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Implementing AI-Driven Traffic Signal Systems for Enhanced Traffic Management in Dammam

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ABSTRACT

Overcrowding poses a major challenge for urban cities, as the increasing number of private and commercial vehicles rapidly leads to congestion and queues at intersections. Similar congestion and long delays are beginning to occur in Dammam city as well. This further leads to increased environmental degradation, potential road accidents, poor public transport services, and a lack of affordable or accessible public facilities. This problem can be addressed by incorporating an AI-powered Traffic Management System with signal systems that focus on collecting and analyzing vast amounts of data, making intelligent predictions, and streamlining traffic flow to enhance road safety in general. The research utilizes Windows software for visual modeling and a fuzzy inference system, comparing the planned application with standard lighting in relation to traffic modeling, microscopic modeling, traffic control, and ITS technologies. The findings demonstrate that incorporating AI-powered traffic management increases efficiency, specifically in utilizing wireless communication technology for accurate data and allocation of clearing times. An adaptive traffic signal control system was also developed, informing passengers and drivers of traffic patterns, with results indicating its efficiency. The chosen model is based on a robust, effective, and accurate advancement focused on signal control performance prediction. Based on the study conclusions, it is appropriate to consider the effectiveness of AI-powered traffic signals for improving transport congestion in Dammam, utilizing the major findings to understand what policymakers may implement in their planning. The study provides a potential framework for Dammam City to adopt, which can be utilized as a tool in the identification of particular autonomous AI-driven traffic signal techniques.

1. INTRODUCTION

1.1 Need of automatic traffic signal systems

The challenge of accommodating the growing number of vehicles in many countries, especially in cities where building new roads is becoming increasingly difficult. To address this issue, the focus is on improving the control of road flow using methods such as traffic lights and similar actuators. Traffic control involves monitoring traffic through sensors, vehicle detection on images, and communication among vehicles. Researchers aim to reduce traffic congestion by proposing various approaches to optimize traffic light control. Early systems utilized fixed-time plans to coordinate a subset of related traffic lights, enabling the generation of "green waves" to improve traffic flow [1-3].

The surge in vehicle numbers over the past five years, especially in DMA has exacerbated urban challenges, such as traffic jams and accidents [4]. Traditional traffic management and the quest for parking contribute to these issues and this leads to congestion, delays, and adverse impacts on the economy, environment, and health [5]. Alwadei [6] reported how pollution is directly related to the traffic in Dammam. The study presented an analysis of hourly air quality data from two stations in Dammam, SA for the period from 2016 to 2019. Hourly, daily and monthly patterns of NO_2, NO, NOx, O_3, CO, SO_2 and PM10 were studied. The monthly patterns showed an increase in the concentration of traffic related pollutants (NO_2, NO and NOx) and SO_2 in the winter, compared to other seasons. CO had its maximum in the winter for Corniche station and in the spring and summer for Rakkah station. The concentration of O_3 showed its maximum in the spring when the temperature is high, and the sky is clear, from photochemical processes in the presence of NOx. PM10 was difficult to study due to the impact of dust storms and the movement of dust from the ground, as the stations are situated in arid locations. The daily pattern of pollutants showed the increase of these elements on the weekdays compared to weekends in Rakkah as a consequence of the influence of human activities. Further, the weekly cycle of traffic-related elements in Corniche had their maximum on Thursday night. This area, as a recreation area, receives more traffic on the weekends compared to other days. In Dammam, people usually like to go outside their homes at night because of the sunlight intensity and high temperatures during the day. Thus, this behaviour is reflected in the level of some pollutants at Corniche station. SO_2 was higher on weekdays than on weekends, indicating the influence of industrial activities on the air quality in Dammam. The hourly pattern showed the impact of heavy vehicles/trucks on the level of NO_2, NO, NOx and CO. These pollutants were higher when heavy trucks were allowed to move inside the city (0800-1200, 1300-1700, 2200-0500). Thus, these pollutants showed their maximum at 0200 and their minimum at 1600. O_3 pattern was almost the inverse of nitrogen dioxide and nitrogen monoxide, suggesting the impact of the NO + O_3 titration reaction. SO_2 had a steady increase from early morning until about 1700, then decreased for a short time and increased again to reach its maximum at midnight. The diurnal pattern of PM10 indicated the influence of rush hours where PM10 was high at 0800 and 2200, affected by the traffic. This analysis shows the impact of traffic on traffic-related pollutant levels in Dammam. In some previous literature, NO_2 and NO were reported to be high in the morning and afternoon during rush hours, while in Dammam, these pollutants were higher in the night when trucks were allowed to be driven inside the city. More works are needed to tackle traffic pollution in Dammam, including improving public transportation to reduce the number of cars, reducing vehicle emissions by introducing lower emission cars and educating the public about some behaviours that reduce vehicle emissions, such as long time idling. Moreover, National Center for Environmental Compliance in SA (NCEC) needs to maintain and improve the quality of stations to provide high-quality data that gives more and accurate measurements [6].

