

INFLUENCING DRIVER BEHAVIOUR THROUGH DIGITAL WARNING SYSTEMS: AN INDUSTRY CASE STUDY OF INTERMATIC D.O.O.

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Digital warning systems are increasingly used to improve traffic safety by influencing driver behaviour in urban environments. This paper examines how radar-based speed displays and warning systems contribute to raising driver awareness and promoting safer driving practices. Using an industry case study of Intermatic d.o.o., the research is based on a qualitative, semi-structured interview with the company's director, complemented by insights from student-led project activities conducted in cooperation with the company. The study explores managerial perspectives on the design, deployment, and perceived behavioural effects of digital warning systems, as well as key challenges related to implementation, data interpretation, and stakeholder cooperation. The findings highlight the role of interactive feedback, contextual placement, and data-supported decision-making in shaping driver responses. The paper contributes to the literature on smart mobility and traffic safety by offering practice-oriented insights into how digital warning technologies can support sustainable urban mobility and safer road environments.

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1 Introduction

Driver behaviour management to enhance road safety is a current and ongoing key issue in the development of smart cities. Speed is currently among the top contributors to accidents and the severity of injury that can occur, especially in areas where urban traffic is mixed (da Silva et al., 2025). To mitigate this, smart cities are employing digital warning displays like radar speed feedback displays and variable message signs to manage the actions of drivers.

The literature highlighted the efficacy of speed feedback systems to lower average speeds and enhance awareness among drivers prone to speeding (Neupane, 2025). Variable message signs were also found to be effective in enhancing drivers' situational awareness and responsiveness to traffic control in the uncertain driving environment (Yang et al., 2024). These technologies are being backed up by intelligent traffic monitoring and control systems that facilitate real time data collection and dynamic control of traffic (Thabit et al., 2024).

On the other hand, although there is an abundance of literature on the quantitative effectiveness of digital warning systems, literature that discusses the managerial and organizational aspects of their implementation is scarce. A systematic review highlighted that the real-world operational context, stakeholder engagement, and implementation approaches are key factors in the successful implementation of intelligent transportation systems for road safety (Kontaxi et al., 2025). To fill this knowledge gap, this paper describes a case study analysis in a private sector company, Intermatic d.o.o., that produces, implements and maintains digital warning systems to manage driver behaviour and improve urban mobility.

2 Literature Review

2.1 Digital Warning Systems and Traffic Safety

Radar speed signs and variable message signs are valuable tools that are widely employed within the framework of intelligent transportation systems and road safety management. These signs present real-time speed, traffic and safety information to drivers to improve their behaviour (Thabit et al., 2024). Such signs are more critical in urban networks where the density of the vehicular traffic is higher and the

probability of mixed traffic flow with other vulnerable road users and various types of road infrastructure is greater.

It has been widely acknowledged in the literature that vehicle speed is a key factor in the frequency and severity of road crashes. Da Silva et al. (2025) demonstrated that small reductions in the mean speed may result in significant enhancements in the traffic safety indicators, and, hence, the need for speed management measures on urban streets.

A few studies emphasized that the perceptual and design aspects of digital warnings are crucial to their effectiveness. For example, the legibility of variable message signs in foggy weather is contingent upon their visual design, with optimal text colour and spacing facilitating quicker information processing and lowering the driver's mental burden (Huo et al., 2024). Inadequately designed signs may even increase the likelihood of accidents.

Likewise, in variable message signs, graph-based visual symbols have demonstrated their superior visibility compared to text-based visual information and overcome the language barrier problem. As a result, these design strategies facilitate drivers' recognition and understanding of traffic and weather advisories (e.g., rain, fog, wind, and snow) (Chen et al., 2013).

2.2 Influence of Speed Feedback on Driver Behaviour

Another common form of digital warning is speed feedback signs. There is research proving their effectiveness in reducing speeds in most cases (Neupane, 2025). The mechanism by which this effect is achieved is the self-awareness and feedback, which leads to self-control.

In addition to speed reduction, speed feedback signs are also found to influence other kinds of behavioural shifts, such as increased adherence to traffic laws and higher levels of caution when driving in areas like school zones and neighbourhood streets (Neupane, 2025).

