XVII International Symposium
"ROAD ACCIDENTS PREVENTION 2026"
Novi Sad, Serbia, 14th and 15th October 2026.

https://doi.org/10.68515/RAP.2026.17.25

DRIVER INTERACTION WITH IN-VEHICLE INFORMATION SYSTEMS: IMPLICATIONS FOR ROAD SAFETY AND FUTURE TRENDS

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Abstract: The proposed review paper examines driver interaction with In-Vehicle Information Systems (IVIS) and their impact on road safety. Modern vehicles are equipped with various navigation, communication, and infotainment systems that provide numerous functionalities to drivers while simultaneously representing potential sources of visual, manual, and cognitive distraction. The aim of this paper is to review the relevant scientific literature in order to identify the key characteristics of IVIS, the ways in which these systems are used during driving, and their positive and negative effects on driver behaviour and driving performance. Particular attention will be given to the safety implications of IVIS use, including their effects on reaction time, lane-keeping performance, situation awareness, and decision-making. Furthermore, the paper will examine current trends in the development of IVIS, such as voice-based interfaces, artificial intelligence, and integration with Advanced Driver Assistance Systems (ADAS), with the aim of assessing their potential impact on future road safety.

Keywords: In-Vehicle Information Systems (IVIS), driver interaction, road safety, driver distraction.

1. INTRODUCTION

Over the past few decades, the automotive industry has undergone an intensive technological transformation, with vehicle digitalisation emerging as one of the most significant development trends. Modern vehicles are no longer merely means of transport but complex information and communication systems that integrate a wide range of functions aimed at enhancing safety, comfort, and user experience. In this context, In-Vehicle Information Systems (IVIS) play a significant role by providing drivers with access to navigation, multimedia content, communication services, and vehicle status information through integrated user interfaces.

The development of IVIS has been characterised by a transition from traditional analogue controls, such as buttons and switches, to digital interfaces based on touchscreens, voice commands, and advanced information display systems. Today, various interaction modalities are widely used, including centre console displays, Head-Up Displays (HUDs), Augmented Reality Head-Up Displays (AR-HUDs), voice user interfaces, and other forms of human-vehicle

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interaction. The development of these technologies is aimed at making interaction more intuitive and delivering information to drivers more efficiently, while seeking to reduce driver workload and minimise adverse effects on driving safety.

At the same time, the increasing functionality of IVIS has resulted in greater complexity of driver-vehicle interaction. The integration of smartphones, Internet services, multimedia content, and numerous applications has enabled a higher level of connectivity, but has also raised new road safety concerns. Numerous studies indicate that the use of information systems while driving can lead to visual, manual, and cognitive distraction (Krstačić et al., 2024; Regan et al., 2011; Strayer et al., 2016; Zhong et al., 2024; Ziakopoulos et al., 2019). These forms of distraction may adversely affect lane-keeping performance, reaction time, hazard detection, and decision-making while driving.

Given the continuous development of IVIS technologies and the increasing diversity of ways in which drivers interact with these systems, it is necessary to review the existing knowledge regarding their effects on driver behaviour and driving safety, as well as the directions of their further development. Based on a review of recent scientific literature, this paper aims to analyse driver interaction with IVIS, identify their implications for road safety, and present the key directions for the future development of these systems.

2. OVERVIEW OF IN-VEHICLE INFORMATION SYSTEMS

IVIS encompass a range of systems and functions that provide drivers, while driving, with access to information related to the journey and vehicle status, as well as communication and multimedia content that is not directly related to the primary driving task (European Commission, 2008; Oviedo-Trespalacios et al., 2019). Their primary role is to make relevant information and functions available to drivers in a manner that allows them to be used with minimal interference with the primary driving task. With the development of digital technologies, the functionality of these systems has expanded considerably, making modern IVIS an important element of driver-vehicle interaction (Cooper et al., 2020).

Driver interaction with IVIS is facilitated through various forms of Human-Machine Interfaces (HMI), which enable information exchange between the driver and the system. Information can be presented to the driver through visual, auditory, and haptic modalities, while commands can be entered using physical controls, touchscreens, voice commands, and other interaction modalities. The selection and combination of these modalities play an important role in determining the level of visual, manual, and cognitive workload imposed on the driver.

