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FIVE NEW CLUES ON HOW V2I TECHNOLOGY CAN CONTRIBUTE TO URBAN MOBILITY PLANNING AND MANAGEMENT

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ABSTRACT
In summary, V2I systems can optimize traffic flow by providing real-time information to vehicles, allowing automatic speed and route adjustments. In this sense, how is the union between the transport intelligence system (ITS) and sustainable development evident in the scientific literature, when it comes to Vehicle-to-Infrastructure (V2I)? Therefore, the overall objective of the study was to identify the relationship between V2I and sustainability. The present exploratory and descriptive research was composed of a scoping review, carried out from the search for scientific articles in English in the Web of Science (WoS) scientific database. The results were analyzed and discussed using the Voyant Tools textual analysis tool. The results indicate five new clues regarding V2I and sustainability based on the scientific evidence that was organized into blocks: (1) Timeliness of the theme; (2) Interdisciplinary teams; (3) Inseparability between intelligence and sustainability; (4) Communication; (5) Technology and Humanities. These new tracks serve to guide both future studies and practices for the application of V2I as allies for the planning and management of urban mobility, as well as it is suggested to create an emerging agenda that guides researchers, planners, managers, and other stakeholders.

Keywords: *Vehicle-to-Infrastructure* (V2I), Intelligent Transportation Systems (ITS), Transportation Planning, Mobility Management, Sustainability.

INTRODUCTION

Accelerated urbanization and the significant increase in the vehicle fleet in cities have placed urban traffic management in a central position in discussions on mobility and sustainability, especially with regard to the adoption of intelligent transport systems (ITS) in mobility management (GM). In this sense, the term zeitgeist, which is of German origin and

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widely used in studies of the human and social sciences, marks the interdisciplinarity with which this type of problem must be treated. Zeitgeist, as a spirit of a time, allows us to realize that the union between the advances in technology arising from ITS and with mobility management strategies can allow a more solid advance towards the construction of a new mentality that combines intelligence and sustainability as inseparable categories as a current paradigm.

In this paradigmatic context of the spirit of the present time, which is rapidly marked by technological disruptions, Vehicle-to-Infrastructure (V2I) communication technology has emerged as a promising solution to mitigate congestion problems and improve the efficiency of urban traffic, which are at the heart of new urban mobility management strategies. V2I allows the exchange of information in real time between vehicles and road infrastructure, such as traffic lights and traffic controllers, enabling dynamic adjustments in vehicle speed and routes based on momentary traffic conditions (Katsaros et al., 2011; Hussain et al., 2013). These capabilities not only optimize traffic flow but also contribute to the reduction of fuel consumption and pollutant emissions, as vehicles can avoid unnecessary stops and accelerations (Han et al., 2019; Namazi and Taghavipour, 2021).

Studies have shown that the application of V2I at smart intersections is effective in reducing waiting times, fuel consumption, and emissions, as well as improving road safety through proactive traffic management strategies (Han et al., 2019; Hussain et al., 2013). Technologies such as Green Light Optimized Speed Advisory (GLOSA) and signal control algorithms, which adapt to congestion conditions in real time, show great potential in densely trafficked urban environments, avoiding blockages and offering alternative routes during periods of congestion (Lourenço et al., 2018; Han et al., 2019).

The implementation of smart transport technologies, such as V2I, is aligned with the Sustainable Development Goals (SDGs) of the 2030 Agenda, in particular SDG 11, which aims to make cities and human settlements inclusive, safe, resilient and sustainable (UN, 2015). In this context, the role of V2I in the interface between intelligence and sustainability is investigated. The general objective of this study is to identify the role of V2I technology in the planning and management of urban mobility. Specific objectives include: (a) analyzing V2I as a technology associated with intelligence and sustainability; and (b) to verify the application of V2I technology from the perspective of transport planning and urban mobility management. The research, of an exploratory and descriptive nature, was based on a scoping review, using the online software Voyant Tools (2024) for textual analysis. This work is structured in three main sections, in addition to this introduction and conclusions, the next one being dedicated to the theoretical framework.

