A ROADSIDE UNIT POSITIONING FRAMEWORK IN THE CONTEXT OF VEHICLE-TO-INFRASTRUCTURE BASED ON INTEGRATED AHP-ENTROPY AND GROUP-VIKOR

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RAMI QAYS MALIK

A thesis submitted in
fulfillment of the requirement for the award of the
Doctor of Philosophy in Electrical Engineering

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I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

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I dedicate this PhD thesis to my beloved mother Mrs. AMERA and my beloved father Mr. QAYS whose dreams for me have resulted in this achievement and without their loving upbringing and nurturing, I would not have been where I am today and what I am today. This one is for you mum and dad with a promise that it will not be the last work of mine dedicated to you.

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ABSTRACT

The positioning of roadside units (RSUs) in a vehicle-to-infrastructure (V2I) communication system may have an impact on network performance. Optimal RSU positioning is required to reduce cost and maintain the quality of service. However, RSU positioning is considered a difficult task due to numerous criteria, such as the cost of RSUs, the intersection area and communication strength, which affect the positioning process and must be considered. Furthermore, the conflict and trade-off amongst these criteria and the significance of each criterion are reflected on the RSU positioning process. Towards this end, a four-stage methodology for a new RSU positioning framework using multi-criteria decision-making (MCDM) in V2I communication system context has been designed. Real time V2I hardware for data collection purpose was developed. This hardware device consisted of multi mobile-nodes (in the car) and RSUs and connected via an nRF24L01+ PA/LNA transceiver module with a microcontroller. In the second phase, different testing scenarios were identified to acquire the required data from the V2I devices. These scenarios were evaluated based on three evaluation attributes. A decision matrix consisted of the scenarios as alternatives and its assessment per criterion was constructed. In the third phase, the alternatives were ranked using hybrid of MCDM techniques, specifically the Analytic Hierarchy Process (AHP), Entropy and Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR). The result of each decision ranking was aggregated using Borda voting approach towards a final group ranking. Finally, the validation process was made to ensure the ranking result undergoes a systematic and valid rank. The results indicate the following: (1) The rank of scenarios obtained from group VIKOR suggested the second scenario with, four RSUs, a maximum distance of 200 meters between RSUs and the antennas height of two-meter, is the best positioning scenarios; and (2) in the objective validation. The study also reported significant differences between the scores of the groups, indicating that the ranking results are

valid. Finally, the integration of AHP, Entropy and VIKOR has effectively solved the RSUs positioning problems.

ABSTRAK

Penempatan Unit Sisi Jalan (RSU) dalam sistem komunikasi Kenderaan-ke-Infrastruktur (V2I) boleh mempengaruhi prestasi rangkaian. Penempatan RSU yang optimum diperlukan untuk mengurangkan kos dan mengekalkan kualiti perkhidmatan. Walau bagaimanapun, penempatan RSU dianggap tugas yang sukar kerana banyak kriteria, seperti kos RSUs, kawasan persimpangan dan kekuatan komunikasi, mempengaruhi proses penempatan dan harus dipertimbangkan. Tambahan lagi, konflik dan pertukaran antara kriteria ini dan kepentingan setiap kriteria tercermin pada proses penempatan RSU. Menjelang akhir ini, metodologi empat peringkat untuk kerangka penempatan RSU baru menggunakan Pembuatan Keputusan Berbilang Kriteria (MCDM) dalam konteks sistem komunikasi V2I telah direkabentuk. Perkakasan V2I masa nyata untuk tujuan pengumpulan data telah dibangunkan. Peranti perkakasan ini terdiri daripada nod-bergerak berbilang (di dalam kereta) dan RSUs disambungkan melalui modul pemancar-penerima nRF24L01+ PA/LNA dengan mikropengawal. Pada fasa kedua, senario ujian yang berbeza dikenalpasti untuk memperoleh data yang diperlukan dari peranti V2I. Senario ini dinilai oleh tiga sifat penilaian. Matriks keputusan terdiri daripada senario sebagai alternatif dan penaksiran per kriteria telah dibina. Pada fasa ketiga, alternatif diberi pangkat menggunakan teknik MCDM hibrid, dinamakan Proses Susunan Analisis (AHP), Entropi dan Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR). Hasil dari setiap pangkat keputusan individu diagregatkan menggunakan pendekatan pengundian Borda menuju pangkat kumpulan terakhir. Akhirnya, proses pengesahan dibuat untuk memastikan hasil pemangkatan menjalani pangkat sah dan bersistem. Keputusan menunjukkan yang berikut: (1) Pangkat senario yang diperoleh dari kumpulan VIKOR mencadangkan senario kedua, iaitu empat RSU, jarak maksimum 200 meters antara RSU dan ketinggian antena dua meter, adalah senario penempatan terbaik; dan (2) dalam pengesahan objektif, perbezaan yang bererti diperhatikan di antara skor kumpulan, yang menunjukkan bahawa hasil pemangkatan adalah sah.

Akhirnya, penyatuan AHP, Entropi dan VIKOR berkesan menyelesaikan masalah penempatan RSU.

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LIST OF ABBREVIATIONS

ANP	-	Analytic Network Process
AHP	-	Analytic Hierarchy Process
AVPP	-	Autonomous Vehicle Path-Planning
C-ITS	-	Cooperative-Intelligent Transportation Systems
DSRC	-	Dedicated Short Range Communication
DSM	-	Distributed Sorting Mechanism
HEV	-	Hybrid Electric Vehicles
ITS	-	Intelligent Transportation Systems
MANET	-	Mobile Ad hoc Network
MCDM	-	Multi-Criteria Decision Making
MAC	-	Medium Access Control
MDP	-	Markov decision process
PKL	-	Packet Loss
QoS	-	Quality of Service
RSUs	-	Road Side Units
RSS	-	Received Signal Strength
RIA	-	Ratio of Intersection Area
TMU	-	Traffic Monitoring Units
TOPSIS	-	Technique for Order Preference by Similarity to Ideal Solution
VANET	-	Vehicular Ad hoc Network
V2X	-	Vehicle to Everything
V2V	-	Vehicle to Vehicle
V2I	-	Vehicle to Infrastructure
VHO	-	Vertical HandOff
VIKOR	-	Vlsekriterijumska Optimizacija I Kompromisno Resenje
WAVE	-	Wireless Access for Vehicular Environment

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter introduces research topic, a brief background about the research, the state of the problem, research question, research objectives and the scope of this research. In Section 1.2, a brief background about the research components is presented. In Section 1.3, the state of the problem on which the direction of the research has been identified and introduced. In Section 1.4 the most important research question is listed. In Section 1.5 and Section 1.6, research objectives and the scope of the study are reported respectively. Finally, outline the main structure of the thesis are briefly reported in section 1.7.

1.2 Background to the study

There are numerous research articles in the area of vehicle-to-infrastructure communication systems published in recent years. As the number of vehicles increases, traffic congestion has become a significant issue globally. It has subsequently decreased the efficiency of transportation, and as a result, people are faced with travel delays, higher fuel consumption and longer exposure to air pollution. To address this issues, researchers have strived to deliver traffic information to assist the drivers to drive safely and smoothly as they navigate the increasingly challenging transportation systems [1]. A number of communications and data exchanges techniques between vehicles and infrastructure have been developed to address this issue. Researchers have been working on improving the transfer and accessibility of traffic data from traffic management centres [2]. The recent technology has increased vehicles' mobility which evokes a rapid change in the topology of a VANET. This scenario has caused weak communication links in vehicles as network resources in vehicles are susceptible to disconnections as they travel from point to point [3].

Based on the above argument, there is need for a new wireless network that could solve communication system issues. There should be a network that provides high data reliability and availability. In this light, the rapid development of wireless communication technologies has provided the adequate data rate, latency or another Quality of Service (QoS) parameter, which are compatible with vehicle-to-infrastructure (V2I) networks.

Vehicle-to-Infrastructure (V2I) communication systems will allow the vehicles to wirelessly transfer and share critical operation and safety data with highway infrastructures as well as with other vehicles. Meanwhile, using Vehicle-to-Vehicle (V2V) communication, a vehicle could receive real-time traffic alerts when there are dangerous situations or incidents, send sensor data and share incident information with other vehicles [4]. V2V offers a viable solution to send data to other vehicles. On the other hand, V2V is still not available for vehicles with manual transmission, and V2I communication is still required to send information on the vehicle's position, direction and intention without any modification to the vehicle's interior [5].

Road side units (RSUs) is a critical component of V2I communication as they ensure traffic information is delivered to driver. In this light, it is important to note that satisfying requirements such as interferences robustness, high the radio link reliability and duration, low message drop and rapid handshake, is crucial in any technology used for vehicles and infrastructure short-range communications. However, often times, conventional mobility management schemes for mobile ad hoc networks (MANET) do not fulfil the need for vehicular communication, specifically for high speed vehicle movements [6]. In recent years, the IEEE 802.11p/WAVE (Wireless Access for Vehicular Environment) has emerged as the standard for wireless access in vehicles [7]. The IEEE 802.11 standard presents a suitable beaconing mechanism that could be used to facilitate the information exchange in V2I communications [8].

1.3 Research problem

The recent years have seen a rapid development of vehicular communications to mitigate traffic problems such as pollution, traffic congestions, road accidents and road hazards [9]. Vehicular ad hoc networking (VANET) emerges as a new technology which could allow the use different communication-based automotive applications, including road safety services and in-vehicle infotainment application [3]. While VANET has been deemed as a future for on-the-road communications, it has significant limitations, including network disconnections caused by vehicles' high mobility and low density. Thus, VANETs require the use of infrastructures such as Roadside Units (RSUs) which enhances the network connectivity [10]. Higher capacity for V2I communication could lead to higher network reliability, more streamlined information exchange and better network coverage, all of which could improve the quality of services, another limitation for V2I) communication as part of the Intelligent Transportation Systems (ITS) is its high deployment cost compared to V2V communication.

Establishing the connection between vehicles and RSUs pose a significant challenge in V2I communication systems. This is because V2I communication systems often have limited coverage area. Furthermore, the passing vehicles will only be within an RSU communication range for a short time [8]. In the mobile context, this situation also limits the use of beaconing as the vehicle is only within the traffic monitoring units (TMU) radio range for a short time. This restricts the connection between TMU and the vehicles, limiting the exchanges of traffic information [11].

