cognitive workload.

Identified Gaps

Notably absent from the literature are studies addressing: (i) Predictive support for stopping or parking in rail transport; (ii) Remote or teleoperated train driving; (iii) Guidance line-based support technologies in this context.

Discussion and Conclusion

The findings highlight a strong concentration of research on automotive applications and visual display technologies, with limited transfer to other transportation domains. The absence of studies in rail and remote driving contexts suggests that existing design and evaluation practices may not directly generalise to these domains. The review further reveals a lack of holistic evaluation, in which the design of predictive technologies, as well as both behavioural and experiential outcomes related to their use are considered.

This paper provides a structured overview of predictive driver support technologies for stopping and parking manoeuvres in ground transportation. By synthesising existing approaches and identifying key gaps, the review offers a foundation for future empirical studies addressing emerging challenges in remote and automated train operation. Based on the review, future studies should: (i) extend predictive support research to rail and remote driving contexts; (ii) systematically compare predictive visual aids, including guidance lines; (iii) adopt mixed methods combining performance-based and experiential measures.

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