The rise in population and traffic congestion contribute to frequent incidents on roads, one death in every four minutes [7], necessitating smarter, cost-effective solutions [8] to reduce casualties due to traffic [9].

The traffic is managed by the traditional three-color traffic signal. The drawback of this system is that the time is fixed for each route irrespective of the volume of traffic. Efficient traffic signals, utilizing three lights to convey messages, play a crucial role in managing vehicle flow and preventing collisions. These traffic control devices, including indicators and banners, are strategically placed to educate and regulate traffic, addressing the escalating challenges posed by rising vehicle numbers and urbanization.

Saudi Arabia's layout designs and land-use policy have promoted the increase of private car ownership as there are sizable spaces allocated for roads. The high traffic volume of Dammam thus contributes to climate change through emissions of carbon dioxide, methane, and nitrous oxide from the vehicles [10]. The poor air quality leads to approximately seven million deaths each year with various health effects like bronchitis, asthma, heart disease, and brain damage [7, 11]. High road accidents are also an economic and health challenge, costing high annual losses of about 21 billion riyals in Saudi Arabia each year [12]. In the last ten years, there were reports of increased deaths from road accidents from 17.4 to 24 per 100,000 people, especially for males aged from 16 to 30 years in Saudi Arabia annually [13].

The transformation of urban traffic management through Artificial Intelligence (AI) indicates the move towards more sustainable, intelligent, and efficient transportation. AI-driven traffic signal systems focus on collecting and analyzing vast amounts of data, making intelligent predictions, and streamlining the flow of traffic to enhance road safety in general [14]. The traffic systems use different forms of technologies powered by AI, like real-time analytics, advanced sensors, adaptive traffic signal control systems, and automated traffic light systems. As such, there is observation of the traffic patterns, adjustment of the traffic signals, and forecasting of traffic congestion, reducing travel time by improving the flow of traffic [15]. Dammam requires the implementation of an AI-driven traffic system that would alleviate the cases of congestion within the city, which occurs due to the lack of use of public transportation, resulting in an increased number of personal car ownership, an insufficient street network accommodating the higher number of cars, and increased population growth in the urban cities. Research by Almatar [14] found that Dammam experiences increased traffic in the morning and evening during the work weeks, corresponding with daily commuting to work, indicating a congestion pattern, especially in the center of the city, unlike the outskirts of the metropolitan area. Such congestion patterns indicate that the normal traffic signals are not adequate enough to cater to the traffic within the city and thus require the inclusion of AI systems within the traffic signals to predict and forecast the levels of traffic congestion, adjusting the traffic signals to meet the demand and this improves the flow of traffic. The ATS system has a promising potential to improve factors as outlined in Figure 1.

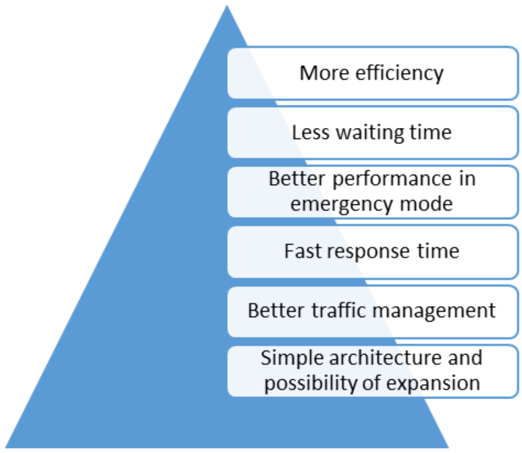

Figure 1. Improvements due to Automatic Traffic Signal (ATS) systems

1.2 Current ATS systems

The system currently in use is managed by traffic signal which consists of three lights, each of which conveys a different message to passing motorists. When there is a red light, the operator is expected to stop; when there is a green light, the motorist is capable of driving through the middle section of the road; and when there is a yellow light, the motorist is warned to either put it on hold when the next beam is red or just to get prepared to go and start the engine on when the next led is green.