It was argued that RSUs must apply different VANET applications, including for sharing incident reports and traffic information. Nonetheless, it is important to note that the application of RSUs could be challenging where there are limited RSU resources. This calls for mechanism to promote the viability of RSUs [12]. Furthermore, RSUs installation location could impact network performance [13]. One of the main issues in the deployment of the vehicular sensor networks (VSN), is the efficient location of the RSUs [14]. In order to maintain the RSUs deployment cost as low as possible and guarantees the minimum level of coverage, quality and budget constraint need to be considered [15].

Infrastructures must be optimally installed by finding the best RSUs placement location while minimizing the number of RSUs and reducing unnecessary infrastructures, and it remains challenging [16]. Therefore, to illuminate the specific problems related to RSUs positioning selection, three issues have been illustrated in this research. In the first issue, several criteria need to be taken into consideration in V2I communication system, specifically regarding the installation of the RSUs. These criteria include RSUs deployment cost, network connection strength and RSUs number and positions [17] (see Figure 1.1).

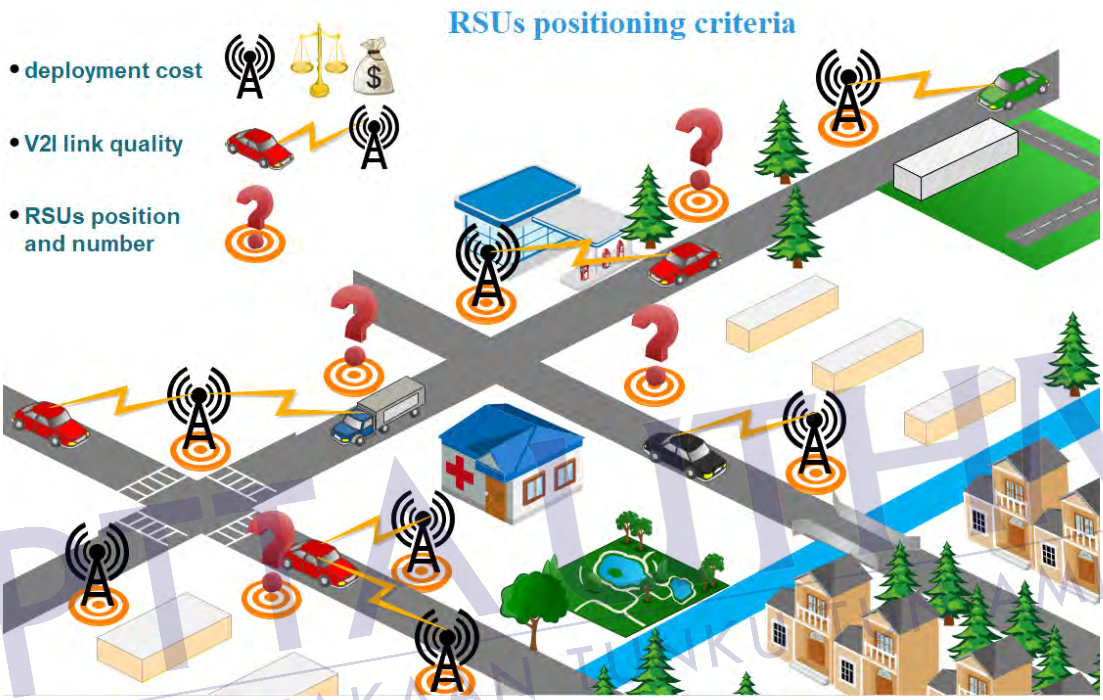

Figure 1.1: The criteria affecting the RSUs positioning

The second issue that should be considered is higher task complexity when different weights are employed. Thus, in the process of selecting the RSUs position, there is a need to consider the conflict and trade-offs among the criteria. This indicates that conflicts among attributes significantly affect the process of RSUs location selection.

Finally, selecting the most suitable RSUs positioning process from several possible positioning is considered as a complicated multi-attributes decision problem. Here, the decision-maker treats each positioning scenario for each RSU as an alternative. Thus, there is a need to find the best method to address this issue. In this study, MCDM methods are deemed as the most fitting solution in addressing the multi-attribute decision-making problem in RSUs positioning selection. The problem statement configuration is illustrated in Figure 1.2.

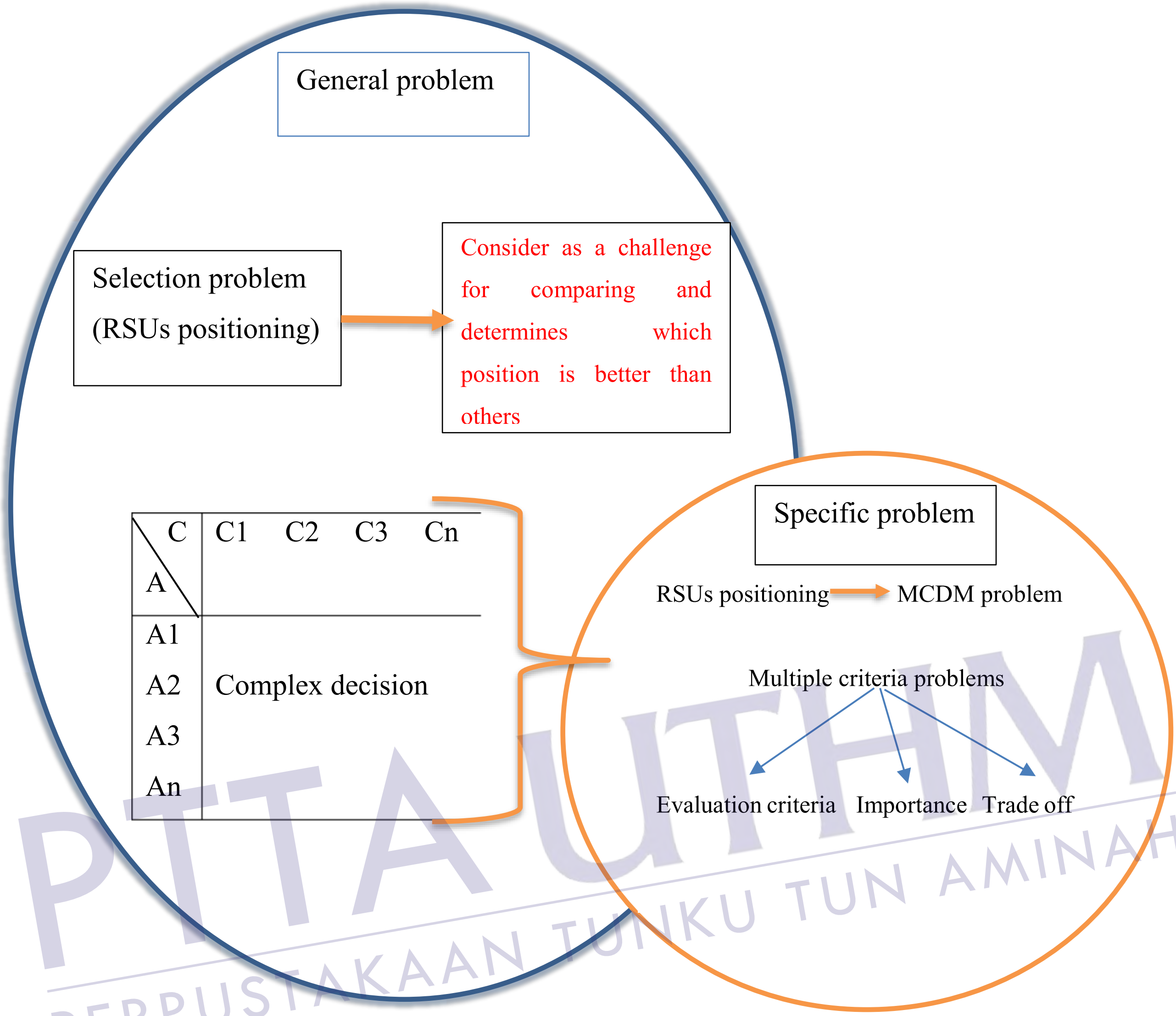

Figure 1.2: Problem statement configurations

Figure 1.2 summarize the research problem statement. It shows that there is general problem in this research which is the RSUs positioning selection. It considers as a challenge for comparing and determines which position is better than others. Figure 1.2 also shows that there are three specific problems related to MCDM techniques namely, Evaluation criteria, Importance, and Trade off.

1.4 Research questions

1. What are trends covered in the vehicle- to- infrastructure context?
2. What are the challenges identified in the literature within the scope of RSU positioning?

3. What is the type of research that discussed MCDM and V2I?
4. How does a researcher develop and collect data related to real-time V2I positioning in multiple scenarios?
5. How does a researcher evaluate and analyse the data in V2I scenario setups?
6. How does a researcher select the best positioning and configuration of RSU?
7. What is the best scenario among the tested V2I positioning scenario?
8. Does the proposed RSUs selection framework systematically valid?

1.5 Research objectives

This research is aimed to develop a real-time RSUs positioning selection framework using multi-criteria analysis. The main research objectives of this research are as follow:

1. To investigate the existence of technology for real time RSU positioning in vehicle- to- infrastructure communication system.
2. To design and develop a real time hardware based RSU position for V2I context.
3. To evaluate the performance of the hardware developed in objective two against multiple RSUs positioning scenarios.
4. To propose a decision matrix (DM) based on the intersection of multiple attribute evaluation metrics and multiple scenarios for RSUs positioning.
5. To select the best RSU positioning using the evaluation matrix in objective four and multi criteria decision making (MCDM) technique.
6. To validate the developed RSUs positioning selection framework.

1.6 Connections among research objectives, questions, and problems

All research questions correspond to the research objectives. Each objective is linked to one or two questions. In this light, both specific and general problem statements are linked to more than one research objectives and questions. Table 1.1

below illustrates the connection between the research objectives, research questions, specific research problems, and the general research problem.

