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ADAPTIVE INTELLIGENT TRAFFIC CONTROL SYSTEMS FOR IMPROVING TRAFFIC QUALITY AND CONGESTION IN SMART CITIES

Abstract: *A systematic review was undertaken to examine the solutions available for traffic congestion and associated problems in smart cities. Google Scholar and Google were used as search engines, leading to the final selection of 35 eligible papers for inclusion in this review, after a serious of screening based on definite criteria. Intelligent transport systems were found to be the most suitable solution to traffic congestion and associated problems in smart cities. Certain models and frameworks of smart cities include smart mobility and transport management systems. These can be approximated to intelligent transport systems. True intelligent transport systems are infrastructure-based or intelligent vehicle based or more preferably, a combination of both. The Internet of Things and cloud computing should be built into the system as they enable the operation of smart transport networks. Some methods of designing traffic control systems combining both Eulerian and Lagrangian approaches have been discussed for the possibility of using any of them to design a new automatic traffic monitoring and control system for smart cities. The practical implication of this research is that it can improve quality of life of people by minimizing traffic congestion. Limitations of this paper include this being a systematic review, availability of very few papers and not considering adaptive intelligent traffic control systems. Explanations for these limitations have been provided.*

Keywords: *Adaptive traffic control; Intelligent traffic system; Smart cities.*

1. Introduction

Traffic congestion has become a daily experience for commuters travelling to their educational institutions, offices or to buy things from shops. Traffic on the road consists of cars, public transport vehicles like buses and vans, office vans of specific firms, school vehicles, trucks etc. In addition, emergency vehicles of police, ambulance, fire service etc. are also on the road on many occasions. During peak hours, there is a ban on trucks on main roads in most cities. Traffic load on the road is maximum during peak hours when most people want to travel on the road at the same time, using a variety of vehicles.

Passengers need to leave much early and come home late to ensure reaching their place of work It almost leaves little time for dealing with children or other family problems. Normal exposure of such a type

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leads to psychosocial discomfort, anger and difficulties. Dietary patterns change, the lack of healthy life without preparation often contributes to physical health issues. The road congestion thus has many serious impacts on residents. Such problems include a greater risk of road injuries, interrupted jobs and decreased probability of traffic offenses.

The reports of Inrix (cited by Korosec, 2018) and of Tom Tom Index listed Los Angeles, Moscow, San Francisco, Atlanta, Miami, Bangkok and Mexico City as the leading cities in traffic congestion, although the order of ranking may be different in other different reports. At an annual rate of 102 hours spent on roads due to congestion, the driver cost is $2828 and the total annual cost to the city of Los Angeles alone is about $19.2 billion directly and indirectly. The corresponding global level impact will run into several billion USD. These data demonstrate the seriousness of the problem and the need to find a solution.

There have been many research studies to find solutions. The smart city concept has traffic control systems component to reduce traffic congestion in it. Separately, there has been research on how to use modern technology for traffic control and management to minimise traffic congestion.

The purpose of this paper is to examine the solutions available to reduce traffic congestion and problems associated with it. A systematic review of published research works is used for this purpose.

2. Methodology

A systematic review is defined as "A systematic review attempts to identify, appraise and synthesize all the empirical evidence that meets pre-specified eligibility criteria to answer a specific research question. Researchers conducting systematic reviews use explicit, systematic methods that are selected with a view aimed at minimizing bias, to produce more reliable findings to inform decision making." (Cochrane Library, 2019).

2.1 Methodology of selection of papers for this review

The following steps describe how the papers were identified and selected for this review. The methodology adopted consists of following parts:

a) Search and identification for literature.
b) Screening process to select papers relevant to the topic using inclusion and exclusion criteria.
c) Final selection of papers for inclusion in this review.
d) Prepare a PRISMA diagram to describe the process through search and selection.

2.1.1 Search and identification

Based on a scoping search, some search terms relevant to the topic were identified. These search terms, "smart city and intelligent traffic control systems", "Internet of Things" and "cloud computing", "intelligent traffic control", "intelligent traffic control systems", "adaptive intelligent traffic control systems" were used in Google Scholar search engine with any time as the time frame first. Searching the first five web pages of this search engine yielded 50 papers. Then the time frame was narrowed to 2015 to 2019, to focus on more recent papers. The first five web pages yielded another 62 papers. Thus, a total of 112 papers were obtained.