The positive impact of speed feedback was further shown in a field study on roundabout approaches, where the application of dynamic warning signs resulted in lower entry speeds of the vehicles. The largest effect of the speed sign was observed when it was positioned around 150 m in front of the roundabout, which proves the need for an optimal positioning of the sign (Cavka et al., 2025).

However, Ratchaneepun et al. (2026) argue that the effects of warning systems on driver's behaviour may differ and that these effects should not be taken for granted. They show that the results of enhanced recognition of hazards do not lead to enhanced speed adjustment and therefore, each individual aspect of driving behaviour should be dealt with separately.

2.3 Variable Message Signs and Situational Awareness

Besides the functionalities of digital warning signs, variable message signs (VMS) can disseminate more tailored and dynamic information to drivers. A recent study by Yang et al. (2024) shows that the VMS can effectively promote the situation awareness of drivers, especially at places where the road geometry is complicated (e.g. freeway off-ramps and urban intersections). With a better situation awareness, drivers can make wiser decisions and decrease the probability of engaging in a dangerous maneuver.

Overall, the results highlight the need for clear, concise messages, appropriate locations, and relevant contexts in order to make use of the full potential of digital warning systems – it is not technology alone that matters but its targeted use.

Likewise, Chen et al. (2013) state that employing graphical symbols on variable message signs (VMS) has the benefit of providing a visual communication strategy that can be detected at a longer distance and is not limited by linguistic barriers. That is, the use of symbols on the VMS helps shorten the reading time and increase the recognition reliability of traffic and weather messages.

More recent studies suggest an evolution toward personal and contextual warning which aims at not only providing knowledge but also at influencing driver's on-line behaviours. The graphic control at the approach of a red light gives drivers sequential and self-explaining feedback on the appropriate moment and pressure of

the foot on the brake, and thereby facilitates more moderate deceleration (He et al., 2024).

They provide focused decision support by presenting only relevant information in the context of a particular traffic situation. Furthermore, combining driver-related information with environmental data reduces false alarms and facilitates more efficient cooperative warnings for other road users such as pedestrians (Stocker et al., 2025).

2.4 Data-Driven Traffic Management and Real-World Contexts

Due to the availability of traffic monitoring sensors, a vast amount of data can be generated for infrastructure planning and traffic management purposes. Thabit et al. (2024) suggest that a monitoring and management integrated system can facilitate real-time intervention and performance assessment, which further binds the data with the policy.

On the other hand, it is important to mention that according to a systematic literature review of Kontaxi et al. (2025) the organisational, managerial and contextual factors play an important role in the actual impact of digital traffic safety interventions. Limited research was found on stakeholder involvement, maintenance, and connectivity with urban mobility planning.

Machine learning techniques are now a key feature of modern data-driven traffic safety research. This is because they are capable of handling big and complex data and have shown superior ability in predicting traffic accidents in comparison with conventional statistical methods, as they can capture non-linear relationship and patterns of the data (Chai et al., 2024).

Empirical applications demonstrate that machine learning methods applied in the spatial context are able to find high-risk locations with high accuracy and that there is potential to derive proposals for safe route planning that are not only optimized by distance but also by traffic risk (Berhanu et al., 2024).

Data-driven approaches are based on data coming from devices used by drivers in their daily activities. For instance, the analysis of the data from smartphone sensors allows recognizing different driving styles and types, and classifying drivers into risk profiles, offering new possibilities for risk assessment and support to automation (Valente et al., 2024).

These results are also supported by practice in the insurance industry, as the use of telematics has already led to a decrease in the number of claim events. A case study of the DRAJV application in Slovenia has shown that observing and giving feedback to the driving behaviour of the users can significantly affect their behaviour in traffic and have a positive effect on road safety (Kop et al., 2022).

While there has been significant progress in this area, there has been relatively little focus on how organizations make sense of such insights, enact them, and integrate them into design and deployment choices.

2.5 Research Gap

Various studies have quantitatively shown that digital warnings (e.g. speed feedback display, variable message sign) can influence driver behaviour (e.g. Neupane, 2025; Yang et al., 2024), and the use of monitoring technologies for data-driven traffic management and infrastructure planning is expanding (Thabit et al., 2024). Yet, systematic reviews state that organizational, managerial, and contextual factors, which are less prevalent in the literature, have a significant impact on the actual impact of these digital warnings (e.g. Kontaxi et al., 2025).