Modern IVIS are increasingly integrated with other in-vehicle technologies, including Advanced Driver Assistance Systems (ADAS), connected services, and Artificial Intelligence (AI)-based systems. Such integration expands the possibilities for providing information and assistance to the driver, while simultaneously increasing the complexity of human-vehicle interaction. Therefore, the design, organisation, and use of IVIS represent important considerations in terms of driver behaviour and road safety (Krstačić et al., 2024).

2.1. Types of IVIS

IVIS can be classified according to the functions they provide to drivers while driving. However, the boundaries between individual categories are not always clearly defined, as modern centralised systems often integrate navigation, communication, information, and entertainment functions within a single user interface (Krstačić et al., 2024; Strayer et al., 2019).

Navigation systems enable vehicle positioning, destination selection, route planning, and guidance to the desired location. Modern navigation functions can be linked to real-time traffic

information and other external data sources, allowing routes to be adapted to current traffic conditions. Information can be displayed via a central display, digital instrument cluster, or HUD. Although navigation systems provide significant support to drivers, interacting with them while driving, particularly when searching for and entering a destination, may require additional visual, manual, and cognitive resources (Krstačić et al., 2024; Zhong et al., 2024).

Infotainment systems integrate information and entertainment functions within the vehicle, including radio, music and other multimedia content, access to applications, and connectivity with mobile devices. In modern vehicles, these functions are typically integrated into a central digital interface, which can be operated via touchscreens, physical controls, or voice commands (Strayer et al., 2019). Given the number and diversity of available functions, the design of infotainment interfaces is particularly important in terms of the demands their use places on the driver (Zhong et al., 2024; Krstačić et al., 2024).

Communication and connected systems enable the exchange of information between drivers, mobile devices, vehicles, and external communication systems. This category includes telephone and messaging functions, smartphone integration, voice control of communication functions, and access to connected services. Vehicle connectivity with external data sources also enables the provision of real-time traffic information, road hazard warnings, and other information relevant to the journey (Krstačić et al., 2024; Zhou et al., 2022).

Vehicle information systems provide drivers with access to data on vehicle status and operation, as well as other information relevant to the journey. This may include information on fuel or energy consumption, driving range, tyre pressure, maintenance requirements, and other parameters that allow drivers to monitor the condition of the vehicle (Zhong et al., 2024).

In addition to the functions described above, modern IVIS are increasingly integrated with ADAS. Although ADAS, such as Adaptive Cruise Control (ACC), Lane Keeping Assistance (LKA), and Autonomous Emergency Braking (AEB), are not considered IVIS in the strict sense, information and warnings generated by these systems are often presented to drivers through the same HMI elements used for IVIS. Their increasing integration therefore represents an important aspect of modern driver-vehicle interaction (Engström et al., 2006).

Regardless of their primary function, the use of different categories of IVIS while driving may require visual, manual, and cognitive resources to be diverted from the primary driving task. Consequently, the manner in which these systems are used represents an important road safety consideration (Strayer et al., 2019; Ziakopoulos et al., 2019).

2.2. Evolution of IVIS

The development of IVIS can be viewed as a gradual transition from traditional physical controls to digital and multimodal interfaces. Earlier systems were primarily based on physical buttons, switches, and other mechanical controls, while advances in digital technologies enabled the integration of an increasing number of functions through central displays and touchscreens. As a result, navigation, communication, multimedia, and other functions have gradually been integrated into a single user interface (Murali et al., 2022; Krstačić et al., 2024).

The further development of IVIS has been characterised by the introduction of various interaction modalities, including voice control and advanced methods of visual information presentation. Advances in speech recognition and Natural Language Processing (NLP) technologies have enabled the wider adoption of voice interfaces, with the aim of reducing the need for manual interaction with the system (Large et al., 2017). At the same time, HUDs have enabled relevant information to be presented within the driver's field of view, while their further development includes AR-HUDs, in which virtual information is overlaid onto elements of the real-world traffic environment (Yöntem et al., 2021).

These developments indicate a gradual transition towards integrated and multimodal IVIS, in which different methods of information presentation and command input are combined within a unified HMI. However, the introduction of new interaction modalities does not necessarily result in reduced driver distraction, as different interfaces may engage the driver's visual, manual, and cognitive resources in different ways. These aspects are discussed in greater detail in the following section.