In addition, Google search engine was used for definitions of traffic congestion, traffic control systems and adaptive traffic control systems and some web articles on traffic congestion and accidents data to use as the background material. This search yielded another 22 papers. Thus, totally, 134 papers were identified.

2.1.2 Screening

Duplicates between Google Scholar and Google, repeat of the same paper after a few articles on the web pages were excluded (27 papers) for a primary selection of 107 articles. Out of the 107 articles, 23 were not useful in any way as they were not dealing with the topic of interest sufficiently well. Thus, 84 papers were obtained. From these 84 papers, 49 articles were excluded for the following reasons:

I. Works are not related to traffic control or management.
II. The need for research is not clear. The objectives were vague.
III. Methodology is not explained clearly.
IV. Results have been given haphazardly with no clarity on what are the findings.
V. Alternate explanations are possible for results.
VI. No relationship between results and conclusions.

Not all defects existed in all papers, but the excluded papers had one or more of these defects, rendering them totally unusable for this paper. Thus, after the entire screening ad exclusions, 35 usable papers were obtained for use in this paper.

A PRISMA diagram of the identification, screening and final selection of the papers is appended.

Two of the papers on traffic congestion and three on definitions of systematic have been already cited in the introduction section above. The rest of the papers have been used in the appropriate sections below.

The purpose of this review is to explore the possibility of designing aa new adaptive intelligent traffic monitoring and control framework for a smart city. Different types of intelligent traffic control systems will be examined by critically reviewing the available research on the topic. The need and scope for designing a new adaptive traffic monitoring and control system and its integration with smart city components will be assessed. The review is expected to generate ideas for procedure to design the proposed new system.

2.1.3 Organization of reviews

The usual practice is to tabulate all the selected papers in one table with brief description of the aim, objective, methods and findings and discuss them subsequently. Making a tabulated statement of 35 papers is too unwieldly. Hence, in this review, the papers are listed in the list of references and they are just discussed under the following sections. This is done since many models and frameworks will be discussed reproducing them from their sources.

1. Smart city concept and extent of inclusion of traffic control and management in urban/smart city concepts and applications.

2. Use of infrastructure-based, intelligent vehicle-based and combined technology methods for intelligent transport system

3. Internet of things (IoT) and cloud computing applications in intelligent traffic control systems.

The above descriptions are followed by conclusions including indications of future research and some limitations of this work. First, the concept of smart city and to what extent different authors have included (urban) traffic control system in this concept, are examined.

3. Result

3.1 The smart city concept and extent to which authors included (urban) traffic control system in smart city concept

Sustainability and smart mobility are two concepts related to intelligent traffic control systems in smart cities. Sustainability elements include reduction of emissions by reduction of fossil fuel use in vehicles. Long waiting time during traffic congestion leads to higher consumption of fossil fuel. So, efficient traffic management leads to reduction of fuel consumption by reducing traffic congestion. Using vehicles with alternate energy sources like electricity is also part of this strategy. Smart mobility is associated with the smart city concept. If a city is fully smart as per the criteria, the mobility of vehicles and people will also be smart. This implies use of modern technologies for traffic management systems in smart cities.

There were 22 papers dealing with this topic. Some issues of definition, appropriateness of naming a city as smart and its relationship with the extent of technologies used were the subjects discussed by Hollands (2008). Social justice, inclusiveness etc. have been largely kept out of the scope of mart cities. Rode, et al. (2017) went further in declaring that more compact, public transport-oriented cities are better than more sprawling, car-dependent urban development, as the former is beneficial in terms of superior economic and social performance and lower carbon emissions. The last said point brings smart cities nearer the sustainability concept. However, Ahvenniemi, Huovila, Pinto-Seppä, and Airaksinen (2017) preferred to differentiate between them, based on their frameworks. Smart cities focus more on social and economic aspects and sustainable cities are more concerned about sustainability points. The only point of convergence between them may be emission reduction. Both types of cities want to reduce emissions through efficient transport management systems. Here, the link between smart city and transport control (management) system is established.

The visionary conceptualisation of smart city by Hall, et al. (2000) includes safe and secure aspect, which is related to transport also. The authors mentioned about efficient structures including transportation. Smart mobility is the element connecting smart city concept with traffic control systems. This is the next topic below.