In addition, the evidence base suggests that the behavioural impacts of digital warning systems are contingent upon specific conditions and cannot be readily extended to other traffic settings or behaviour areas (Ratchaneepun et al., 2026; Cavka et al., 2025). Although system design and data processing studies offer important knowledge about the systems (Huo et al., 2024; Chen et al., 2013; Chai et al., 2024; Berhanu et al., 2024; Valente et al., 2024), they are less concerned with how organizational decision-making processes contribute to the design, data interpretation, and system application. The knowledge gap is particularly evident from the standpoint of the companies that offer and implement traffic safety services.

In particular, there is a scarcity of qualitative studies that have examined the perspectives of the developers and providers of digital warning systems regarding their contributions to traffic safety, the factors and considerations involved in the decision making and management, and the cooperation with researchers and policy makers. As a result, little is known about the actual issues, potential, and decision-making mechanisms with respect to the application and effectiveness of digital warning technologies in the real traffic environments, especially in urban areas.

3 Research

This paper addresses the research gap by applying an industry-focused qualitative case study design, investigating the case of Intermatic d.o.o., a private company that supplies digital traffic safety services. The addition of a managerial perspective from the top management level of the company is intended to enrich the existing body of behavioural and technical research with practice-oriented knowledge relevant to the fields of smart mobility and sustainable urban development.

We use a qualitative case study approach. The data for the study were collected through a semi-structured, in-depth interview comprised of twenty questions with the director of the company Intermatic d.o.o., Mr. Sašo Živković. Such a method allows for an in-depth understanding of the managers' views on the design, implementation and perceived behavioural impact of the digital warning messages as well as of the organizational and contextual variables that moderate the effectiveness of the messages.

The semi-structured interview is then analysed by thematic analysis to find out the themes associated with driver behaviour influence, data usage, difficulties of application and working with other external parties (e.g. academia and cities).

Based on the identified research gap and study objectives, the following research questions are proposed:

- RQ1: How does Intermatic d.o.o. conceptualize the role of digital warning systems in influencing driver behaviour and improving traffic safety?
- RQ2: What managerial and organizational factors influence the design and implementation of digital warning systems in urban traffic environments?

- RQ3: How are data collected through digital warning systems used to support traffic safety interventions and infrastructure improvement proposals?
- RQ4: What challenges and opportunities does Intermatic d.o.o. identify in deploying digital warning systems in cooperation with public authorities and academic partners?
- RQ5: How can industry-academia collaboration contribute to the effectiveness and innovation of digital traffic safety solutions?

4 Discussion and implications

By conducting this research, we contributed to the existing traffic safety literature by discussing digital warning system usage and its impact on driver behaviour from an industry, managerial point of view. Based on the qualitative case study of Intermatic d.o.o. and the in-depth interview with the company's director, the argument is organised around the five research questions.

The results reveal that Intermatic d.o.o. views digital warning systems (RQ1, according to answers to interview questions: 2-6) as tools to encourage safe driving rather than a tool for punishment. Digital warning systems are an integral part of the company's strategic orientation and are perceived as real-time feedback systems that increase drivers' awareness and encourage them to voluntarily reduce speed. This perspective is consistent with previous studies that identified self-regulation and awareness as dominant behavioural mechanisms underlying speed feedback displays (Neupane, 2025).

The interview results revealed that the drivers are more likely to respond to immediate and direct feedback, and especially to speed feedback displays. The context-dependent nature of behavioural responses was also identified, with more pronounced effects in sensitive areas (school zones and residential streets). This is in line with the literature that warns that the effects of warning systems may depend on location and traffic environment and cannot be generalised (Cavka et al., 2025; Ratchaneepun et al., 2026). Thus, the industry perspective also points to the need for a context-dependent deployment strategy as highlighted by the literature.