Table 1.1: Connections among research objectives, questions and problems

Research objectives	Research questions	Specific problem	General problem
1. To investigate the existence of technology for real time RSU positioning in vehicle- to-infrastructure communication system.	1. What are trends covered in the vehicle-to- infrastructure context? 2. What is the type of research that discussed MCDM and V2I? 3. What are the challenges identified in the literature within the scope of RSU positioning?	Systematic review protocol, article filtering, inclusion and exclusion criteria.	
2. To design and develop a real time hardware based RSU position for V2I context.	4. How does a researcher develop and collect data related to real-time V2I positioning in multiple scenarios?	Devices configurations and performance evaluation.	RSUs positioning selection Problem
3. To evaluate the performance of the hardware developed in objective two against multiple RSUs positioning scenarios.	5. How does a researcher evaluate and analyse the data in V2I scenario setups?	Multi-Criteria (multi-evaluation criteria for RSUs positioning selection)	
4. To propose a decision matrix (DM) based on the intersection of multiple attribute evaluation metrics and multiple scenarios for RSUs positioning.	6. How does a researcher select the best positioning and configuration of RSU?		
5. To select the best RSU positioning using the evaluation matrix in	7. What is the best scenario among the	-Importance criterion	

objective four and multi criteria discoing making (MCDM) technique.	tested V2I positioning scenarios?	-Trade off and Conflict Criteria
6. To validate the developed RSUs positioning selection framework.	8. Does the proposed RSUs selection framework is valid systematically?	

Table 1.1 shows that the first research objective corresponds to the first three research questions. Furthermore, the second research objective is linked to the fourth research question; while the third research objective corresponds to the fifth research question. The sixth research question corresponds to the fourth research objective, while the fifth objective is linked to the seventh research question. Lastly, the sixth research objective corresponds to the eighth research question. Moreover, three specific problem, 'systematic review protocol, article filtering, inclusion and exclusion criteria is linked to the first research objective and 'devices configurations and performance evaluation is linked to the second objective while 'multi-evaluation criteria for RSUs positioning selection' is linked to two research objectives and two research questions, and two problems, namely, 'Importance Criterion' and 'Trade-off and Conflict Criteria' correspond to one research objective and research question. Finally, the general problem of this research which is 'RSUs positioning selection Problem' is linked to four research objectives and research questions.

1.7 Scope of the study

This study's scope is as follows,

a) The primary focus on this research is on developing a hardware-based system for the vehicle-to-infrastructure communication system. Therefore, the development of vehicle-to-vehicle communication for pedestrians is not the main issue.

b) The data extracted were used for scenario evaluation. Therefore, the type of data (i.e., video, text, image, etc.) used are not important.

c) For the initial distribution positions, low connectivity segments are considered as the best RSUs location candidate for this study.

d) This research considers that the communications between vehicles and roadside units (RSU) require nRF24L01+ PA/LNA transceiver module, and examine whether successful information exchange between vehicle and RSUs could be established when a vehicle is within the RSU radio for a short duration.

e) The selected study case will focus on urban roads with different types of scenarios, including using a different number of cars with multiple speeds.

1.8 Thesis outlines

There are six chapters in this thesis. Chapter One is an introductory chapter which describes the problem that will be examined in this study, specifically on vehicle-to-infrastructure communication system. The chapter also lists the research questions, research objective and research scope. In ***Chapter Two***, a comprehensive discussion on vehicle-to- infrastructure communication system evaluation approaches is presented based on past academic works on the topic. It also presented a systematic review of literature, focusing on the challenges in developing a taxonomy for vehicle-to- infrastructure communication system. Benefits and methodologies provided by previous researchers are presented, a critical analysis is conducted and developed. Finally, a brief investigation about multi-criteria decision making techniques are presented.

Chapter Three discusses the study's research methodology, specifically the research design and reporting methods. This chapter also describes the research design and the different approaches applied to fulfil the research objectives.

Chapter Four describes the process of data collection. The main challenges, tolls used in order to collect the data. Furthermore, the main experiment setup are presented and the experiment scenarios is listed. Finally, the main evaluation criteria of the experiment are briefly reported.

Chapter Five outlines the findings from the data analysis. This chapter also describes the Multi-Criteria Decision Making (MCDM) technique applied to reach to a decision about the final optimal place of RSUs placement are presented.

Chapter Six presents the research goals attained, contribution, limitation, and conclusion. This chapter also discusses the areas to be pursued by future researchers.

CHAPTER 2

LITERATURE REVIEW ON VEHICLE-TO-INFRASTRUCTURE SYSTEM

2.1 Introduction

This chapter reviews the academic literature related to the vehicle-to-infrastructure communication. This chapter presents a systematic review of vehicle-to-infrastructure communication approaches which classifies academic works on vehicle-to-infrastructure communication. Then, a taxonomy was created to identify the research gaps. This chapter will identify the challenges and obstacles of V2I communication highlighted in previous works to identify possible hindrance of vehicle-to-infrastructure communication in this study's context.

This chapter discusses past findings related to evaluation criteria, specifically communication type, communication quality, scenario and location. Moreover, this chapter reviews past works on Multi-Criteria Decision Making in the vehicular network with the focus of V2I applications.

Section 2.1 provides a brief overview about the chapter; Section 2.2 discusses the protocol for the systematic review protocol and the findings from literature analysis. Meanwhile, distributed results are introduced in Chapter 2.3. In section 2.4, the discussion is reported with all benefits, issues, recommendations, and methodological aspects related to vehicle-to-infrastructure system. In section 2.5 and Section 2.6, the material that utilised in the research and critical analysis are presented respectively.

2.2 Systematic review protocol and analysis

The main keyword for the literature search is “Vehicle to Infrastructure (V2I) communications.” Thus, any academic works related non-V2I- communication networks, including vehicle to pedestrian communication and vehicle-to-vehicle communication were excluded. Based on the study’s scope, only academic papers written in English were reviewed, but all works focusing on V2I communication in varied scenarios were included. The search was conducted in three digital databases; Science Direct, which hold many scientific and medical references, Web of Science (WoS) which provides indices of studies in different fields including arts, social sciences, humanities as well in scientific fields such as. electronic and technologies. The next database is IEEE Xplore which is known to provide most reliable and extensive number of academic works across the fields of electrical engineering, electronic technologies and computer science. The academic references on V2I and all communication types available in these databases are deemed as adequate and these papers represent the current research on this topic across different research fields.

For the purpose of filtering articles that are related only to the research topic, three levels of filtering and screening were performed. All unrelated articles were neglected in the first level of filtering. Secondly, the title and abstract of each article was checked and then all duplicates articles were removed. In the third level of filtering, the full-text articles from the second level of filtering were cautiously studied. All filtering levels used the same suitability standards followed by authors. The search was done by utilizing three databases search boxes to find the articles related to this area. The query that used to this research includes "Vehicle-to-Infrastructure", "V2I", "Car to Infrastructure", "C2I", in different variations and combined by the operator "OR", and "Information Exchange", "Exchanging Information", "Data Exchange", "Exchanging Data", "Data Integration", "Information Integration" in different variations, combined by the operator “AND”. The query text exactly shown in Figure 2.1.