Smart mobility is one of the six elements of smart city according to Neirotti, De Marco, Cagliano, Mangano, and Scorrano (2014) and Pellicer, et al. (2013). Based on an examination of three smart cities and 10 other cities, the latter authors observed that sustainable transport systems take care of local emissions, noise, congestion and accidents in smart cities. According to Monzon (2015), mobility challenges are the main challenges of European smart cities. Smart mobility encompasses sustainable, inclusive, multimodal transport, pressure of urban ecosystems, traffic congestion, mobility other than using cars, ICT infrastructure to support the mobility systems. Mobility challenges in Mediterranean cities were related to lack of infrastructure, rapid growth, public transport inefficiency and pollution.

In his list of seven critical infrastructure and services for smart cities, Washburn, et al. (2009) included transport system in which there is greater use of public transport to reduce traffic congestion. Other aspects related to transport in his list were: ensuring public safety by using real-time information for rapid response to emergencies and threats; reduction of operating costs and increase of value. Some of these are indirectly related. Vanolo (2014) discovered that a new moral order is created when technology is used to upgrade cities to make it smart. Regulated, well-disciplined traffic control systems minimise accidents and is part of this moral order of smart cities. Thus, intelligent automated transport systems which delivers disciplined traffic, is justified.

Out of the four strategies of smart cities implementation discussed by Angelidou (2014), funds limitations for local governments may affect implementation, especially of intelligent traffic control systems. When smart traffic control systems are planned at the national level, coordination among the local bodies, and between local bodies and the national government is required. A national authority for transportation and traffic control systems may be the answer to get around this issue.

Adaptive intelligent traffic control systems are largely technology-based. Choice of several technologies are available, as will be seen later. Innovative approaches in technology, management and creation of policy and context environment are required but rarely researched in making cities smarter, according to Nam and Pardo (2011). Shelton, Zook, and Wiig (2015) recommended a balanced combination of neo-liberal and community-driven approaches to develop a good urban transport system. Stakeholder consultation is an important aspect in any development plan affecting the population.

A conceptual six-layered smart city reference model was proposed by Zygiaris (2013) and the layers were discussed. The framework is reproduced in Fig 1. These layers were applied to Barcelona as an integrated structure of all layers, to Amsterdam as a targeted layer structure and to Edinburgh as a limited layer structure. The author claimed that the framework can be applied to any smart city. Intelligent transport control and its various elements are included in almost all layers.

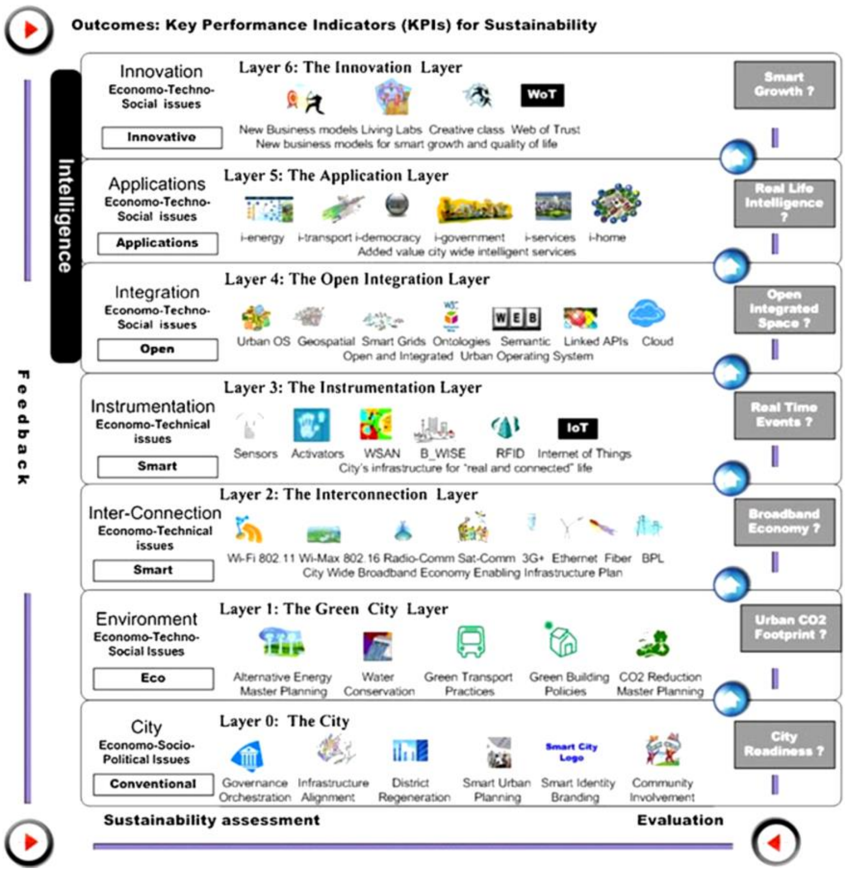

Figure 1. The six-layered conceptual framework for smart cities proposed by Zygiaris (2013)