3. DRIVER INTERACTION WITH IVIS

Driver interaction with IVIS is a complex process in which the resources required for safe vehicle operation are allocated between the primary driving task and secondary tasks performed through IVIS. Such tasks may include using navigation systems, selecting music or radio stations, making phone calls, sending messages, and using other functions integrated into the vehicle.

Interaction with IVIS may engage the driver's visual, manual, and cognitive resources, with these demands often occurring simultaneously under real-world driving conditions. Visual distraction occurs when the driver looks away from the road towards the system; manual distraction occurs when system use requires the driver to take one or both hands away from the driving task; while cognitive distraction involves diverting attention and mental resources from the primary driving task to a secondary task (NHTSA, 2012; Regan et al., 2011). The level and type of distraction depend on the characteristics of the IVIS, the interaction modality, and the complexity of the task being performed by the driver (Strayer et al., 2019).

3.1 Visual and Manual Distraction

Visual and manual distraction are closely related consequences of driver interaction with IVIS. Using centre console displays, selecting menu options, browsing content, or entering information into a navigation system may require drivers to simultaneously look away from the road and use one hand to operate the system. Consequently, visual and manual demands often occur simultaneously under real-world conditions of IVIS use, particularly when interacting with touchscreens (Strayer et al., 2019; Zhong et al., 2024; Hazoor & Marinelli, 2026).

From the perspective of visual distraction, important indicators include the frequency and duration of individual off-road glances, as well as the total time during which the driver's visual attention is directed towards the IVIS. Research has shown that visual-manual tasks can increase the time spent looking away from the road and adversely affect the detection of driving-relevant events (Strayer et al., 2019). Analysis of naturalistic data on touchscreen interface use further indicates that the visual demands of interaction depend on the characteristics of the user interface and the conditions under which the interaction takes place (Ebel et al., 2023). In the study by Zhong et al. (2024), visual-manual interaction was associated with a greater number and longer total duration of glances towards the IVIS compared with auditory-vocal interaction. Prolonged off-road glances are of particular importance, as they may be associated with increased risk while driving (Zhong et al., 2024).

The level of visual and manual engagement also depends on the type and complexity of the secondary task. Tasks that require searching for information, navigating through multiple menu levels, or performing a greater number of consecutive steps may increase the time required to interact with the system. Zhong et al. (2024) identified differences among individual IVIS tasks, with navigation and music selection being more visually demanding than simpler tasks, such as making a phone call or selecting a radio station. Drivers may attempt to limit the duration of individual glances towards the system by frequently returning their gaze to the road; however,

this strategy may increase the number of glances and the total time required to complete the task (Zhong et al., 2024).

Entering a destination into a navigation system represents a typical example of combined visual-manual engagement, as it may require locating the appropriate function, entering or selecting information, and visually confirming the executed command. The findings of Starkey and Charlton (2020) indicate that drivers engage in various activities requiring direct interaction with a device while driving, including destination entry, music selection, and messaging. Participants associated certain navigation-related activities with slower responses to changes in traffic conditions, variations in speed, and a reduced ability to monitor the road (Starkey & Charlton, 2020).

These findings indicate that the safety implications of visual-manual interaction with IVIS depend not only on the type of interface but also on task complexity, the number of required steps, and the time needed to complete the task. Reducing the need for prolonged off-road glances and manual interaction therefore represents an important consideration in IVIS interface design.

3.2 Cognitive Distraction

Cognitive distraction occurs when a secondary task diverts the driver's attention and mental resources away from the primary driving task, even when the driver's eyes remain on the road and their hands remain on the steering wheel. Interaction with IVIS may require information processing, decision-making, memorising commands, or formulating responses, thereby increasing the driver's cognitive workload. The level of cognitive workload depends on the type and complexity of the task, the mode of interaction with the system, and the time required to complete it (Strayer et al., 2016; Strayer et al., 2019).