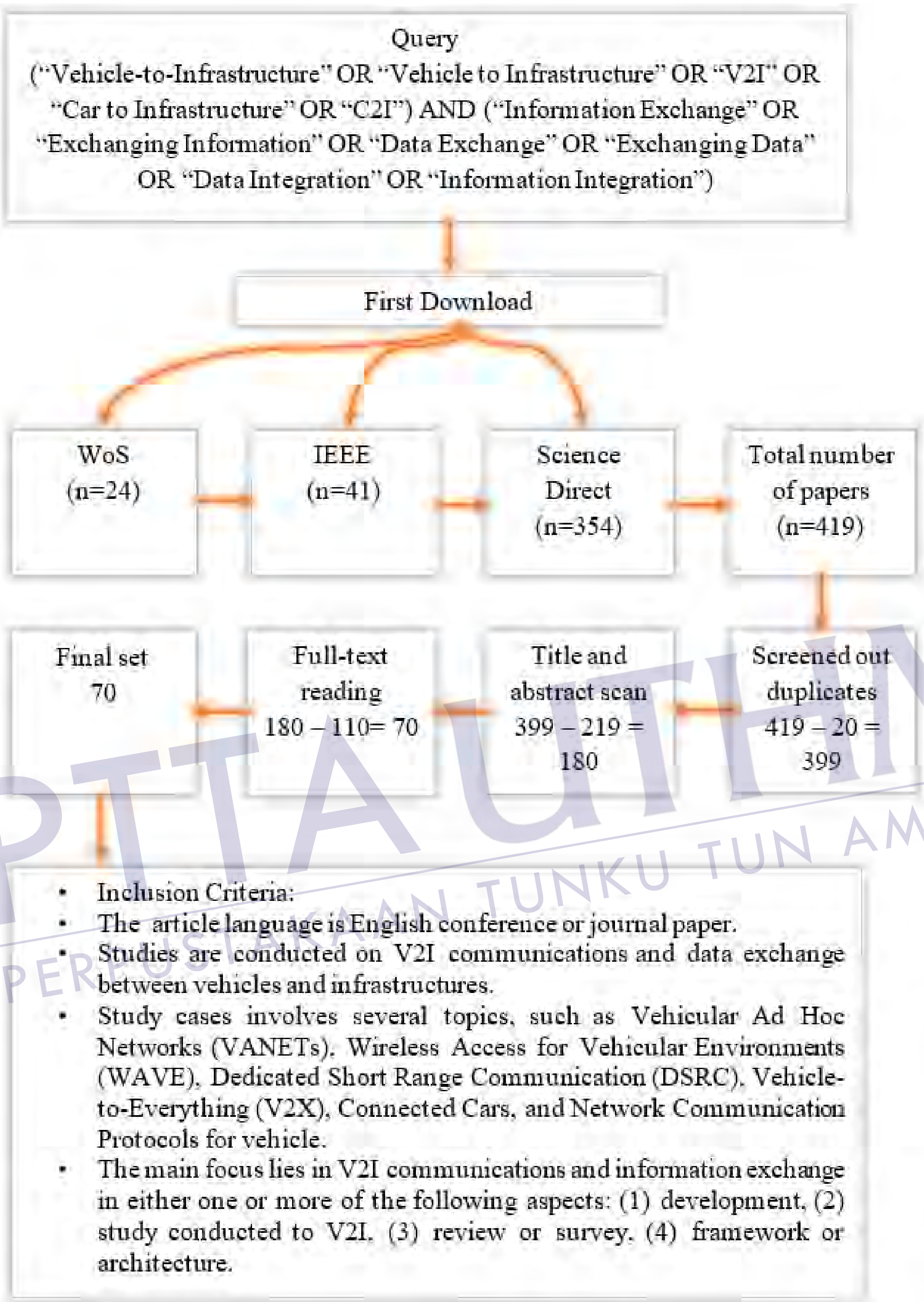

Figure 2.1: Study selection flowchart

The inclusion criteria for the literature search are shown in Figure 2. During the initial search, the researcher aimed to map the current research in V2I communication to develop a taxonomy of research in the study area. Three categories were set for the taxonomy based on the pre-survey of the literature. After removing redundant results, the articles obtained during the initial search were screened through two repeated screening and filtering process to eliminate an article that did not fulfil the inclusion criteria. Three exclusion criteria were applied, first the articles that were not written in English, and second, articles focused on irrelevant aspects like smart cities and customer-to-customer (C2C) or car-to-car communication networks. The last exclusion criteria are that the articles should not focus on communication between vehicles a pedestrian. To ease the process, the remaining articles were saved and analysed in the word format. The articles were then carefully classified based on the taxonomy and important points were highlighted. The taxonomy was used to identify main categories which are developments, studies conducted on V2I and surveys/reviews, as well as the different classes and subclasses of each article. Furthermore, the articles were classified according to authors' preferred style. The remaining articles were then analysed to provide comprehensive data and information to answer the research questions. The relevant data and relevant information were saved as Word files for easy reference.

2.2.1 Results of literature taxonomy

The initial search resulted in 419 articles. The largest number of articles were derived from Science Direct (354), followed by IEEE Xplore (41) and WOS (24). The articles were put into three groups. A total of 20 out of 419 articles from the three databases were duplicates. 219 articles were further excluded when the titles and abstracts were reviewed, thereby resulting in 180 articles. The final full-text review excluded 110 articles. The final set included a total of 70 articles. Subsequently, the research articles were reviewed using the taxonomy illustrated in Figure 2.2.

The taxonomy illustrates the robust development of studies and applications on the topic. The articles were then classified based on classes and subclasses; the first class comprises of 42 studies which tried to develop V2I communication systems through simulations, real time, or a combination of both. The next class constitutes of 6 articles that present a review or survey articles on V2I communications. The final class included 22 studies conducted on V2I communication systems. Figure 2.2 presents the breakdown of the articles based on the articles classes and sub-classes.

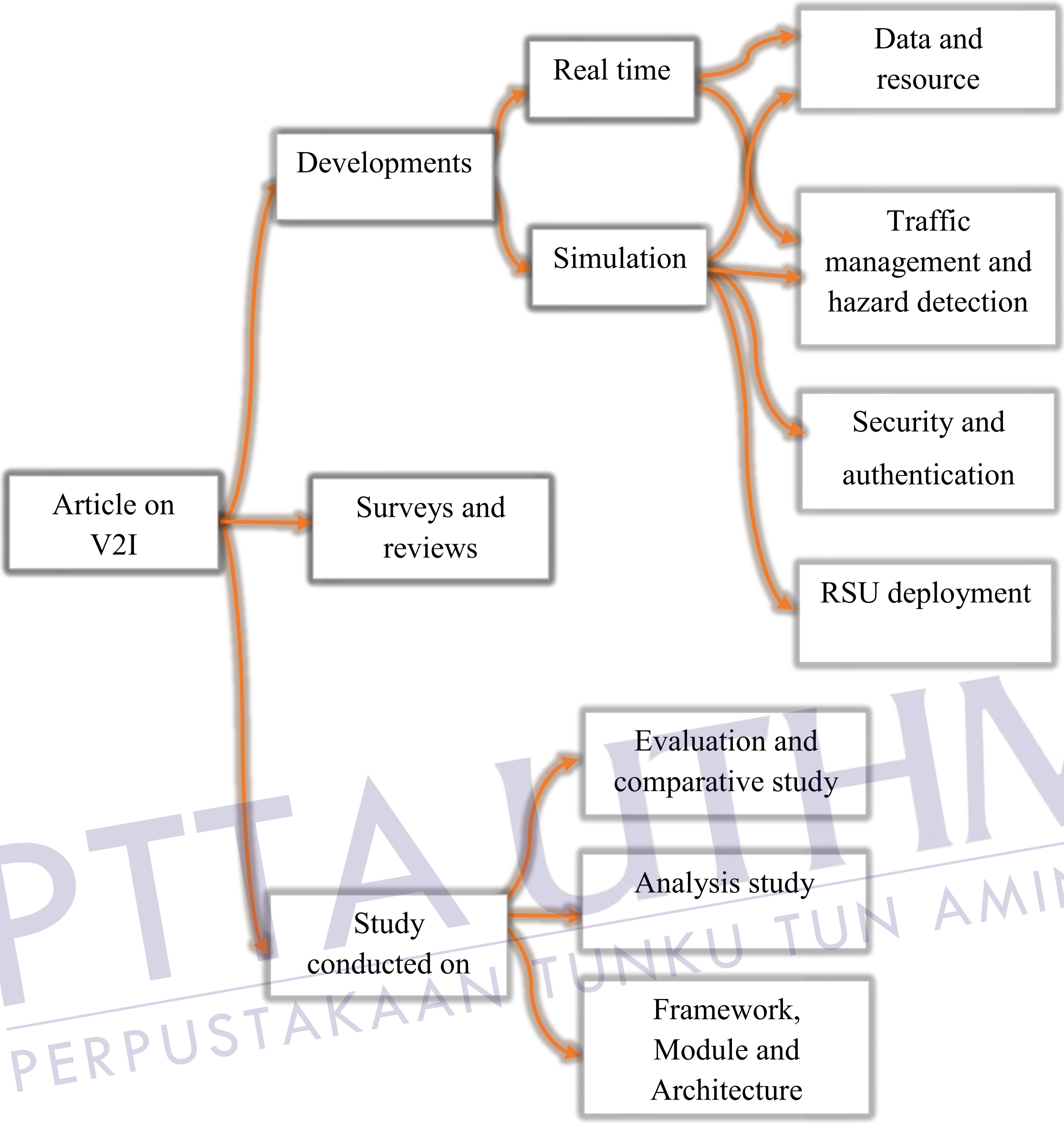

Figure 2.2: A taxonomy of research articles on V2I communications

2.2.1.1 Development

This section reviews the articles focused on the development of V2I communication systems. Out of 70 articles chosen for this review, 42 presented the development of V2I communication systems. These articles were further classified based on the type of development used. 11 out of the 42 articles focused on the real-time development which were evaluated through field tests to examine efficiency of the system developed. Meanwhile, 31 papers featured simulation development. These articles were further classified into four subgroups based on the goal of the development. Studies that featured real-time development of the V2I communication systems could be further classified into two sub-categories, development for hazard detection and development for data and resource management and traffic management. [5] proposed a V2I-based architecture to facilitate communication between self-driving vehicles and manually driven vehicles (AVs) to provide continuous data traffic flow [1]. A mechanism to deliver traffic information to drivers based on DSRC/WAVE was developed. [18] presented a cloud-based traffic monitoring mobile application to reduce traffic congestions and road accidents while [19] proposed a V2X architecture used in a smart traffic sign controller system to improve transport efficiency and enhance traffic safety. Another study [20] demonstrated the use of a budget-friendly ZigBee infrastructure network which send alerts on unexpected incidents like accidents. Moreover, [4] developed and deployed a fog vision sensor to transmit a warning message to drivers on road weather conditions through a V2I system. [21] proposed a semantic Web of things framework which supports cooperative environmental risk monitoring and collaborative sensing in vehicular networks and hybrid sensors. A generic method to detect road events through distributed data fusion to alert drivers in the presence of inaccurate data sources was proposed in [22]. Meanwhile, another study [23] illustrated a context-aware driver assistance system to improve drivers' behaviour by integrating the different advanced driver assistance functions into one system. Furthermore [24] proposed an integrated advanced driver assistance system for rural and intercity environments while [25] develop a mechanism to prevent rear-end collisions in congested roads.

The second group of studies proposed the development of new V2I communication systems through simulation development. The studies can be further classified into four subgroups, two of which focused on similar topics as the real-time development, namely, data and resource management and traffic management. The other subgroups were on security and RUS deployment. [26] proposed a handover algorithm based on V2I communications that reduces handover latency and packet loss was. [13] proposed an emergency broadcast scheme that utilises RSUs with a reasonable delay and high delivery rate. Moreover, an enhanced cooperative load-balancing approach for efficient dissemination of data was proposed in [27]. Several protocols were proposed to overcome data delivery problems, such as the cross-layer protocol for V2I systems to deliver packets over minimum delay paths in [28] and the hybrid routing protocol for VANETs that was proposed in [29]. [30] proposed a multiple priority-supported medium access control (MAC) protocol to optimise transmission probabilities of safety packets. [7] developed an IEEE 802.11p protocol which supports non-safety applications whilst maintaining safety services delivery A linear programming model to overcome message delivery problems and extend network lifetimes was proposed in [31]. Furthermore, [32] proposed data based real-time traffic adaptive protocol to minimise the network communication overhead. Algorithms for spectrum allocation and sensing to expand the spectrum assigned for the control channel in DSRCs was proposed in [33]. Meanwhile, a distributed sorting mechanism was proposed in [12] to enhance RSU utility. In addition, an access request deadline-aware scheme that reduces blocking probability and response time was proposed in [34]. An intracluster-based V2I access protocol that provides resource management for real-time applications in the VANET was proposed in [35]. [36] presented a primary–secondary user resource-management controller for cognitive radio vehicular networks under both soft and hard collision limits. In [37], the performance of a distributed and adaptive resource management controller in cloud-assisted cognitive radio vehicular networks was designed and tested. [38] proposed a primary–secondary resource management controller for vehicular networks while [39] presented a fuel efficient control strategy for a network of hybrid electric vehicles (HEVs) used in urban roads. Finally, an optimal speed control to maximise the fuel efficiency of heavy-duty vehicles was presented in [40] where ITS facilitated by V2I communications is assumed to provide information on speed limitations to platoon leaders.