Relative efficiencies of traffic control and management in a smart city compared to another, can be a competitiveness factor and this may be a trigger for increased private investments. Cities with better managed traffic systems may attract more private investments, especially from logistics sector (Caragliu, Bo, & Nijkamp, 2011). Making a city smart itself is aimed to increase its competitiveness vis-à-vis other cities. An urban audit of E27 smart cities done by the authors included travel and transport as one factor.

Paskaleva (2009) noted that e-governance is a part of smart city management to provide various products and services through technological means. Transport systems management is also a part of e-governance. E-governance involving human collaborations and ICT was also endorsed by Meijer and Bolívar (2016). On the other hand, corporate governance culture was considered harmful by Hollands (2015), who suggested two methods to avoid corporate governance culture entering into smart city and traffic control management systems. However, it may be difficult to discard corporate governance structure and system completely, and good points from corporate governance can be adapted to smart city and traffic control management systems.

Now we look at certain specific factors of traffic management in smart cities. Raid changes in spatial and social structure arising out of smart city become challenging to transport planners, according to Behan, Maoh, and Kanaroglou (2008). The authors used a simulation tool called IMULATE, to address the problems of increasing dependency on automobile, commuting distances and congestion on the urban roads for the development of an integrated land use and urban transportation model and many development scenarios models for anticipated growth. Changes in vehicular emissions, traffic congestion and energy consumption were also examined. Thus, some sustainability issues were also addressed using the simulation tool.

Smart mobility objectives are pollution reduction, safe transport, reducing traffic congestion, reducing noise pollution, improving transfer speed with minimum cost. Therefore, smart mobility applies to fast forwarding the applications of ICT to optimise of traffic fluxes and to collect opinions of people on the liveability in cities or on local public transport services quality. In the discussions of Benevolo, Dameri, and D’Auria (2016) on these points, components of efficient adaptive intelligent transport systems were also included.

Thus, smart city or even sustainable city concept includes efficient urban traffic control systems, which will be necessary due to the increased number of vehicles on the road, longer commuting distances, traffic congestion and emissions. Other dangers of increasing traffic congestion, pointed out in the Introduction section, are also relevant. Inevitable use of ICT for making urban traffic control systems efficient makes it smart, intelligent and adaptive to current traffic conditions. This is what is needed in intelligent traffic control systems. The infrastructure facilities of smart cities related to intelligent traffic control systems are examined next.

Smart city mobility of the future consists of new vehicle technologies, new vehicle control methods, new business models of ownership and use, mobile technologies to equip and empower people and opportunities for undertaking activities without any travelling needs. If the stress is only on technology, issues of affordability, effectiveness, attractiveness and sustainability are relegated to the background, noted Lyons (2018). The importance of smart city infrastructure arises here.

Calderoni, Maio, and Rovis (2014) discussed the application of a city kernel framework to handle many subsystems. The subsystems included an infrastructure for wide traffic control via a vision sensor network. There was a network of smart cameras operating over an outdoor public lighting in this infrastructure. Power line communication technology and a vehicle counting, and classification algorithm facilitated traffic control well.

Anttiroiko (2013) observed that that ubiquitous technologies are utilised for developing urban infrastructure for town planning, street and property maintenance, water supply, public transportation and environmental protection, all of which are related to traffic control systems. The infrastructure should provide access all services for everyone through democratisation.

Most intelligent traffic control systems use either intelligent vehicle-based or infrastructure-based methods. Combined method also exists. Examples of these are reviewed here.

3.2 Infrastructure-based, intelligent vehicle-based and combined technology methods for intelligent transport systems for smart city applications (Nellore &Hancke, 2016)

From an examination of literature on the methods of designing intelligent transport systems (ITS), it appears that the sensor can be in the vehicle, making it intelligent or on the road infrastructures, making it infrastructure-based. It is also not unusual to combine both and connect them into a combined methodology. Sometimes IoT or cloud computing are also used as intermediary tools, as some of the above models show.