Voice-based interfaces are particularly relevant from the perspective of cognitive distraction. Their use reduces the need for manual interaction and may limit visual demands compared with visual-manual interaction with IVIS, but does not eliminate the cognitive demands associated with the secondary task. Strayer et al. (2016) found that interaction with different voice-based IVIS can result in moderate to high levels of cognitive workload, with more intuitive systems, lower interaction complexity, and shorter task completion times being associated with lower workload. A more recent study by Loew et al. (2023) also showed that interaction with speech-based assistants while driving can induce cognitive distraction even when the visual and manual demands of the interaction are reduced. In this study, speech-based tasks were associated with higher cognitive workload than driving without a secondary task, but lower workload than a highly demanding cognitive task (Loew et al., 2023). These findings indicate that hands-free interaction does not, in itself, imply the absence of distraction (Strayer et al., 2016; Loew et al., 2023).

Cognitive demands also vary depending on the type of task performed through IVIS. Tasks requiring more complex information processing, a greater number of steps, or longer completion times may place greater demands on attention and working memory. Strayer et al. (2019) showed that cognitive demands vary across different IVIS functions and interaction modalities, while the findings of Zhong et al. (2024) also indicate that the type of secondary task and the manner in which it is performed affect the driver's overall workload. Therefore, the assessment of distraction should not be based solely on whether the interaction requires the driver to look away from the road or use their hands, but should also take into account the mental demands that a particular task places on the driver.

In addition to the workload experienced during the interaction itself, research also indicates the possibility of residual effects after completion of the secondary task. Strayer et al. (2016)

identified persistent interference following IVIS interaction, with residual effects on driving performance lasting for up to 27 seconds after the interaction had ended. The authors associate this finding with the time required for drivers to re-establish situational awareness of the traffic environment following interaction with IVIS. These findings indicate that the end of an interaction with the system does not necessarily coincide with the complete reallocation of cognitive resources to the primary driving task (Strayer et al., 2016).

3.3 Differences in IVIS Interaction among Driver Groups

The effects of interaction with IVIS may vary across different groups of drivers depending on their individual characteristics, driving experience, and familiarity with technology. Age is an important factor, as changes in perceptual, motor, and cognitive abilities, as well as different levels of experience with digital technologies, may influence the way drivers interact with the system and the demands that such interaction places on them.

Research indicates significant differences between younger and older drivers in the demands associated with IVIS use. Cooper et al. (2020), comparing younger and older drivers while performing various IVIS tasks, found that older drivers required more time to complete the tasks, responded more slowly to the Detection Response Task (DRT), and reported higher levels of subjective workload (Cooper et al., 2020). Similarly, Strayer et al. (2016) found higher cognitive workload among older drivers compared with younger drivers when performing the same voice-based IVIS tasks. These findings indicate that the same interaction with IVIS may not impose the same level of demand on drivers of different age groups (Strayer et al., 2016; Cooper et al., 2020).

In addition to age, previous experience with a specific system may also play an important role. In the study by Strayer et al. (2016), following the initial assessment, participants used the vehicle and practised interacting with the IVIS over a five-day period, after which cognitive workload was reassessed. The results showed that practice did not eliminate the interference associated with IVIS use, with systems that were initially, more demanding remaining relatively demanding even after the period of use (Strayer et al., 2016). These findings suggest that familiarisation with the system alone may not be sufficient to overcome the demands that complex IVIS interfaces place on drivers.

Differences between driver groups highlight the importance of considering user characteristics when designing and evaluating IVIS. Rather than assuming that the same mode of interaction is equally suitable for all drivers, interface design should take into account differences in user abilities, experience, and needs, particularly with regard to task complexity and the methods used for information presentation and input.

4. SAFETY IMPLICATIONS

The use of IVIS may have both positive and negative implications for road safety, depending on the type of system, the characteristics of the interaction, and the conditions under which the system is used. The systematic literature review by Krstačić et al. (2024) indicates that the safety implications of IVIS can be considered across several interrelated areas, including driver distraction, situational awareness, cognitive workload, driving performance, interaction effectiveness, and the driver's emotional state. This section examines the effects of IVIS use on driving performance, the factors influencing the safety of their use, and the potential positive effects of these systems.

4.1 Effects on Driving Performance

The use of IVIS while driving may affect various measures of driving performance, including driving speed, lane-keeping performance, and reaction time. The magnitude of these effects depends on the type of secondary task, its complexity, and the interaction modality used.