On the organizational level (RQ2, based on answers to interview questions: 1, 3, 7, 8, 13 and 14), the success of digital alerting systems is dependent not only on the technological solution, but also on the organizational competences and the implementation process. Intermatic d.o.o. points out project management, team integration, legislation and information towards the public as key factors for success. This answers to the part of the organizational dimension that was determined as still lacking (Kontaxi et al., 2025).

Practical implementation difficulties such as site restrictions, environmental impact, power supply, maintenance needs, and cost constraints highlight the difficulty of applying theoretically optimal solutions in the real world. The choice of the company to prefer the modular, proven, and commonly used solutions indicates a trade-off between technology and practicality. This result contributes to the literature by emphasizing the importance of managerial decision in the actual effectiveness of the ITS solutions.

The responses to the interview show that digital warning signs are primarily valued for their ability to collect data (RQ3, derived from interview questions 10-12). Specifically, Intermatic d.o.o. utilizes the collected data related to speed, traffic volume, and time of the day for a before-after analysis, analysis of the effectiveness of countermeasures, and evidence-based decision making, which is in line with research that emphasizes the importance of data-driven traffic management and infrastructure planning (Thabit et al., 2024).

The data, however, are not the goal in and of themselves, but are used as a means to justify a suite of other infrastructure changes, including enhanced signage and lighting, reconstructed crosswalks and permanent traffic calming infrastructure. This implementation of data responds to a literature where a lot of attention is paid to data analytics, but less to the translation of data meaning to operational and planning practices.

These findings stress the importance of collaboration (RQ4, answered by questions: 9, 15 and 20) and policy adherence in the implementation of digital alertness systems, since the existing legislations, data protection and municipality's support define the design and location of the system. Such boundaries are certainly a limitation, but may become a source of legitimacy, acceptability and sustainability.

This case study highlights the key lesson that stakeholder engagement from the outset is crucial, that behavioural changes may be overestimated and that monitoring and maintenance should be on going. This paper adds to the literature by highlighting that governance and institutional factors are as critical as the technical issues for the implementation of ITS for traffic safety.

Our results show that the collaboration between industry and academia (RQ5, through interview questions: 16-18) is a win-win model for innovation and knowledge sharing. Firstly, the company believes that the collaboration with academia (including student projects) brings data analysis, new ideas and challenging ideas to conventional wisdom. The students are especially expected to find out the blind spots and provide customer-focused or creative solutions.

Success in collaboration requires well defined goals, mutual advantages, availability of real data or pilot sites and free communication. All these are conducive to the goals of applied learning programs and the argument of universities as a partner to solve real world problems and hence expand the scope of discussion on sustainable university-industry relations.

In terms of practical implications, our study offers recommendations for policymakers, urban planners, and traffic safety professionals, indicating that a digital warning system should be embedded in the context of mobility policies, with a strong focus on prevention and evidence-based policies and collaborative partnerships between industry, academia, and community.

From a theoretical perspective, the study adds to the literature on traffic safety and intelligent transport systems from an organizational and management angle. By focusing on the industrial point of view, our study complements previous behavioural and technical studies and answers directly to the recent appeal for more qualitative, context-dependent research on traffic safety measures.

5 Conclusion

This paper investigated the use of digital warning systems as driver behaviour management tools based on industry case study of Intermatic d.o.o. and provided one of the first insights into the managerial and organizational dimensions of the use

of this technology that the relevant literature lacked. Our results indicate that digital warning systems are mainly conceived of as preventive, non-punitive, driver awareness and self-management aids rather than enforcement tools, and that their actual impact heavily depends on the contextual factors such as design, location and contextual embeddedness of the system in the local traffic setting.

The research emphasizes that implementation-related factors such as the existence of competencies within the organization, the cooperation between stakeholders, and the compliance with the legislation are important factors for the success of the projects. Another important aspect is the data that the digital alert systems generate, as they serve as an important tool for decision making for investment and infrastructure improvement on a justified basis and also for long-term planning for traffic safety. The interaction between industry and academia also contributes to innovation, as it gathers the knowledge of the people in the field together with the analytical and research-based approach.

In summary, our paper provides additional empirically grounded practical knowledge that adds to the current behavioural and technological science and can help with mainstreaming digital warning tools into smart mobility and sustainable urban planning contexts.

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