The scope of using sensors both on infrastructures and in vehicles was examined in a review by Nkoro and Vershinin (2014). Application of an intelligent vehicle for intelligent traffic control shown in a diagram is reproduced in Fig 2. In this diagram, only vehicle-to-vehicle communication occurs and the arrival time to the intersection is determined by how near each vehicle is. The traffic is controlled using this information. On the other hand, it is also possible to design a system in which intelligent vehicles communicate to a road-side infrastructure, which guides the traffic through the road reaching the intersection. This system is depicted in Fig 3 taken from the same authors.

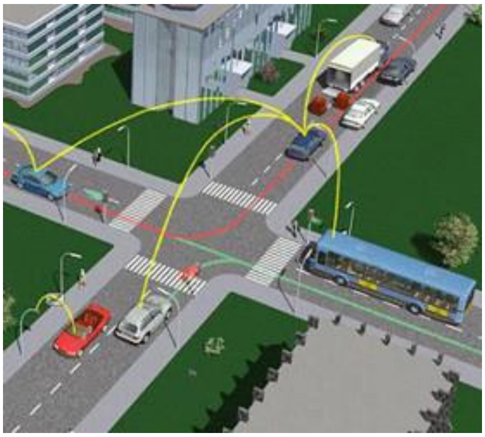

Figure 2. Intelligent vehicle method of ITS (Nkoro &Vershinin, 2014)

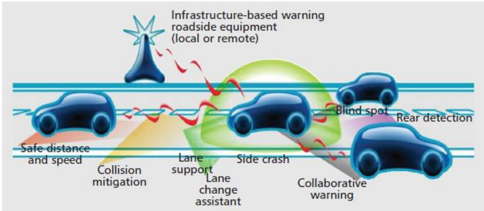

Figure 3. Intelligent vehicle to infrastructure communication (Nkoro &Vershinin, 2014)

In Fig 3, V21 system is used, requiring both vehicle and infrastructure to be intelligent to facilitate communication. More often, wireless sensor networks both on the road infrastructures and vehicles are used in an integrated system, as was described by Nellore and Hancke (2016) and reproduced in Fig 4.

In this system, there are sensors (WSNs) placed on the road. There is a Traffic Management Unit (TMU) and a Road Side Unit (RSU). There are WSN units on the vehicles serving as On Board Units (OBU).

Thus, it becomes a combined technology. WSN-based traffic light control systems also exist. RSU and TMU are meant to collect data, analyse them and determine how to control the traffic flow as smooth as possible.

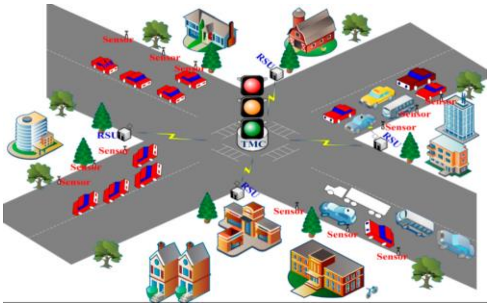

Figure 4. A WSN-based intelligent traffic management system (Nellore & Hancke, 2016)

Sometimes, internet of things (IoT) and cloud computing applications are conveniently used for intelligent traffic management. Some of these are discussed below.

3.3 Internet of things (IoT) and cloud computing applications in intelligent traffic control systems

What should traffic IoT consist of? An answer to this was provided by Al-Sakran (2015). According to him, IoT for traffic control systems should consist of traffic elements including roads, bridges, tunnels, traffic signals, vehicles and drivers conveniently identified and managed using internet using sensor devices like radiofrequency identification (RFID), infrared sensors, global positioning systems (GPS) and laser scanners. Large areas of roads are monitored automatically and intelligently by IoT. Traffic monitoring is done by generation of data with sensors and wireless sensor networks (WSN). These data acquisition, processing and storage processes need to be protected from security threats. Various types of Fuzzy logic, agent-based technology, integrating agents (including mobile) for passing messages with cloud computing were highlighted as useful technologies. The system proposed by the author had various tasks for locating and identifying mobile objects (primarily vehicles) and transmitting acquired data for processing at the monitoring and controlling centre. All these were ordered into operational layers: application layer (intelligent traffic management, intelligent driver management, monitoring and collection of information and information services), network layer (internet; Wi-Fi, 3G & 4G; WiMAX; GPS & GPRS respectively for the four application layers) and acquisition layer (RFID, RFID Reader, WSN and intelligent terminals respectively for the four application layers). In applications, all these components are agent-based. Agents act as an effective communication mechanism among the networked heterogeneous devices within the traffic information system. Thus, there are RFID agent, user agent, sensor agent etc. Simulation studies validated the model.