THEORETICAL FRAMEWORK

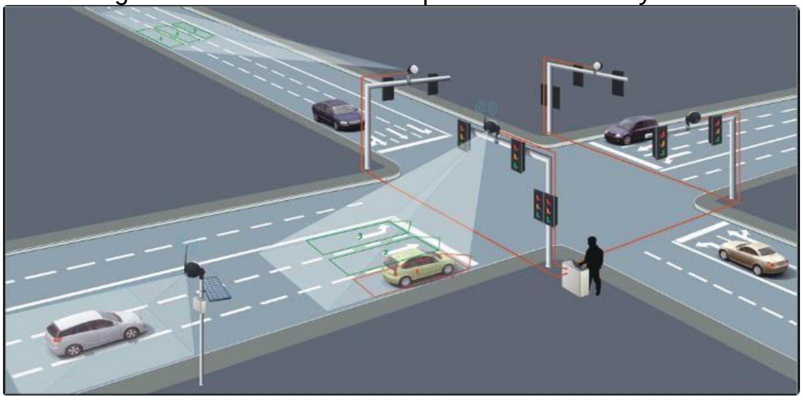
Simulations indicate that V2I-based traffic management solutions can significantly reduce travel times and increase overall traffic efficiency, suggesting that the adoption of these technologies could transform the way traffic is managed in densely populated urban areas (Zadobrischi et al., 2020; Lourenço et al., 2018). Therefore, the objective of this conceptual theoretical framework was to extract the conceptual theoretical category V2I, as a technology linked to intelligence and sustainability (subsection 2.1); contextualize the application of V21 technology from the perspective of transportation planning and mobility management (subsection 2.2.).

INTELLIGENCE AND SUSTAINABILITY: VEHICLE-TO-INFRASTRUCTURE (V2I)

V2I communication is one of the main emerging technologies in the field of Intelligent Transportation Systems (ITS), aimed at improving the efficiency, safety and sustainability of urban traffic. This technology allows the exchange of information in real time between vehicles and road infrastructure, such as traffic lights, traffic sensors, and message boards, creating a more dynamic and responsive traffic environment (Katsaros et al., 2011). Figure 1 is an illustration of the V2I concept, with vehicles connected to traffic lights and traffic sensors.

The concept of V2I is based on the ability of modern vehicles to communicate with fixed components of urban infrastructure through wireless networks. This communication occurs in a bidirectional way: vehicles transmit information about their location, speed, and direction to the infrastructure, which, in turn, responds with data such as traffic conditions ahead, signal times, and possible adjustments to routes, in order to avoid congestion (Han et al., 2019). This continuous interaction makes it possible to implement advanced solutions for traffic management, such as traffic light coordination, which adjusts signaling times in real time to optimize the flow of vehicles at high-demand intersections (Namazi and Taghavipour, 2021).

Figure 1. Illustration of the operation of a V2I system



Source: Dias (2015).

Among the main practical applications of V2I technology are Green Light Optimized Speed Advisory (GLOSA) and Adaptive Route Change (ARC), systems designed to optimize traffic flow in urban areas. These solutions aim to reduce frequent stops and vehicle starts, factors that directly contribute to the increase in fuel consumption and emissions of polluting gases. GLOSA, by providing accurate information on the timing of traffic lights, can significantly reduce downtime and fuel consumption. In conditions of high traffic density, the adoption of GLOSA can reduce downtime by up to 80%, as well as decrease total travel time by 9.85% and fuel consumption by 7%. In turn, ARC adapts vehicle routes in real time, based on traffic conditions, providing a reduction of up to 26.5% in average travel time and 32.5% in stopping time, especially when applied with a penetration rate of equipped vehicles close to 80% (Han et al., 2019; Katsaros et al., 2011).

In addition, V2I technology plays an essential role in road safety by providing early warnings of risky situations, such as accidents or stopped vehicles, allowing drivers to make decisions faster and more effectively. As demonstrated by Han et al. (2019), V2I communication allows for real-time monitoring of traffic and the dissemination of critical information to vehicles, which improves drivers' ability to react to imminent dangers, thereby reducing the risk of collisions at urban intersections.

APPLICATIONS OF TECHNOLOGY WITHIN THE SCOPE OF MOBILITY PLANNING AND MANAGEMENT

Transportation planning requires a concatenated long, medium and short-term vision (Bruton, 1979; Campos, 2013), articulating models such as the four-stage model that makes it possible to generate transport alternatives from data in the face of the sequential application of models of: (1) trip generation, (2) trip distribution, (3) modal division and (4) traffic allocation. Mobility management, on the other hand, is derived from the very notion of sustainable development, shifting the focus on expanding supply to strategies focused on demand (Lopes, 2005; Campos, 2013).