Secondly, an autonomous vehicle path-planning (AVPP) algorithm to predict obstacle position and improve the autonomous vehicle safety was introduced in [41]. In [42], data integration was designed from a mobile measurement platform into the VANET application to send warning messages on road degradations to drivers. Furthermore, a new cooperative localisation scheme that combines V2V and V2I measurements to overcome the problem of cooperative localisation in tunnel environments was proposed in [43]. Another study proposes a novel technique for speed-based lane changing, to avoid collision and time of arrival based on localisation in VANETs [44]. Other works such as [35] focused on designing a trust model for vehicular networks by taking advantage of V2I communications to collect vehicle behaviour information. A decentralised platooning control strategy was proposed in [45], and [46] presented a cooperative driving system facilitated by V2X communication to enhance the stability of local traffic flow. Thirdly, a flexible, secure and decentralised attribute-based key management framework, was proposed in [47] to establish trust between vehicles and to ensure security and authentication in VANETs. [48] presented a computationally efficient privacy-preserving anonymous authentication scheme utilizing anonymous VANET signatures and certificates. In addition, a general framework to measure traffic in three or more locations whilst preserving vehicle privacy was developed in [49]. Moreover, [50] proposed an efficient and secure scheme for message dissemination scheme with policy enforcement in the VANET. Fourthly, to enhance RSU deployment, a genetic and Dijkstra algorithm was proposed in [16] to minimise the number of RSUs based on deployment costs and delivery time requirements. In contrast, a new geometry-based sparse coverage (GeoCover) RSU deployment protocol in vehicular networks was developed in [15].

2.2.1.2 Survey and review articles

Survey and review articles on the current understanding of V2I communication system are reviewed in this section. Only 6 out 70 the studies [51], [52], [3], [6], [53] and [54] (6/70) were included in this category. [51] highlighted the main privacy and security issues in vehicular communication, including authentication in V2I, Meanwhile, [52] reported the result of a survey on spectrum access technologies and the challenges related to V2I communications . Another study presented a comprehensive examination of radio channel access protocols and resource management approaches. V2I communication characteristics in heterogeneous multitier network was surveyed in [6], whereas the utilisation of cellular and DSRC networks to support V2I communications was discussed in [53]. Other works such as [54] focused on vehicular sensor networks and sensor information collection using two infrastructure-based VSN platform techniques (Senster and CarTel).

2.2.1.3 Study conducted to V2I communication

22 out the 70 studies reviewed the V2I communication system. These articles can be further classified into three subgroups. 14 out of 22 studies included evaluation and comparative studies. These studies evaluated and compared the connectivity-aware routing performance and multipath transmission control protocols between RSUs and vehicles during multihop data exchanges [55]. [8, 56] evaluated the use of IEEE 802.11p for V2I communications. Meanwhile, [14] discussed the adoption of the WAVE/IEEE 802.11p protocols to offload cellular networks was In [57], a highway-merging decision algorithm was developed to determine whether IEEE 802.11p supports the merging controls, and the use of a beaconing mechanism for V2I communication was presented in [11]. [58] evaluated the possibility of supporting extended V2I messaging facilities through field tests of Bluetooth and ZigBee technologies. Several experiments were designed to demonstrate that Bluetooth could be used in R2V/V2I communications [59]. [60] demonstrated the use of specific tools that determine the conformance of a cooperative–ITS (C-ITS). A simulation framework to test and evaluate the C-ITS applications was shown in [61]. Other works focused on V2X security [62]. Furthermore, [63], examined the impact of mobility on V2X communication performance of while in [64], it was found that 6 Mbps is not necessarily the best beaconing data rate for vehicular networks. Lastly, [65] studied techniques to address VANETs misbehaviours.

5 studies presented analyses of the existing or future developments. [66] examined the probable used of driverless technologies for vehicles like cars pa and trucks as well as their degree of automation. The stability of the information consensus for a multiple, autonomous intersection was analysed in [67]. Other works analysed the reliability of data transfer through IP-based DSRC communications networks designed for logistics [68]. [69] presented key indices analysis of V2I systems based on IEEE 802.11p in highway, Lastly, [70] analysed the performance of DSRCs for roadside-to-vehicle environments with different traffic loads.

3 studies presented frameworks, models and architecture related to V2I. The framework proposed in [71] provide a generalised firewall protecting vehicular networks from cyber threats while a traffic model for self-driving and connected

vehicles was designed in [72]. [73] presented a new approach to deploy an ITS communications architecture.

2.3 Distribution results

This study has reviewed the research trend in this field, by performing content analysis on all 70 articles. Figure (2.3) presents the findings of the review. The articles were divided into four main categories based on the focus of study, real-time developments, simulation developments, surveys, and reviews. The final category comprised studies on V2I. Figure (2.3) shows the increasing interests in the simulation developments of V2I communication system.

The largest number of articles were derived from the ScienceDirect database (42 out of 70 article). 7 of the articles focused on real-time developments, 19 articles on simulation developments, 5 articles on surveys and reviews and 11 articles on V2I studies. 15 articles were retrieved from IEEE database, with 2 articles in real-time developments, 9 on simulation developments and 4 on V2I studies. 13 articles were derived from the WoS database, of 1 article on real-time developments, 4 on simulation developments, 1 on surveys and reviews and 7 on studies conducted on V2I.

The articles were also classified into 4 categories based on the year of publication, as illustrated in Figure (2.4). 13, 12 and 16 articles were published in 2015, 2016 and 2017. No articles were published in 2008. 2 articles were published in 2009, and 3 articles were published in 2010 and 2011. Moreover, 7 were published in 2012 and 5 articles in 2013. 5 recent articles were published in 2014 while 4 were published in 2018.

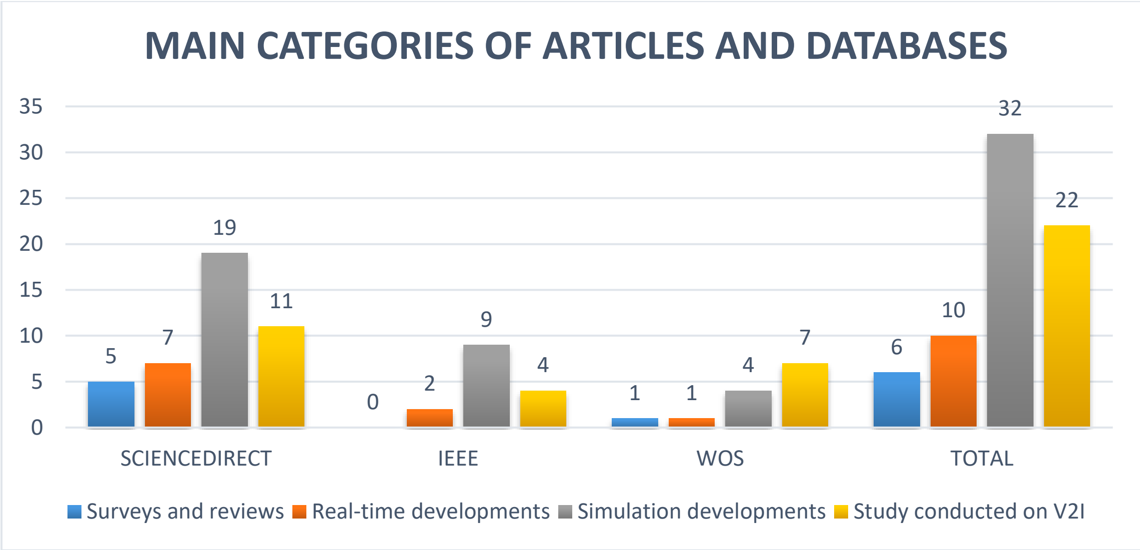

Figure 2.3: Number of included articles based on main categories and database sources

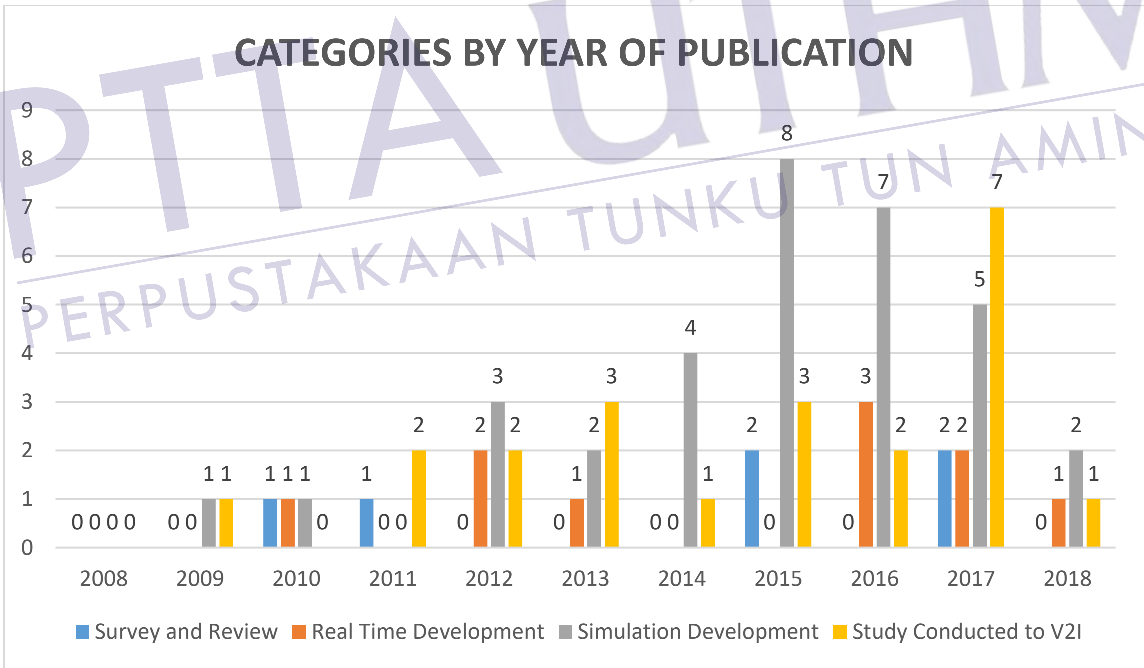

Figure 2.4: Number of articles in each category by publication year

2.4 Discussion

The articles reviewed for this study encompass the most relevant and recent studies on V2I communication systems. The literature review has highlighted the research trends in this area. This chapter has presented a taxonomy of the related literature. As there are a plethora of articles focusing on different aspects, ranging from an introductory to the system to examining existing data-exchange applications in V2I systems, this taxonomy will help to classify and organise the different academic works in this topic. This could help researchers to navigate through a large number of works in this field and provide them with an overview of research trends in this area. The taxonomy of the related literature will help organise research articles based on their focus and findings into a clear layout. Finally, the taxonomy demonstrates a structure to provides researchers with important insights into the subject in several ways.