A computerized traffic control network consists of four fundamental components: the processor (or pcs), telecommunications equipment, traffic lights and the hardware linked with them, and sensors for detecting cars. The detectors placed along the route are responsible for gathering data on the flow of traffic, which is then sent to the software system for further processing. In most cases, the sensors are either permanently affixed to the highway or hung above it. Frequencies of vehicles and their speeds are commonly encountered, and information on the types of vehicles (such as cars or trucks) may also be gathered. The information on the traffic stream is sent to the processor, which analyses it to establish the right combination for the signals at the junctions [16]. The data needed to sequence the events is sent from the software to the outputs through the communication systems in between. Information is also communicated from the signalized intersections to the software, verifying that the traffic light is operating correctly. This is done to ensure the correct and safe functioning of the system. The most common types of traffic calming devices are raised paving indicators, speed limits, bollards that prevent streets, transform restrictions, and warning signals [17].

Programs that encourage the use of bicycles and pedestrians are frequently included in traffic restriction initiatives. Wider pavements, which may on occasion also include chairs and seating areas, and bike lanes are frequently provided in conjunction with restraint behavior.

1.3 Potential ATS system for Dammam

There are several approaches to traffic signaling that may be implemented. However, to maximize productivity, the administration of the Dammam region has to take several factors into consideration. The most important things to look for are ensuring that maximum efficiency is provided with the assistance of traffic signals without having many constructions on the roadside ensuring that vehicle delays and long queues are minimized, and ensuring that the presence of air and noise pollution is minimized. This automated system minimizes the time cars spend on the road, contributing to effective traffic control. It also helps reduce pollution, accidents, and traffic-related delays to a minimum.

In view of continuously increasing traffic the need for Automatic Traffic Control system is deemed necessary. Furthermore, the upgrade in other premier cities is underway and eventually, the signal system of Dammam would be upgraded. However, since, the traffic volume and behavior of Dammam are different from other cities, a new system would have to be devised after analyzing the lessons learnt from ATS system and technologies used worldwide and especially in Saudi Arabia. This customized solution for Dammam has not been found in literature. Thus, this research synthesizes ATS systems and proposes guidelines for the implementation of ATS system in Dammam Metropolitan Area.

2. IMPACT OF ATS ON TRAFFIC

2.1 Relative advantage/impact of ATS

Traffic signals exert significant influence at junctions, guiding vehicle movements and allocating right of way. They enhance safety and efficiency when used appropriately, reducing the severity of certain crashes, especially those at right angles. However, misuse or unwarranted installation can lead to issues like increased rear-end accidents, signal violations, and traffic redirection. It's crucial to ensure that traffic lights are strategically placed to optimize overall traffic flow while prioritizing safety [18-23]. The constituents of an automatic traffic control system are shown in Figure 2. The city of Pittsburgh, USA, implemented the use of AI-powered traffic signals developed by Surtac, using real-time traffic data in adjusting the traffic signals, resulting in a 26% faster travel time and a 40% reduction in idling time, optimizing traffic flow [24]. The Adaptive Traffic Signal Control (ATSAC) system in Los Angeles also uses AI in monitoring and controlling over 4500 traffic signals, leading to a 16% decrease in fuel consumption and a 12% reduction in travel time [25].

2.2 Methods used to assess the impact of ATSs

Various papers, including the Federal Transit Administration's report, highlight approaches to assess the effectiveness of motorway amenities, particularly automatic traffic signal (ATS) systems. The Federal Highway Administration (FHWA) provides a traffic analysis toolkit for researchers and traffic professionals, enabling a deeper understanding of traffic challenges through various models. Analytical techniques within these toolboxes, including microscopic simulation programs, allow for a seven-step procedure to evaluate if ATS meets expectations. Recent observations stress the importance of field tests to validate ATS formulation and implementation, addressing the complexity arising from numerous traffic simulation models. Conducting such tests becomes crucial for understanding and ensuring desired outcomes in regulating and monitoring traffic with ATS [2, 3, 26-28]. The authors applied the deep Q-network (DQN) framework with transfer planning in the selection of optimal light configurations for traffic intersections and then ran experiments using the SUMO traffic simulator. This approach ensured that there is more scalable and faster learning, reinforcing AI learning for traffic light control. Using a case study approach, the researchers test the Simulation of Urban Mobility in an experimental setup, demonstrating the suitability of RL-TSC in dealing with time variation flows and random patterns of traffic compared to a control scheme of fixed time [3]. The researchers reveal that using various simulation scenarios evaluating the impact of SAS at various levels of congestion and the penetration rates of vehicles. The findings showed that there is employment of sub-optimal solutions like drivability and fuel economy with SAS-equipped vehicles.