When performing secondary tasks, drivers may adopt compensatory strategies, such as reducing their driving speed, in response to the increased demands associated with IVIS interaction. Zhong et al. (2024) found that average driving speed was lower during auditory-speech and visual-manual interaction than during driving without a secondary task, with a greater reduction observed during visual-manual interaction. However, speed adaptation was not sufficient to compensate for the effects of certain secondary tasks on lateral vehicle control. Navigation and music selection were associated with the highest number of lane departure warnings, indicating that more demanding IVIS tasks may adversely affect the driver's ability to maintain an appropriate position within the lane (Zhong et al., 2024).

Interaction with in-vehicle secondary tasks may also affect driver reaction time in situations requiring a timely response. In a driving simulator study, Hibberd et al. (2013) found that braking reaction time increased when drivers were engaged in an in-vehicle secondary task. This effect was more pronounced when the time interval between the secondary task and the event requiring braking was shorter. These findings indicate that engagement in secondary tasks may delay driver responses to unexpected traffic events, representing an important safety implication of in-vehicle system use (Hibberd et al., 2013).

4.2 Factors Affecting the Safety of IVIS Use

The safety implications of IVIS use depend on the interaction of multiple factors related to the characteristics of the secondary task, the mode of interaction with the system, driver characteristics, and the conditions under which the interaction takes place. Therefore, the same IVIS or function may impose different levels of demand under different driving conditions.

The complexity and duration of the secondary task are important factors in determining the demands associated with IVIS interaction. Tasks that require a greater number of steps, information searching, or longer completion times extend the period during which the driver's resources are engaged in the secondary task. Research indicates that longer and more complex IVIS interactions are associated with greater visual and cognitive demands, whereas more intuitive systems and shorter task completion times may be associated with lower driver workload (Strayer et al., 2016; Cooper et al., 2020).

The interaction modality also has an important influence on the safety of IVIS use. Visual-manual interaction, particularly through touchscreen interfaces, requires drivers to divert their visual attention away from the road and engage manually with the system, whereas voice-based interaction may reduce visual and manual demands but does not eliminate cognitive workload. Therefore, the safety implications of a particular interaction modality also depend on the type and complexity of the task performed through it (Strayer et al., 2019; Zhong et al., 2024).

In addition to system and task characteristics, driver characteristics and the driving context also play an important role. Age and experience with the system may influence the demands associated with IVIS interaction, with older drivers found to require longer task completion times and experience greater visual and cognitive demands (Cooper et al., 2020). At the same time, naturalistic data indicate that the conditions under which driving takes place also influence the manner and frequency of IVIS interaction. Hilbert et al. (2026) found that factors such as road type, driving dynamics, environmental conditions, and the use of automated driving functions influence the likelihood of initiating touchscreen interaction, as well as the characteristics of the

interaction itself. These findings indicate that the safety of IVIS use depends not only on the technical characteristics of the system but also on the combination of secondary-task demands, interaction modality, user characteristics, and the current driving context (Hilbert et al., 2026).

4.3 Potential Positive Effects of IVIS on Safety

Although IVIS use may be a source of driver distraction, well-designed systems may also have potential positive effects on driving safety. These effects primarily relate to the timely provision of information relevant to the journey and traffic conditions, support for driver situational awareness, and the use of interaction modalities that may reduce visual and manual demands during system use.

Navigation systems and connected information functions can provide drivers with information that supports route planning and monitoring, as well as situational awareness. Ma and Kaber (2007) found that reliable navigation information can contribute to improved driver situational awareness and performance, highlighting the importance of the reliability of the information provided by the system (Ma & Kaber, 2007). Timely information in critical situations may also provide potential safety benefits. David et al. (2025) showed that appropriately designed navigation warnings presented via HUDs can contribute to shorter reaction times and improved driver situational awareness in situations involving approaching emergency vehicles (David et al., 2025). These findings indicate that the potential safety benefits of information functions depend not only on the content of the information but also on its reliability, relevance, timeliness, and the manner in which it is presented to the driver.

Interaction modalities that reduce the need to look away from the road and manually operate the system may also offer potential benefits. Maciej and Vollrath (2009) found that speech-based control of various IVIS functions was generally associated with better driving performance, more favourable glance behaviour, and lower self-reported distraction compared with manual control. However, performance generally did not reach the level observed when driving without a secondary task, indicating that speech-based interaction may reduce certain demands associated with IVIS use but does not eliminate them entirely (Maciej & Vollrath, 2009).