Intelligent transportation was one major component in the applications of IoT for smart cities by Li, Shan, Shao, Zhou, and Yao (2013). In their model reproduced in Fig 5, ubiquitous sensor networks or the IoT are used for integrating digital city into a smart city. Intelligent transportation is a prominent component here. Smart cities will provide more efficient infrastructure delivery for urban administration and public services by huge, dynamic computation, analysis and data mining on cloud storage platforms. The authors used smart transportation as one of the examples of these applications.

A novel system integrating IoT and cloud computing for intelligent traffic control administration system was proposed by Leng and Zhao (2011). It was called internet of vehicles management system. The cost of the system was low. It was highly scalable, highly compatible, and easily upgradable. It was also environment friendly. These advantages made it highly suitable for replacement of traditional traffic management system and improve road traffic tremendously.

The network architecture and other system details of IoT application for intelligent traffic control systems were presented and discussed by Xiao and Wang (2011). Automatic identification of vehicles based on IoT using RFID reader solved the problem for all-weather operations. GPS was used for positioning information. GPRS was used for wireless transmission of data. The balance components consisted of network architecture, data flow analysis, software and hardware logic structure and intelligent decision-making module. Such a system based on internet of things was low cost, high reliability and no problems with adverse weather conditions.

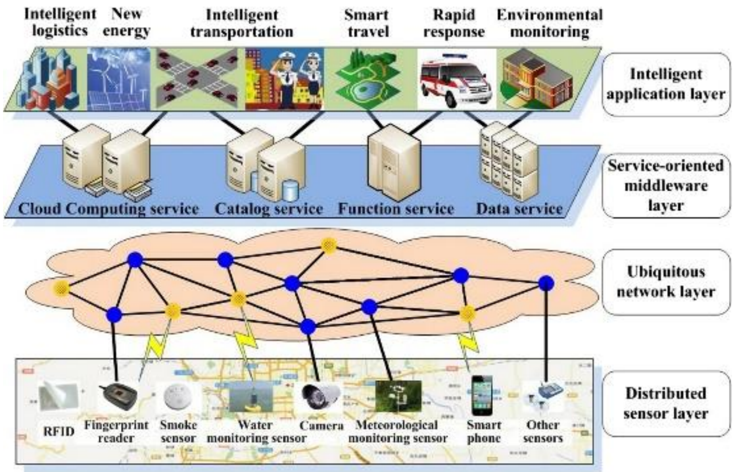

Figure 5. Smart city framework with IoT in intelligent transportation as a component (Li, Shan, Shao, Zhou, & Yao, 2013)

Methods of integrating vehicles and sensing devices to enhance their sensing and communication capabilities and to leverage and achieve smart and intelligent transportation systems were discussed by Guerrero-Ibáñez, Zeadally, and Contreras-Castillo (2018). A taxonomy of ITS management applications presented by the authors is reproduced in Fig 6. This gives an idea of how the integration of IoT, cloud computing and connected vehicle can be achieved. All the activities related to traffic management, viz., traffic monitoring and control, diagnostic, environment, user, assistance and safety were included in the model as is evident from Fig 6. In emergency situations, the in-vehicle sensors are used in the first few stages and then the roadside infrastructure systems, as a case study shows.

Gerla, Lee, Pau, and Lee (2014), in their model, considered internet of autonomous vehicles as the next step in connected vehicles technology. The technology is initiated by Google car. It will be a distributed transport system, which can make its own decisions about driving. Communications, storage, intelligence, learning capacities to anticipate driver intentions are a few aspects related to internet of things. The actual operational set up of the concept using cloud resources, diagrammatised by the authors, is reproduced in Fig 7. V21 communication architecture of VANET was adopted here.