In terms of smart technologies, V2I has been widely adopted in several cities around the world with the aim of improving traffic efficiency and raising road safety levels. Cities such as Las Vegas, Aurora and Columbus exemplify the successful implementation of this technology, demonstrating its potential in solving the challenges related to urban mobility. In São Paulo, although the adopted solution does not yet configure a complete V2I system, being unilateral communication, it represents a significant advance towards the future implementation of this technology.

In Las Vegas, V2I technology was implemented in partnership with the company Acyclica, which installed sensors at about 2,300 intersections throughout the city. These sensors allow traffic to be monitored in real-time, providing traffic controllers with the ability to dynamically adjust traffic light timings to optimize vehicle flow. In addition, the system informs drivers of the state of traffic signals and offers real-time data to autonomous vehicles, allowing them to adjust their routes and speeds to avoid congestion and improve road safety (Traffic Technology Today, 2017a).

Aurora, Colorado, has adopted V2I technology as part of a project developed by Traffic Technology Services Inc. (TTS) in collaboration with Siemens USA. The project utilizes the TACTICS ATMS (Advanced Traffic Management System) platform, which integrates traffic signaling data with cloud services to provide detailed information on the state of traffic signals and forecasts. This data is essential for the safe operation of connected and autonomous vehicles, which rely on accurate information on signage to safely navigate intersections. The ability to predict the timing of signal changes and adjust vehicle behavior according to these predictions is one of the key benefits offered by this technology (Traffic Technology Today, 2017b).

Columbus, Ohio, has taken a slightly different approach, focusing on adaptive traffic signals that utilize data collected from government vehicles to adjust traffic light timings in real time. This system allows for a significant reduction in waiting times at intersections, in addition to contributing to the reduction of pollutant gas emissions due to the reduction of frequent stops and starts of vehicles. The city uses this data to analyze traffic patterns and optimize signage according to the actual conditions of the roads, promoting a more fluid and safer circulation (Traffic Safety Store, 2024).

The city of São Paulo has invested in smart traffic light technologies to improve traffic flow, although it has not yet configured a V2I technology, as communication is not bidirectional. A recent example is the implementation of these traffic lights in the West Zone of the capital, which use real-time data to automatically adjust operating times according to the flow of vehicles. The system, monitored by cameras (Figure 2) and connected to traffic light controllers, aims to reduce traffic jams and optimize circulation in the most congested areas (G1, 2023).

Figure 2. One of the cameras used in the system implemented in São Paulo

Source: G1 (2023).

In summary, the adoption of V2I technology has demonstrated significant improvements in traffic efficiency and road safety, as seen in cities such as Las Vegas, Aurora and Columbus. Although São Paulo does not yet have a complete V2I system, current investments in smart traffic lights indicate an important advance towards the integration of this technology into its transportation system.

METHODOLOGY

The present exploratory and descriptive research was composed of two consecutive stages, namely: (1) Scoping review - carried out from the search for scientific articles in English in the Web of Science (WoS) scientific database on September 7, 2024 (WoS, 2024). Additionally, the Prisma flowchart (2020 apud Page, 2021) was used as a parameter for identification, selection, eligibility, inclusion and exclusion criteria; (2) Textual Analysis - carried out with the support of the Voyant Tools tool (2024), Chart 1 presents the step-by-step methodology adopted:

Table 1. Methodological steps

Steps	Description
1. Scope Review	In the identification step, the following search string was used in WoS on September 07, 2024: "Vehicle-to-Infrastructure" (topic) AND sustainable (topic), resulting in n=42. Subsequently, articles (n=26) published in English (n=42) were selected, resulting in: n=26. Afterwards, they were organized by the most cited, and all those who presented an abstract available were chosen (n=26). Considering as inclusion criteria works that dealt with V2I, nine studies were excluded (n=9), and the result was n=17 for the composition of the textual corpus.
2. Textual Analysis	*Voyant Tools* (2024) was used to treat the textual corpus (n=17), which allowed two results to be elaborated: (a) Cirrus, which is a word cloud with more frequent terms considering the limit of terms=100; (b) Link, which is the formation of relationships between terms by occurrences (Voyant Tools, 2024).