Further potential lies in the integration of IVIS with other in-vehicle systems and the coordinated presentation of safety-relevant information. Although ADAS are not considered IVIS in the strict sense, information and warnings generated by these systems are often presented to drivers through a shared HMI. The safety benefits of such integration depend on how the information is organised and presented, as an excessive number of warnings or overly complex presentation may increase the demands placed on the driver (Krstačić et al., 2024). Therefore, the integration and presentation of information represent important aspects of safe driver interaction with modern in-vehicle systems.

5. EMERGING TRENDS AND FUTURE CHALLENGES

The future development of IVIS is increasingly focused on the application of artificial intelligence, advanced voice interfaces, personalisation and adaptive information delivery, as well as integration with connected and automated vehicles. These technologies may enable more natural and context-sensitive interaction between drivers and vehicles, while at the same time raising new concerns related to cognitive distraction, system reliability, data privacy, and driver interaction with automation.

Advances in AI and NLP are enabling a transition from predefined voice commands towards more flexible and natural communication with the system. Conversational and generative AI assistants represent a particularly important direction of development, as they could integrate

navigation, communication, and other IVIS functions while adapting their responses to the driver's current needs (Kim et al., 2017). However, reducing visual-manual demands does not necessarily result in a reduction in overall distraction. Previous research on speech-based assistants has shown that interaction with these systems may induce cognitive workload even when drivers keep their eyes on the road and their hands on the steering wheel (Loew et al., 2023). Therefore, a particular challenge for future AI assistants will be determining when, how, and to what extent it is appropriate to engage drivers in more complex conversations.

Another important direction is the development of personalised and context-aware IVIS that adapt the manner and amount of information presented according to driver characteristics and current driving conditions. Naturalistic data indicate that factors such as road type, driving dynamics, environmental conditions, and the level of automation influence the likelihood and characteristics of driver interaction with IVIS (Hilbert et al., 2026). Such findings provide a basis for developing systems that could restrict or postpone less important interactions in demanding driving situations. However, personalisation and predictive system adaptation require the collection and processing of data on drivers and the driving context, making privacy, data protection, and algorithmic transparency additional challenges for future development.

The development of connected and automated vehicles is further changing the role of IVIS and the way drivers interact with their vehicles. Connectivity with other vehicles, infrastructure, and external data sources may enable the timely provision of information on traffic conditions and potential hazards; however, the increasing amount of available information also requires careful filtering and prioritisation. At the same time, partial driving automation may change the way drivers use IVIS, with data indicating a greater likelihood of initiating IVIS interactions under conditions of partial automation (Hilbert et al., 2026). Therefore, one of the key challenges will be to align IVIS with increasing levels of driving automation while maintaining adequate driver situational awareness and the ability to take control of the vehicle in a timely manner.

6. CONCLUSION

The literature review indicates that driver interaction with IVIS represents an important factor that may influence driver behaviour and driving performance. The safety implications of IVIS use depend on the type and complexity of the secondary task, interaction modality, driver characteristics, and driving context. Visual, manual, and cognitive demands often occur simultaneously, and their effects may be reflected in longer reaction times, changes in lane-keeping performance, and reduced situational awareness.

At the same time, IVIS should not be viewed solely as a source of distraction. Reliable and timely information, appropriate interaction modalities, and carefully designed interfaces can support drivers and reduce certain demands associated with system interaction. The future development of IVIS should therefore aim to achieve a balance between the increasing number of available functions and the need to limit drivers' visual, manual, and cognitive workload. Advances in AI, personalised and context-aware interfaces, as well as integration with connected and automated vehicles, further increase the importance of addressing this issue.

Future research should focus particularly on the effects of conversational and generative AI assistants on cognitive distraction, the effectiveness of adaptive IVIS across different driver groups and driving conditions, and the interaction between IVIS and different levels of driving automation. Greater emphasis should be placed on real-world and naturalistic studies to assess the safety implications of modern IVIS under the complex and dynamic conditions of real-world traffic.

ACKNOWLEDGMENTS

The results presented in this paper are part of the research project „Researching trends in the development of sustainable transport and logistics systems“, Department of Traffic Engineering, Faculty of Technical Sciences, University in Novi Sad, Republic of Serbia.

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