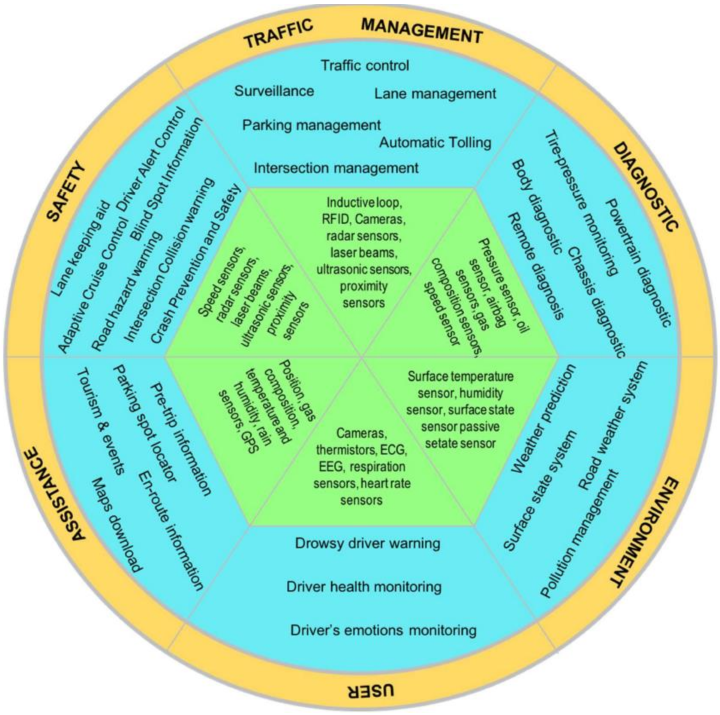

Figure 6. Taxonomy of ITS management applications integrating IoT and cloud computing with connected vehicles (Guerrero-Ibáñez, Zeadally, & Contreras-Castillo, 2018)

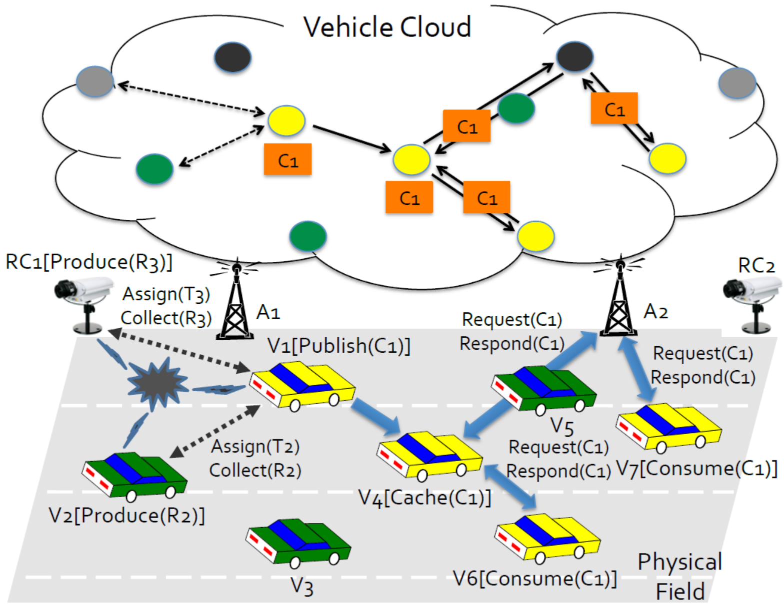

Figure 7. How the system will function on the road traffic conditions- an illustration (Gerla, Lee, Pau, & Lee, 2014)

3.4 The need and scope for designing a new system for adaptive intelligent traffic management relying on Eulerian or Lagrangian principles (PSU, 2020)

Basically two approaches are used for prediction of motion of substances through a given space, usually for situations like distribution of suspended particles in aerosols and particles in inhaled air passing through the lungs. The two approaches are Lagrangian and Eulerian approaches. In The Lagrangian approach, individual fluid particles in a through a fluid or any other space are tracked. Tracking of billiard balls in a high school physics experiments is an example. In traffic systems, this means, vehicle-based traffic control systems.

On the other hand, in the Eulerian approach, individual fluid particles are not identified or tracked. Only a control volume is defined. Pressure, velocity, acceleration, and all other flow properties are described as fields within the control volume. Thus, each characteristic of the system is defined both in terms of time and space. The interest is not on the location or velocity of any particular particle, but rather about the velocity, acceleration etc of whatever particle at a particular location of interest at a particular time. So, this can be equated to road-based intelligent traffic control systems.

It may be more precise and beneficial if both vehicle-based and road-based systems are combined using IoT, cloud etc for integration of the large volume of data more conveniently and efficiently. Such models were already discussed above.

3.5 Researches using both approaches useful to design traffic monitoring and control systems in smart cities

A statistical probability approach to detect vehicles on the road for obtaining vehicles statistics on the road by integrating vehicle detection systems with post-processing subsystems for intelligent traffic monitoring and control was designed by UrRehman, Khan, and Tariq (2015) This was a vehicle-based approach and hence Lagrangian in nature.