Source: Prepared by the authors (2024).

Next, the results are presented and discussed, from the characterization of the object of study in the face of the theoretical categories based on the identification of new clues from the methodological path adopted.

RESULTS AND DISCUSSIONS

The objective of this section is to characterize V21 as the object of study of the scoping review (subsection 4.1), as well as to present and discuss the results under the aegis of building new clues related to the scientific problem posed, that is, how to unite intelligent transport systems (ITS) and sustainable development (subsection 4.2.).

CHARACTERIZATION OF THE OBJECT OF STUDY

It was evident in the theoretical framework that the implementation of V2I technology presents significant benefits for urban traffic management, however, it faces substantial challenges, such as high infrastructure costs, which include the installation of sensors and communication systems. These costs represent a particularly significant barrier in cities with limited financial resources or aging infrastructure, making large-scale adoption difficult, i.e., sustainability also needs to be discussed under this economic dimension. In addition, the absence of universal standards for V2I and the need for interoperability between different systems and manufacturers can complicate technological integration, affecting the technical dimension of sustainability. Furthermore, issues related to cybersecurity and data privacy also require strict protection measures (Namazi and Taghavipour, 2021; Han et al., 2019) and are under the debate on the technical dimension of V2I to contribute to development in a sustainable way, considering intelligence as an essential step for mobility management in the twenty-first century.

Alongside the technical challenges, public acceptance plays a crucial role in the successful implementation of V2I technology. Resistance resulting from ignorance or distrust of new technologies can delay their adoption, and awareness campaigns and educational programs are necessary. These efforts should be complemented by public policies that encourage the modernization of transportation infrastructure, such as financing programs and tax incentives. Regulation and standardization are essential to ensure consistent and safe implementation, as discussed by Traffic Technology Today (2017a) and Traffic Safety Store (2024).

By improving traffic efficiency and reducing pollutant emissions, V2I technology directly contributes to the creation of resilient, safe, and sustainable cities, aligning with Sustainable Development Goal 11 (SDG 11), which aims to make cities and human settlements inclusive and resilient (UN, 2015). In this way, V2I not only addresses the contemporary challenges of urban mobility, but also supports the transformation of cities towards a more sustainable and intelligent future.

The implementation of V2I technology in urban environments requires the integration of hardware, infrastructure, and communication protocols for efficient exchange of information between vehicles and road infrastructure. Roadside Units (RSUs), which use IEEE 802.11p technology, stand out as essential devices for collecting and disseminating traffic data. Installed at strategic intersections, these units ensure efficient coverage and can be connected to a wired infrastructure, increasing the accuracy of the information shared (Lourenço et al., 2018).

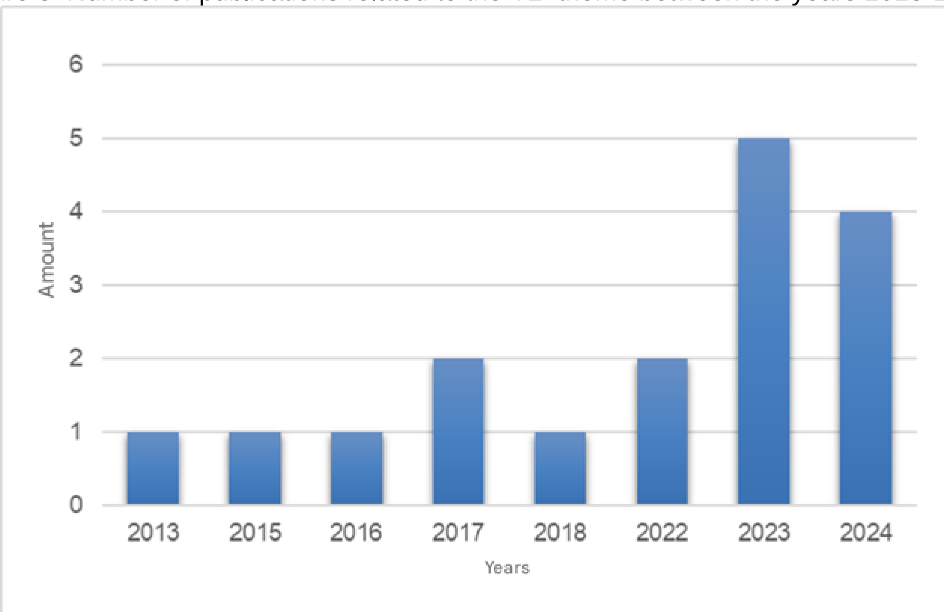
The application of optimized signal control algorithms for traffic light intersections is an essential technique in the context of V2I communication. Such algorithms use trajectory data from individual vehicles to estimate, with high accuracy, the arrival time and delays in traffic queues. This approach enables the dynamic adjustment of signaling times and traffic light phase sequences, promoting greater efficiency in vehicle flow. To this end, trajectory data is transmitted through Basic Safety Messages (BSM), using Dedicated Short Range Communication (DSRC) technology (Han et al., 2019).