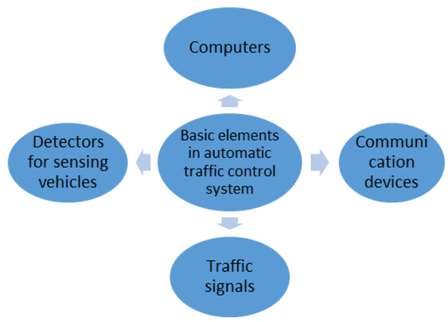

Figure 2. Elements in automatic traffic control system

2.3 Effect of ATS system on traffic parameters

Factors like community growth, increased social prosperity, and accessible repayment plans for buying cars contribute to a rise in motor vehicles and traffic volume throughout the day. This leads to congestion, causing delays, increased fuel consumption, financial losses, and heightened pollution levels, particularly in urban areas. Due to budget constraints, developing a precise and efficient traffic management system becomes challenging for urban management. To address this, there is a need for a quick, cost-effective monitoring system such as "Automatic Traffic Signal Systems". If traffic management is done by Automated traffic system, problems such as congestion, delays, increased fuel consumption, financial losses, and heightened pollution levels, particularly in urban areas can be controlled effectively [29-35].

3. TYPES OF ATSS

3.1 Methods used in the design of ATS systems

In designing traffic control systems, it is essential to consider the design methods and components. This involves the digital simulation approach, focused on satisfying the basic requirements evaluating the traffic patterns, peak hours, traffic volume, number of lanes, lane configurations, intersection layout, and pedestrian crossings [36]. The cycle length is considered according to the expected length of the queue, total delays, and probabilities of entering the intersections [37]. Dammam can develop a suitable system considering its strategic location and urban growth evaluating the challenges of road accidents, traffic congestion, level of environmental pollution, and high-energy consumption while enhancing traffic flow through suitable designs of the traffic signals. The design needs to enhance the traffic flow, reducing wait time and ensuring less congestion.

A framework was proposed that would assess the recordings generated by real-time recording devices to immediately manage traffic [38]. This evaluation would be done so that the framework could determine how best to direct traffic. This might be achieved by allocating a certain amount of time to the flow of traffic, which would be based on the results of counting the volume of traffic, which would reveal the total number of cars. After that, this information would be put to use as a guide for an automated system that would figure out the best time of day for autos to pass at a crossroads.

Yuan et al. [39] developed a fuzzy inference system technology-based visual modeling of windows software for the construction and delivery of an instantaneous traffic lights control system. This was accomplished by using the Windows software. They also did comparisons between the application that was built and those of a typical lighting device, and they determined that the designed one was superior in terms of quality as well as profitability.

The researchers Huang et al. [40] proposed a system that is a combination of inferential loop detectors and probabilistic reasoning [40]. Impedance loop detectors were directly to blame for genuine traffic information, and probabilistic reasoning technology has been liable for the disbursement of peak hours to the vehicles to release off the crossroads in an effective manner. Both of these technologies have been liable for several other issues as well. The outcomes of applying this tactic to the problem of managing the flow of traffic revealed that it was highly effective.

The concept of employing wireless communication technology to gather genuine traffic information at a junction and then distribute the necessary clearing periods to the different lanes of traffic was proposed by Arcos -Garcia et al. [41]. This proposal was first presented in their study. Since this process did not need the installation of any specialized gear in the vehicles that were a part of the operation, it was deemed to be successful. Zhang et al. [42] came up with a new technique that they call the "Adaptive traffic signal control system." This method has made more use of GSM services to accomplish its objectives, which included disseminating information to consumers about the direction of traffic through the use of short message service (SMS) messages. This method has also made greater use of GSM services to accomplish its objectives. In addition, sensors were mounted at crossings so that the right time to clear the interconnection could be determined. The effectiveness of this strategy was shown to be much higher than that of traffic lights that are operated conventionally [26].

3.2 Advantages and disadvantages of modern ATSs

Intelligent transportation platforms assist in identifying congested locations, which, in turn, leads to a decrease in the amount of traffic that is experienced globally. Meaningful analysis and synchronization of wearable sensors are used in this specific endeavor so that it may be completed successfully. The statistics that were entered will be used to assess the volume of traffic, and the traffic signal will flash accordingly. It is feasible, via the use of this technology, to reduce the levels of pollutants and increase the amount of protection against accidents caused by vehicles [38].

It is essential to have traffic signals to facilitate the safe movement of pedestrians and motorists alike. They increase the flow of movement and its efficacy, which ultimately contributes to a reduction in the number of collisions that take place. They provide unambiguous directions for when autos or individuals may reach a junction and when they may just wait before continuing through the crossroads. These instructions are quite specific. Even though having traffic lights is vital for preserving order on the roads and making traveling as easy as possible, there are both advantages and disadvantages to having them.