The taxonomy helps to pinpoint the potential directions for future research in this field. In this study, the V2I communication systems literature taxonomy showed that the researchers are focused on proposing V2I traffic management system development frameworks, which could steer the direction of research in this area. Such literature taxonomy could also help identify any research gaps on this topic.

Furthermore, the taxonomy allows the researcher to map and categorise the V2I applications development and pinpoint the weakness and strength of the studies in addressing the issue. In this study, the taxonomy demonstrates researchers' tendency to use and review specific applications evaluations rather than exploring the use of integrated solutions, frameworks and developments. The taxonomy shows that there is a lack of studies on RSU deployment. Similar to taxonomies in other fields, the proposed taxonomy employed a common language for researcher to communicate and discuss different works in vehicular communication. The literature review focused on seven aspects, which are, the forms of datasets used in the articles, the evaluation techniques used, the criteria for the evaluation, the motivations behind the development, challenges in using these technologies, recommendations to address challenges and the methodological aspects.

2.4.1 Datasets

In this survey, the datasets are dependent on the types of data sources for V2I communication systems in real-time developments, including devices communicating the data between the vehicles and infrastructure. The details of V2I communication data sources in this survey are summarised in Table 2.1.

Table 2.1: Dataset used in reviewed articles

Ref	Real time data														
	Type of data							Source							
	Vehicle speed	Vehicle position	Communication state	SPaT information	RSU position	Distance to the object	Road/weather conditions	GPS	temperature sensor	Laser scanner	Ultrasonic sensor	wireless card	camera	On-board unit (OBU)	On-board diagnostics (OBD)
[5]	*	*	*					*				*			
[1]	*	*		*	*			*				*	*	*	
[21]	*	*					*	*	*			*			*
[19]				*	*			*				*		*	
[20]	*	*						*				*		*	
[23]	*					*					*	*			
[4]	*	*				*	*	*	*	*		*	*	*	
[22]	*				*		*	*	*			*		*	
[18]	*	*						*				*	*	*	
[59]	*	*						*				*		*	
[24]	*	*				*		*		*		*	*		
[25]	*	*						*				*	*		
[44]	*	*						*				*	*	*	
[42]						*		*		*					

Table 2.1 illustrates the articles where the researchers used experiments to generate their own datasets. It also shows a detailed description of research experiments on the development of a hardware based V2I communication system based on numerous factors. A majority of these studies used GPS and a wireless card, such as a Wi-Fi, Bluetooth or ZigBee card. In this regard, only several studies used a real device to generate their dataset while other used public datasets or existing data from literature.

2.4.2 Evaluation techniques

The studies reviewed also used different evaluation processes to determine the efficiency of the V2I networking networks. In general, the studies used three main evaluation approaches, which are actual experiments, simulations, and comparisons. Table 2.2 presents the evaluation techniques used in articles reviewed.

Table 2.2: Evaluation techniques used in articles reviewed

Ref	Evaluation technique		
	Actual experiments	Simulations	Comparisons
[1, 5, 19-21, 23] [4, 18, 22, 24, 25, 59]	✓		
[5, 18, 20-22] [7, 12, 13, 15, 16, 24-50, 57, 59, 74]		✓	
[4, 21, 22, 30, 32, 42] [12, 26, 27] [7, 13, 15, 28, 29, 38-40, 43, 48-50, 59]			✓

As shown, most studies evaluated the communication system using simulations. This is followed by comparisons and only a small number of studies used actual experiment. A few of the studies used all three evaluation techniques. The reason that only few studies were used the actual experiments as evaluation technique is because the difficulty in insulation process regarding the V2I communication system as well as the cost in term of time and money and lastly the difficulties in collecting the required data when conducting a real time field test.

2.4.3 Performance measurements

These studies evaluated the performance of the vehicular communication system using different measures. Performance was mainly evaluated based on time, data rate and resource management, fairness index, service rate, blocking probability, reliable link range, authentication, pignistic probabilities, localisation, emergency message generation, effectiveness, efficiency, accuracy, impact of measurement errors for traffic flow, impact of V2I deployment for traffic flow, deviation, probability of successful CWS detection, collision rate, request–transfer ratio, deadline miss ratio (DMR), percentage success rate and conflict request count per broadcast. Table 2.3 illustrates the measurement criteria applied in the studies reviewed.

The different criteria used to evaluate the V2I communication systems in the studies reviewed are presented in Table 2.3. The evaluation criteria include delay, cost, packet loss, throughput, efficiency, packet delivery, goodput, time response, authentication, localisation, and deviation in 33%, 24%, 17%, 17%, 14%, 12%, 12%, 7%, 7%, 7% and 7% of the studies, respectively. Other criteria such as fairness index, service rate, emergency message generation, effectiveness and collision rate were used sparingly (only 5%). Other criteria were only used once (2%). Table 2.3 also shown that no study used all the measurement criteria. The varied measurement criteria used reflects the challenges in adopting a specific approach to measure V2I communication systems. Table 2.3 summarize all the important evaluation criteria that have been used in previous studies regarding V2I communication system so it can help the researcher in V2I system to figure out what kind of evaluation criteria that he will used to evaluate his data and what is the importance of each criteria in evaluating V2I system.

REFERENCES

[1] H. Su, C. H. Cho, Y. H. Chu, W. Y. Chang, and IEEE, *A Traffic Information Dissemination Mechanism Based on DSRC/WAVE and Its Applications*, 2012.

[2] F. Wolf, S. Libbe, and A. Herrmann, "Communication and Co-operation for Traffic Systems," *IFAC Proceedings Volumes,* vol. 43, pp. 25-30, 2010.

[3] H. T. Cheng, H. Shan, and W. Zhuang, "Infotainment and road safety service support in vehicular networking: From a communication perspective," *Mechanical Systems and Signal Processing,* vol. 25, pp. 2020-2038, 2011.

[4] J. Scholliers, M. Jutila, M. Valta, K. Kauvo, A. Virtanen, and P. Pyykönen, "Co-operative Traffic Solutions for Hybrid Communication Environments," *Transportation Research Procedia,* vol. 14, pp. 4542-4551, 2016.

[5] V. Milanés, J. Godoy, J. Pérez, B. Vinagre, C. González, E. Onieva*, et al.*, "V2I-Based Architecture for Information Exchange among Vehicles," *IFAC Proceedings Volumes,* vol. 43, pp. 85-90, 2010.

[6] E. Ndashimye, S. K. Ray, N. I. Sarkar, and J. A. Gutiérrez, "Vehicle-to-infrastructure communication over multi-tier heterogeneous networks: A survey," *Computer Networks,* vol. 112, pp. 144-166, 2017.

[7] M. Amadeo, C. Campolo, and A. Molinaro, "Enhancing IEEE 802.11p/WAVE to provide infotainment applications in VANETs," *Ad Hoc Networks,* vol. 10, pp. 253-269, 2012.

[8] S. A. Sha-Mohammad, H. M. Abdel-Wahab, D. C. Popescu, and IEEE, "A Study of IEEE 802.11 Standard for Use in Vehicle to Infrastructure Communication," in *2013 IEEE Globecom Workshops*, pp. 1303-1307, 2013.

[9] T. Varum, J. N. Matos, R. Abreu, P. Pinho, and IEEE, "Non-uniform microstrip antenna array for Rx DSRC communications," in *2014 IEEE Antennas and Propagation Society International Symposium*, pp. 1071-1072, 2014.

[10] S.-I. Sou and O. K. Tonguz, "Enhancing VANET Connectivity Through Roadside Units on Highways," *IEEE Transactions on Vehicular Technology - IEEE TRANS VEH TECHNOL,* vol. 60, pp. 3586-3602, 2011.

[11] A. Daniel, D. C. Popescu, S. Olariu, and IEEE, "A Study of Beaconing Mechanism for Vehicle-to-Infrastructure Communications," in *2012 IEEE International Conference on Communications*, 2012.

[12] T.-Y. Wu, S. Guizani, W.-T. Lee, and K.-H. Liao, "Improving RSU service time by Distributed Sorting Mechanism," *Ad Hoc Networks,* vol. 10, pp. 212-221, 2012.

[13] X. Fan, B. Yang, R. Yamamoto, and Y. Tanaka, "Road side unit assisted stochastic multi-hop broadcast scheme for instant emergency message propagation," in *2015 17th International Conference on Advanced Communication Technology (ICACT)*, pp. 450-457, 2015.

[14] A. Bazzi, B. M. Masini, A. Zanella, and G. Pasolini, "IEEE 802.11p for cellular offloading in vehicular sensor networks," *Computer Communications,* vol. 60, pp. 97-108, 2015.

[15] H. Cheng, X. Fei, A. Boukerche, and M. Almulla, "GeoCover: An efficient sparse coverage protocol for RSU deployment over urban VANETs," *Ad Hoc Networks,* vol. 24, Part B, pp. 85-102, 2015.

[16] S. Mehar, S. M. Senouci, A. Kies, and M. M. Zoulikha, "An Optimized Roadside Units (RSU) placement for delay-sensitive applications in vehicular networks," in *2015 12th Annual IEEE Consumer Communications and Networking Conference (CCNC)*, pp. 121-127, 2015.

[17] C. Ghorai and I. Banerjee, "A constrained Delaunay Triangulation based RSUs deployment strategy to cover a convex region with obstacles for maximizing communications probability between V2I," *Vehicular Communications,* vol. 13, pp. 89-103, 2018.