Communication infrastructure is essential for the collection and dissemination of traffic information. In addition to MSW, cities with V2I systems require a robust network of Embedded Units (OBUs) in vehicles, which communicate with MSRs and process data such as traffic alerts and alternative routes (Lourenço et al., 2018). The accuracy of the information depends on advanced positioning systems, such as enhanced GPS, which ensures the exact location of vehicles, crucial to the effectiveness of V2I systems (Han et al., 2019). New clues are presented from the method of this study.

NEW TRACKS

After characterizing the object of study, extracting new clues from the scope review requires not only understanding the temporal arc (Figure 3) or the main journals related to the theme (Figure 4), but mainly the content of the textual corpus formed by the 17 abstracts selected based on the identification, selection, and eligibility criteria described in section 3 (Methodology). Thus, this section is divided into two parts: the first presents two new clues from Figures 3 and 4, while the second addresses three new clues derived from textual analysis (Figures 4 and 5).

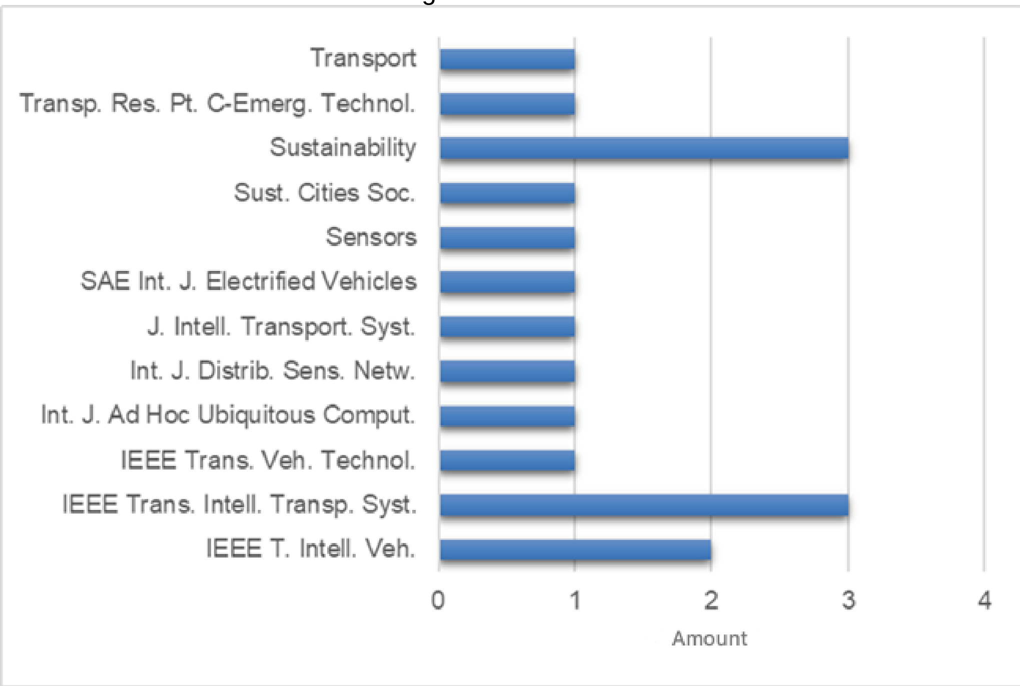
Figure 3. Number of publications related to the V2I theme between the years 2013-2024



Source: Prepared by the authors (2024).