It is very important to determine the precise location of the predominant traffic condition in real-time and intelligent traffic management and monitoring systems (ITMCS) applications, based on speed and distance. In this function, methods for estimating traffic condition are used. The most common approaches are model-based traffic condition estimators. This method uses a model of fluid flow to forecast the creation of the state variables. For this reason, a series of measurement equations linked to the device state sensor observations are created. For integrating model estimation and sensor measurements, data assimilation techniques are used. Eulerian co-ordinates (space time) are the cornerstone of mechanism and observation models alike. Nevertheless, Yuan, Van Lint, Van Wageningen-Kessels and Hoogendoorn (2014) observed that recent work indicates that macroscopic traffic flow models can be used to make use of Lagrangian solutions more effective and precise, based on the amount of vehicle time coordinates that are used in transport rather than in Eulserian fixed space coordinates. The authors identified such a Lagrangian approach to traffic management. A robust Kalman filtering technique has been used to enhance the accurate identification of the vehicle in the complex unbalanced state of the cycle equation. As the measurement function, the average relation between vehicle distances and speeds was used. A method based on the Lagrangian approach was tested and contrasted with a related Eulerian method using data from a microscopic simulation environment. It showed the potential for a network-wide Lagrangian solution, which succeeded the Eulerian method.

How a Eulerian-Lagrangian combined system can be designed in swarming behaviour of a competition-cooperation profile as exists in road traffic, was shown by Hu, Wen, Yu, Xuan, and Chen (2018).

A method of combining both approaches in actual traffic flow situations was described by Herrera and Bayen (2007) in the following manner-

"The problem of interest for the present study is the traffic state estimation when Lagrangian data is available. This section describes the proposed approaches to address this problem. Considering Eulerian data only, provided by loop detectors at the boundaries of the section under analysis, at time t the traffic flow model will provide a first estimate of the density field ρ(x,t), denoted by ˆ ρ−(x,t). At time t, Lagrangian sensors will provide the observed local density at some specific locations xi, denoted by ρo(xi,t) (the superscript o denotes observation). For these specific locations, the first estimate and the observed density will probably differ from each other. This difference (ˆρ−(xi,t)−ρo(xi,t)) will be usedto compute a second estimate of the density everywhere at time t, denoted by ˆ ρ (x, t). The present study proposes to use data assimilation techniques such as nudging or Kalman filtering techniques to obtain the second estimate ˆ ρ (x, t)." (p 5-6).

Thus, many papers on combining both Eulerian and Lagrangian approaches to design automatic intelligent traffic monitoring and control systems are available. The suitability of these methods for use in smart cities needs to be evaluated and a suitable design may be selected for use in this work. The new adaptive traffic monitoring and control system, so designed, needs to be tested under simulated conditions to identify and solve any problems unforeseen in the design. The successfully tested simulation framework of the system will be compared against a state-of-the-art benchmark for performance.

4. Conclusion

In the above review, smart mobility as a part of smart city concept was highlighted. Smart mobility has ingredients of intelligent transport system. Many models of this are available.

Intelligent transport systems could be infrastructure-based or intelligent vehicle-based or a combination of both. Feasibility and cost may be the main factor to determine which type is best under a given context.

New technologies like IoT and cloud computing can facilitate design architecture, operation and management of intelligent transport systems. More works integrate both together rather than use only either IoT or cloud computing.

Thus, many options are available when a city is made smart with smart mobility concept, which necessarily builds on intelligent traffic management systems. Systems adaptable to rapidly changing traffic conditions are more suitable for smart cities. But the technology, effort and cost of making it adaptable may be high. This is where the city administration also needs to be intelligent in decision making.

Intelligent transport systems using infrastructure-based and intelligent vehicle-based technologies incorporating IoT and cloud computing may the ideal solutions. But such a perfection may not be possible always. So, a diluted adaptive version may be practised in actual smart city contexts.

4.1 Limitations

First limitation is that it is a systematic review. Most reviewed papers had diagrams and models and not much quantitative results. So, a meta-analytical approach was not possible.

The availability of only 35 papers shows paucity of research on critical areas. Case studies in actual designing, implementing and measurement of traffic parameters are rare, if not totally absent, although some case examples fitting frameworks and models on some of the current smart cities have been done.

It may be argued that adaptive systems have not been considered, for example adaptation of traffic lights to changing traffic conditions. Although this is implied in the model of Nellore & Hancke (2016), this point was not discussed in detail using other works. This topic was deliberately omitted due to the limitations of length of paper for publication in a journal.

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