[18] Y. Agarwal, K. Jain, and O. Karabasoglu, "Smart vehicle monitoring and assistance using cloud computing in vehicular Ad Hoc networks," *International Journal of Transportation Science and Technology*., vol. 7, no. 1, pp. 60–73, 2018.

[19] N. Varga, L. Bokor, A. Takács, J. Kovács, and L. Virág, "An architecture proposal for V2X communication-centric traffic light controller systems," in *2017 15th International Conference on ITS Telecommunications (ITST)*, pp. 1-7, 2017.

[20] J. Godoy, V. Milanés, J. Pérez, J. Villagrá, and E. Onieva, "An auxiliary V2I network for road transport and dynamic environments," *Transportation Research Part C: Emerging Technologies,* vol. 37, pp. 145-156, 2013.

[21] M. Ruta, F. Scioscia, A. Pinto, F. Gramegna, S. Ieva, G. Loseto*, et al.*, "A CoAP-based framework for collaborative sensing in the Semantic Web of Things," *Procedia Computer Science,* vol. 109, pp. 1047-1052, 2017.

[22] J. Radak, B. Ducourthial, V. Cherfaoui, and S. Bonnet, "Detecting Road Events Using Distributed Data Fusion: Experimental Evaluation for the Icy Roads Case," *IEEE Transactions on Intelligent Transportation Systems,* vol. 17, pp. 184-194, 2016.

[23] W. Alghamdi, E. Shakshuki, and T. R.Sheltami, "Context-Aware Driver Assistance System," *Procedia Computer Science,* vol. 10, pp. 785-794, 2012.

[24] F. Jiménez, J. E. Naranjo, J. J. Anaya, F. García, A. Ponz, and J. M. Armingol, "Advanced Driver Assistance System for Road Environments to Improve Safety and Efficiency," *Transportation Research Procedia,* vol. 14, pp. 2245-2254, 2016.

[25] V. Milanés, J. Pérez, J. Godoy, and E. Onieva, "A fuzzy aid rear-end collision warning/avoidance system," *Expert Systems with Applications,* vol. 39, pp. 9097-9107, 2012.

[26] R. Zagrouba, T. Hayouni, F. Kamoun, and IEEE, *Handover optimization within vehicular networks*, World Congr. Comput. Appl. Inf. Syst. WCCAIS, pp. 0–4, 2014.

[27] G. G. M. Nawaz Ali, P. H. J. Chong, S. K. Samantha, and E. Chan, "Efficient data dissemination in cooperative multi-RSU Vehicular Ad Hoc Networks (VANETs)," *Journal of Systems and Software,* vol. 117, pp. 508-527, 2016.

[28] B. Jarupan and E. Ekici, "PROMPT: A cross-layer position-based communication protocol for delay-aware vehicular access networks," *Ad Hoc Networks,* vol. 8, pp. 489-505, Jul 2010.

[29] M. Srotyr, T. Zelinka, and Z. Lokaj, "Hybrid communication solution for C-ITS and its evaluation," in *2017 Smart City Symposium Prague (SCSP)*, pp. 1-7, 2017.

[30] C. Shao, S. Leng, Y. Zhang, and H. Fu, "A multi-priority supported medium access control in Vehicular Ad Hoc Networks," *Computer Communications,* vol. 39, pp. 11-21, 2014.

[31] M. Sadou and L. Bouallouche-Medjkoune, "Efficient message delivery in hybrid sensor and vehicular networks based on mathematical linear programming," *Computers & Electrical Engineering,* vol. 64, pp. 496-505, 2017.

[32] Z. He and D. Zhang, "Cost-efficient traffic-aware data collection protocol in VANET," *Ad Hoc Networks,* vol. 55, pp. 28-39, 2017.

[33] A. J. Ghandour, K. Fawaz, H. Artail, M. Di Felice, and L. Bononi, "Improving vehicular safety message delivery through the implementation of a cognitive vehicular network," *Ad Hoc Networks,* vol. 11, pp. 2408-2422, 2013.

[34] M. Khabbaz, C. Assi, M. Hasna, A. Ghrayeb, and W. Fawaz, "Modelling, analysis and performance improvement of an SRU's access request queue in multi-channel V2I communications," *Pervasive and Mobile Computing,* vol. 21, pp. 92-102, 2015.

[35] N. Cordeschi, D. Amendola, and E. Baccarelli, "Resource-Management for Vehicular Real-Time Application under Hard Reliability Constraints," in *2014 IEEE/ACM 18th International Symposium on Distributed Simulation and Real Time Applications*, pp. 219-226, 2014.

[36] N. Cordeschi, D. Amendola, and E. Baccarelli, "Fairness-constrained optimized time-window controllers for secondary-users with primary-user reliability guarantees," *Computer Communications,* vol. 116, pp. 63-76, 2018.

[37] N. Cordeschi, D. Amendola, M. Shojafar, and E. Baccarelli, "Distributed and adaptive resource management in Cloud-assisted Cognitive Radio Vehicular Networks with hard reliability guarantees," *Vehicular Communications,* vol. 2, pp. 1-12, 2015.

[38] N. Cordeschi, D. Amendola, and E. Baccarelli, "Hard and soft optimal resource allocation for primary and secondary users in infrastructure Vehicular Networks," in *2015 12th Annual IEEE Consumer Communications and Networking Conference (CCNC)*, pp. 708-713, 2015.

[39] B. HomChaudhuri, R. Lin, and P. Pisu, "Hierarchical control strategies for energy management of connected hybrid electric vehicles in urban roads," *Transportation Research Part C: Emerging Technologies,* vol. 62, pp. 70-86, 2016.

[40] I. Johansson, J. Jin, X. Ma, and H. Pettersson, "Look-ahead speed planning for heavy-duty vehicle platoons using traffic information," *Transportation Research Procedia,* vol. 22, pp. 561-569, 2017.

[41] D. G. Perumal, B. Subathra, G. Saravanakumar, and S. Srinivasan, "Extended Kalman Filter Based Path-Planning Algorithm for Autonomous Vehicles with I2V Communication," *IFAC-PapersOnLine,* vol. 49, pp. 652-657, 2016.

[42] J. Ďurech, M. Hruboš, M. Franeková, and A. Janota, "Implementation of data from the mobile measurement platform to VANET application," in *2014 ELEKTRO*, pp. 430-434, 2014.

[43] G. M. Hoang, B. Denis, J. Härri, and D. T. M. Slock, "Robust data fusion for cooperative vehicular localization in tunnels," in *2017 IEEE Intelligent Vehicles Symposium (IV)*, pp. 1372-1377, 2017.

[44] Y. Agarwal, K. Jain, S. Kumar, G. N. Bhardwaj, and IEEE, *TLST: Time of Arrival Based Localization and Smart Tunnel concept in VANETs*, in 2016 3rd International Conference on Signal Processing and Integrated Networks (SPIN), pp. 763–768, 2016.

[45] A. Saxena, H. Li, D. Goswami, C. B. Math, and IEEE, *Design and Analysis of Control Strategies for Vehicle Platooning*, in 2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC), pp. 1805–1812, 2016.

[46] D. Jia and D. Ngoduy, "Enhanced cooperative car-following traffic model with the combination of V2V and V2I communication," *Transportation Research Part B: Methodological,* vol. 90, pp. 172-191, 2016.

[47] D. Huang and M. Verma, "ASPE: attribute-based secure policy enforcement in vehicular ad hoc networks," *Ad Hoc Networks,* vol. 7, pp. 1526-1535, 2009.

[48] P. Vijayakumar, V. Chang, L. Jegatha Deborah, B. Balusamy, and P. G. Shynu, "Computationally efficient privacy preserving anonymous mutual and batch authentication schemes for vehicular ad hoc networks," *Future Generation Computer Systems,* vol. 78, Part 3, pp. 943-955, 2018.

[49] Y. Zhou, S. Chen, Y. Zhou, M. Chen, and Q. Xiao, "Privacy-Preserving Multi-Point Traffic Volume Measurement Through Vehicle-to-Infrastructure Communications," *IEEE Transactions on Vehicular Technology,* vol. 64, pp. 5619-5630, 2015.

[50] X. Liu, Y. Xia, W. Chen, Y. Xiang, M. M. Hassan, and A. Alelaiwi, "SEMD: Secure and efficient message dissemination with policy enforcement in VANET," *Journal of Computer and System Sciences,* vol. 82, pp. 1316-1328, 2016.

[51] C. Bernardini, M. R. Asghar, and B. Crispo, "Security and privacy in vehicular communications: Challenges and opportunities," *Vehicular Communications,* vol. 10, pp. 13-28, 2017.

[52] R. F. Atallah, M. J. Khabbaz, and C. M. Assi, "Vehicular networking: A survey on spectrum access technologies and persisting challenges," *Vehicular Communications,* vol. 2, pp. 125-149, 2015.

[53] K. Zheng, Q. Zheng, P. Chatzimisios, W. Xiang, and Y. Q. Zhou, "Heterogeneous Vehicular Networking: A Survey on Architecture, Challenges, and Solutions," *Ieee Communications Surveys and Tutorials,* vol. 17, pp. 2377-2396, 2015.

[54] U. Lee and M. Gerla, "A survey of urban vehicular sensing platforms," *Computer Networks,* vol. 54, pp. 527-544, 2010.

[55] S. K. Gupta, S. Khara, and IEEE, *Technique to Improve the File Transfer Outcomes Between Road Side Unit and Vehicles in Vehicular Ad-Hoc Networks*, in International Conference on Computing, Communication & Automation, pp. 360–366, 2015.

[56] A. Sassi, Y. Elhillali, and F. Charfi, "Evaluating Experimental Measurements of the IEEE 802.11p Communication Using ARADA LocoMate OBU Device Compared to the Theoretical Simulation Results," *Wireless Personal Communications,* vol. 97, pp. 3861-3874, Dec 2017.

[57] O. Shagdar, P. Muhlethaler, and IEEE, "Study on Merging Control Supported by IEEE 802.11p Systems for Highway Environments'," in *2013 Ifip Wireless Days*, 2013.