The first new clue focuses on the results of the scoping review, which show: (a) the fact that the studies covered are more than a decade old, covering the period from 2013 to 2024, which demonstrates the robustness of the area, since it is not necessarily a new topic in the context of sustainability; in addition, (b) it is observed, in temporal terms, that after 2015, that is, after the publication of the 2030 Agenda with the 17 SDGs, there was the largest number of articles analyzed (n=14); Finally, (c) the topicality of the topic is highlighted by the fact that, in 2023, five papers were identified (n=5), and, although 2024 is not yet over, by September four papers had already been registered (n=4), reinforcing the topic as a relevant issue among researchers. In summary, Track 1 indicates that it is a topic of current interest. Figure 4 presents the audience on the subject, considering the scientific areas of the journals in which the studies were published.

Figure 4. Audience



Source: Prepared by the authors (2024).

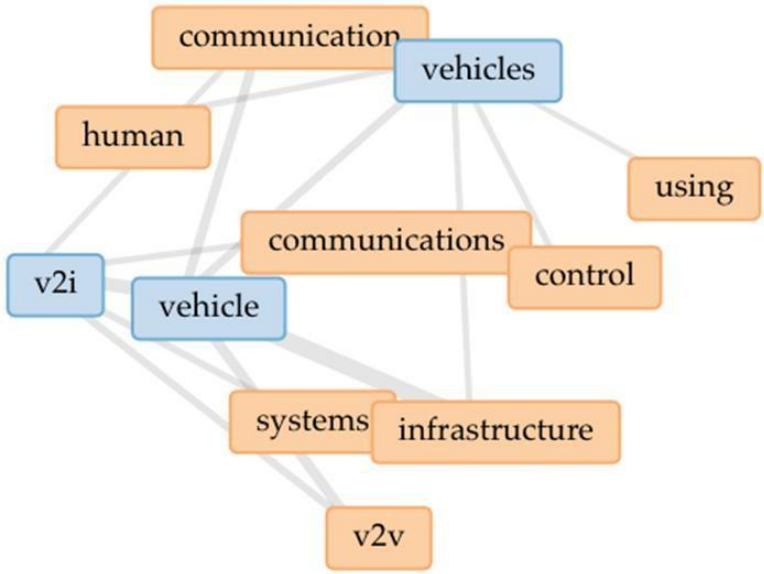
It is clear to observe in Figure 4 the second clue, which is the journals that offered an audience to the V2I theme has different scopes, marking the interdisciplinarity with which the theme needs to be treated, uniting from technological areas (e.g., Sensor magazine, n=1) to areas more focused on sustainability (e.g., Sustainability Magazine, n=3). Although there is a centrality of journals in the area of intelligent transport as a relevant core, for example when they coalesce: IEEE Trans.Intell. Transp Syst. (n=3) and J. Intel. Transport. Syst. (n=1), and this may be related to the fact that research in the area is more than ten years old, it is noteworthy that there is equality between "intelligence" and "sustainability" in the journals that have published the most articles, since Sustainability (n=3) is also IEEE Trans.Intell. Transp Syst. (n=3). Therefore, Track 2 would be: The interdisciplinarity with which V2I needs to be approached in terms of research, favoring the formation of teams with diverse academic backgrounds, in order to achieve the best results in the face of the problems presented in the context of urban planning and mobility management, for example. The thematic results of the use of Voyant Tools (2024) are discussed in more detail below:

Figure 4. *Cirrus* (Word Cloud) (n=17)

Source: Prepared by the authors (2024).

In Figure 4, several relevant aspects were clear, such as the type of vehicle, the bus (bus, whose frequency f was f=17) and one of the most expressive, which dialogues with the theoretical foundation and characterization of the object. However, the discussion that leads to Track 3, which focuses on the frequency distribution of terms central to the research problem, namely: (a) that the term vehicle (f=63) and the most frequently, which if added to the plural term vehicles (f=30) is quite expressive. Although the term V2I had a lower frequency (f=20), it is understood that a considerable part of the terms vehicle and vehicles refer to V2I, as this was the target of the search, which makes it robust to look carefully not only at V2I in isolation, but within this broader semantic context; (b) The same occurs with the terms related to sustainability (sustainability/sustentabilidade f=15 and sustainable/sustentável f=16); (c) Also, with the terms smart (f=10) and intelligent (f=15). However, there seems to be a slight discrepancy regarding intelligence and sustainability, and terms related to sustainability seem more frequent than those related to intelligence, when added together. The third clue deals with the inseparability of the thematic order evident in the treated textual corpus, which can be useful to understand the ontology and epistemology of V2I studies. In other words, when it comes to V2I, it is emphasized that intelligence and sustainability should not be seen as different kingdoms, but kingdoms that feed each other, being one in function of the other. Next, in Figure 5, magnifying glasses are placed on the terms V2I, vehicle and vehicles to verify more expressive links, based on the use of the Voyant Tools tool (2024).