[58] V. Iordache, R. A. Gheorghiu, M. Minea, and A. C. Cormos, "Field testing of Bluetooth and ZigBee technologies for vehicle-to-infrastructure applications," in *2017 13th International Conference on Advanced Technologies, Systems and Services in Telecommunications (TELSIKS)*, pp. 248-251, 2017.

[59] D. Perez-Diaz de Cerio and J. L. Valenzuela, "Provisioning Vehicular Services and Communications Based on a Bluetooth Sensor Network Deployment," *Sensors,* vol. 15, pp. 12765-12781, Jun 2015.

[60] H. Fouchal, E. Bourdy, G. Wilhelm, and M. Ayaida, "A validation tool for cooperative intelligent transport systems," *Journal of Computational Science,* vol. 22, pp. 283-288, 2017.

[61] M. Aramrattana, T. Larsson, J. Jansson, and A. Nåbo, "A simulation framework for cooperative intelligent transport systems testing and evaluation," *T*ransportation Research Part F: Traffic Psychology and Behaviour. vol. 61, pp. 268–280, 2019.

[62] Y. Yang, Z. Wei, Y. Zhang, H. Lu, K.-K. R. Choo, and H. Cai, "V2X security: A case study of anonymous authentication," *Pervasive and Mobile Computing,* vol. 41, pp. 259-269, 2017.

[63] A. Sassi, F. Charfi, L. Kamoun, Y. Elhillali, and A. Rivenq, "The impact of mobility on the performance of V2X communication," in *2011 4th International Conference on Logistics*, pp. 434-438, 2011.

[64] M. Sepulcre, J. Gozalvez, and B. Coll-Perales, "Why 6 Mbps is Not (Always) the Optimum Data Rate for Beaconing in Vehicular Networks," *IEEE Transactions on Mobile Computing,* vol. 16, pp. 3568-3579, 2017.

[65] J. Sun and Y. Fang, "Defense against misbehavior in anonymous vehicular ad hoc networks," *Ad Hoc Networks,* vol. 7, pp. 1515-1525, 2009.

[66] L. Shi and P. Prevedouros, "Autonomous and Connected Cars: HCM Estimates for Freeways with Various Market Penetration Rates," *Transportation Research Procedia,* vol. 15, pp. 389-402, 2016.

[67] C. Wuthishuwong and A. Traechtler, "Stability of the consensus in the network of multiple Autonomous Intesections Management," in *2014 20th International Conference on Automation and Computing*, pp. 295-300, 2014.

[68] A. E. Coronado Mondragon, E. S. Coronado Mondragon, C. E. Coronado Mondragon, and F. Mung'au, "Estimating the performance of intelligent transport systems wireless services for multimodal logistics applications," *Expert Systems with Applications,* vol. 39, pp. 3939-3949, 2012.

[69] S. Chen, W. Nai, D. Dong, W. Zheng, and W. Jing, "Key Indices Analysis of IEEE 802.11p based Vehicle to Infrastructure System in Highway Environment," *Procedia - Social and Behavioral Sciences,* vol. 96, pp. 188-195, 2013.

[70] J. Vales-Alonso, F. Vicente-Carrasco, and J. J. Alcaraz, "Optimal configuration of roadside beacons in V2I communications," *Computer Networks,* vol. 55, pp. 3142-3153, 2011.

[71] Z. Li and M. Shahidehpour, "Deployment of cybersecurity for managing traffic efficiency and safety in smart cities," *The Electricity Journal,* vol. 30, pp. 52-61, 2017.

[72] P. Gora and I. Rub, "Traffic models for self-driving connected cars," in *Transport Research Arena Tra2016*. vol. 14, L. Rafalski and A. Zofka, Eds, pp. 2207-2216, 2016.

[73] S. Sousa, A. Santos, A. Costa, B. Dias, B. Ribeiro, F. Gonçalves. "A New Approach on Communications Architectures for Intelligent Transportation Systems," *Procedia Computer Science,* vol. 110, pp. 320-327, 2017.

[74] C. Liao, J. Chang, I. Lee, and K. K. Venkatasubramanian, "A trust model for vehicular network-based incident reports," in *2013 IEEE 5th International Symposium on Wireless Vehicular Communications (WiVeC)*, pp. 1-5, 2013.

[75] G. E. M. Zhioua, H. Labiod, N. Tabbane, and S. Tabbane, "A multi-metric QoS-balancing scheme for gateway selection in a clustered hybrid VANET network," in *2012 IEEE 8th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob)*, pp. 150-156, 2012.

[76] M. Patra, S. Mishra, and C. S. R. Murthy, "An Analytic Hierarchy Process Based Approach for Optimal Road Side Unit Placement in Vehicular Ad Hoc Networks," in *2014 IEEE 79th Vehicular Technology Conference (VTC Spring)*, pp. 1-5, 2014.

[77] I. Chantaksinopas, P. Oothongsap, and A. Prayote, "Network selection delay comparison of network selection techniques for safety applications on VANET," in *2011 13th Asia-Pacific Network Operations and Management Symposium*, pp. 1-7, 2011.

[78] E. Skondras, A. Michalas, and D. D. Vergados, "Mobility management on 5G Vehicular Cloud Computing systems," *Vehicular Communications,* vol. 16, pp. 15-44, 2019.

[79] S. Goudarzi, M. H. Anisi, A. H. Abdullah, J. Lloret, S. A. Soleymani, and W. H. Hassan, "A hybrid intelligent model for network selection in the industrial Internet of Things," *Applied Soft Computing,* vol. 74, pp. 529-546, 2019.

[80] S. Datta, S. Dhar, R. N. Bera, and A. Ray, "ANP based vertical handover algorithm for vehicular communication," in *2012 1st International Conference on Recent Advances in Information Technology (RAIT)*, pp. 228-234, 2012.

[81] M. Alhabo and L. Zhang, "Multi-Criteria Handover Using Modified Weighted TOPSIS Methods for Heterogeneous Networks," *IEEE Access,* vol. 6, pp. 40547-40558, 2018.

[82] E. Alizadeh, K. R. Lejjy, and E. Amiri, "Improving Routing in Vehicular Ad-hoc Network with VIKOR Algorithm," in *2018 9th International Symposium on Telecommunications (IST)*, pp. 337-341, 2018.

[83] S. Sharma and A. Kaul, "Hybrid fuzzy multi-criteria decision making based multi cluster head dolphin swarm optimized IDS for VANET," *Vehicular Communications,* vol. 12, pp. 23-38, 2018.

[84] M. A. Yaqub, S. H. Ahmed, and D. Kim, "Asking neighbors a favor: Cooperative video retrieval using cellular networks in VANETs," *Vehicular Communications,* vol. 12, pp. 39-49, 2018.

[85] K. Roscher, J. Jiru, and R. Knorr, "Low-delay forwarding with multiple candidates for VANETs using multi-criteria decision making," in *2016 IEEE Vehicular Networking Conference (VNC)*, pp. 1-8, 2016.

[86] O. S. Albahri, A. A. Zaidan, B. B. Zaidan, M. Hashim, A. S. Albahri, and M. A. Alsalem, "Real-Time Remote Health-Monitoring Systems in a Medical Centre: A Review of the Provision of Healthcare Services-Based Body Sensor Information, Open Challenges and Methodological Aspects," *Journal of Medical Systems,* vol. 42, p. 164, 2018.

[87] H. Nilsson, E.-M. Nordström, and K. Öhman, "Decision Support for Participatory Forest Planning Using AHP and TOPSIS," *Forests,* vol. 7, 2016.

[88] T. L. Saaty and M. S. Ozdemir, "Why the magic number seven plus or minus two," *Mathematical and Computer Modelling,* vol. 38, pp. 233-244, 2003.

[89] M. A. O. Barrios, F. De Felice, K. P. Negrete, B. A. Romero, A. Y. Arenas, and A. Petrillo, "An AHP-Topsis Integrated Model for Selecting the Most Appropriate Tomography Equipment," *International Journal of Information Technology & Decision Making,* vol. 15, pp. 861-885, 2016.

[90] R. Tavakkoli-Moghaddam, M. Heydar, and S. M. Mousavi, "An integrated AHP-VIKOR methodology for plant location selection," *International Journal of Engineering,* vol. 24, pp. 127-137, 2011.

[91] O. Mohsen and N. Fereshteh, "An extended VIKOR method based on entropy measure for the failure modes risk assessment – A case study of the geothermal power plant (GPP)," *Safety Science,* vol. 92, pp. 160-172, 2017.

[92] N. Pothirasan and M. P. Rajasekaran, "Automatic vehicle to vehicle communication and vehicle to infrastructure communication using NRF24L01 module," in *2016 International Conference on Control, Instrumentation, Communication and Computational Technologies (ICCICCT)*, pp. 400-405, 2016.

[93] S. Han, C. Cheng-Hsuan, C. Yi-Hong, and C. Wen-Yao, "A traffic information dissemination mechanism based on DSRC/WAVE and its applications," in *2012 12th International Conference on ITS Telecommunications*, pp. 635-638, 2012.

[94] S. Xiao and Z. Xu, "Reliable and Energy Efficient Communication Algorithm in Hierarchical Wireless Sensor Networks," *Wireless Personal Communications,* vol. 95, pp. 1891-1909, 2017.

[95] K. Kolomvatsos, P. Oikonomou, M. Koziri, and T. Loukopoulos, "A Distributed Data Allocation Scheme for Autonomous Nodes," in *2018 IEEE SmartWorld, Ubiquitous Intelligence & Computing, Advanced & Trusted Computing, Scalable Computing & Communications, Cloud & Big Data Computing, Internet of People and Smart City Innovation (SmartWorld/SCALCOM/UIC/ATC/CBDCom/IOP/SCI)*, pp. 1651-1658, 2018.

[96] P. Emerson, "The original Borda count and partial voting," *Social Choice and Welfare,* vol. 40, pp. 353-358, 2013.

[97] M. A. Qader, B. B. Zaidan, A. A. Zaidan, S. K. Ali, M. A. Kamaluddin, and W. B. Radzi, "A methodology for football players selection problem based on multi-measurements criteria analysis," *Measurement,* vol. 111, pp. 38-50, 2017.