Figure 5. Link (n=17)



Source: Prepared by the authors (2024).

In Figure 5 it was evident that the treatment of the V2I theme is not yet treated as an object of sustainability and intelligence in isolation, as well as in combination, although the third clue pointed to the need for this, and the journals that gave an audience to the theme dealt with it (Figure 4). Thus, the fourth clue refers to the need to understand V2I in front of not only infrastructure, but communication, which is the main asset of this type of proposal, and also those related to V2V, that is, vehicle to vehicle. Therefore, the fifth and perhaps the most important clue deals with the need for technological and humanistic dimensions to be agglutinated with common goals, this treats intelligence and sustainability as ontological paradigms for the treatment of V2I problems. The five new clues are summarized in Table 2:

Table 2: Synthesis of the 5 new tracks

Clues	Description
1. Timeliness of the topic	This track puts researchers and decision-makers, as well as other *stakeholders* face to face with the *designer* of future solutions linked to the planning and management of urban mobility, and state-of-the-art studies are relevant to strengthen the area.
2. Interdisciplinary teams	Interdisciplinarity requires the formation of teams with diverse academic backgrounds, in order to achieve the best results in the face of the V2I problems presented in the context of urban mobility planning and management.
3. Inseparability: intelligence and sustainability	The thematic inseparability between intelligence and sustainability allows us to understand a key feature of the ontology and epistemology of V2I studies, which need to be further illuminated in future investigations on urban mobility planning and management
4.Communication	The key role of communication in the planning and management of urban mobility, which is one of the main assets of V2I, is what leads to continuities with V2V, i.e. vehicle or vehicle.

5. Technology and Humanities	Holistic view of the technological and humanistic dimensions when it comes to V2I from the perspective of planning and managing urban mobility. These dimensions must be agglutinated with common objectives, which will allow further progress in the treatment of intelligence and sustainability as ontological paradigms for the treatment of V2I problems.

Source: Prepared by the authors (2024).

Based on the new five clues on how V21 technology can contribute to the planning and management of urban mobility, extracted from the scientific evidence processed by the scoping review and textual analysis, it inaugurates a new phase regarding important steps to unite intelligence and sustainability in favor of technologies and humanities.

FINAL CONSIDERATIONS

In the present work it is reaffirmed that in the twenty-first century in terms of urban planning and urban mobility management it is not possible to have any smart technology that is not sustainable, and vice versa, and this includes V2I.

In general, the general objective of this study was fulfilled because the role of V2I technology in the planning and management of urban mobility was identified, which was achieved based on scientific evidence and summarized in Chart 2 from a methodological path that dynamized a series of techniques in the field of scoping review and textual analysis described in the Methodology section.

It is noteworthy that in order to meet the general objective due to the V2I problem, it was essential to achieve the specific objectives, that is, V2I was analyzed as a technology associated with intelligence and sustainability and the application of V2I technology from the perspective of transport planning and urban mobility management was verified, bringing national and international examples.

In methodological terms, it is emphasized that the research was exploratory and descriptive in nature, and was based on a scoping review, future studies may expand to a systematic review of the literature (RSL) that is, more robust, including other scientific databases such as Scopus, and other more targeted questions based on what was identified in Chart 2.

Specifically regarding the support of the online software Voyant Tools (2024) used for textual analysis, it is recommended in future studies that other software be used to find other metrics, comparing the results, this can help in the ontological and epistemological understanding of the theme. An example of additional textual analysis software would be Iramuteq, which allows producing similarity analysis based on Graph Theory, and correspondence factor analysis based on Hypergeometric Law, as described in Salviati's Manual (2017).

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