The usage of a signalized junction unit is one way to achieve both the aim of identifying traffic and the purpose of reducing the amount of traffic at an intersection [43, 44]. This gadget assists in the process of recognizing and managing traffic by collecting data from a variety of other devices and connections to do so. Because of the way it was designed, the system may draw its conclusions and will act on its own to reduce the volume of traffic that the devices have identified [45].

Since the automatic signal systems make it possible for the traffic lights to operate in real-time, the timing of the lights may be more precisely determined. The volume of traffic in an area continually and dynamically controls how the flow of traffic is managed [46] and as a result, accidents occurring on the route has decreased [47], pollution reduced [48] and rear end and head on collision also minimized [49, 50].

Disadvantages associated with traffic signals include unacceptable number of interruptions occurring due to traffic, long wait periods which increase pollution [51]. Long delays may cause frustration which leads to negative outcomes such as disobeying traffic rules [52]. Another disadvantage with traffic signal is the high cost of installing and maintaining traffic signals and ongoing maintenance expenses might differ from one state to the next [53]. When it comes to cutting costs, installing stop signs is a more cost-effective choice [54]. Installation of traffic signal also involves scrutiny and lengthy approval process [55].

3.3 Technologies used in ATSs

Recent research on autonomous cars suggests that the idea of the average IoT may play an important role in the management of traffic congestion. This may be performed by connecting the physical items via the web to send data, analyze and control vehicle traffic, and oversee traffic flow. Other goals that can be fulfilled with this method include: Correct information about roads may be gathered by a variety of approaches, such as worldwide postulating networks, detectors, inquiry vehicles, and vehicular connection, to name a few of these approaches. In several of the most recent car monitoring systems, the detectors, including auditory and electromagnetic sensors have been widely used. They are also cost-effective and efficient in their use of electricity [56].

The data on congestion that has been obtained from a wide variety of viewpoints has the potential to be used in the forecasting as well as the management of traffic congestion [57]. The majority of the solutions currently available give accurate traffic data on urban highways, in particular via the use of sophisticated mobile devices; in contrast, minor routes have gotten relatively little study. In light of this, the research that is being presented here presents a notion for an Internet of Things-based system that may genuinely deliver traffic information by making use of highway signaling systems. The application of the proposed approach is in no way limited by the usage of collector lanes as a prerequisite for implementation [58].

An arrangement of the software architecture has been made, and it has been composed of four strands: (i) a series of sophisticated detectors; (ii) a protocol stack, which reflects the manner of communication and procedures; (iii) a usage pattern, which suggests the market research and stockpiling; and (iv) an application server, which describes the end framework. The perception layer is in charge of gathering information from moving cars by making use of the sensors that have been installed along highways [53]. After that, the real statistics are sent utilizing microcontrollers that are based on WiFi to the protocol stack.

There are many distinct cloud infrastructure IoT systems available, each with the capacity to manage smart devices, provide storage for data that has been gathered, and carry out data processing. In this inquiry, the role of the service layer is performed by Thinger.io, which is an accessible platform for merging data synthesis services. It is part of the Internet of Things. Scorecards and highway message display systems provide the terminal with the most recent information on the state of the traffic. The physical structures, which may include cameras and roadside message displays, are installed at various crossroads along the roads. The message units that are positioned at key intersections of roads act as a substitute for the driver's smart devices and keep drivers up to date simply on the current traffic status [32, 33, 59, 60].

As part of automated traffic monitoring, which is at the foundation of urban planning systems, smart wearable networks are being utilized to analyze the flow of traffic, predict bottlenecks, and control highways in a flexible manner. When this is accomplished correctly, it creates an awareness that enables the use of assets and equipment in a way that is more effective [61]. The Internet of Automobiles, often known as linked vehicles, is a relatively new research arena that enables the creation of a wide variety of possible uses in Smart City applications that are built on Intelligent Transportation Systems (ITS).

It will see widespread use in the deployment of Smart Cities. Therefore, rather than deploying dedicated infrastructure and extremely difficult and pricey manual processes to organize and monitor traffic, why not just use the necessary building frame of intelligent transportation systems even without additional complexity as well as provide higher performance, thereby solving the majority of the issues that were caused by the older system [62].

4. TYPES OF SIGNALS USED IN KSA

4.1 Case studies in Riyadh and Jeddah

The growing concern over a rise in traffic incidents in various cities of Saudi Arabia, prompting authorities to consider strict measures against individuals who change lanes without signaling. The Ministry of Traffic emphasizes the need to implement new traffic rules and obligations in cities like Riyadh and Jeddah. The transformation of Riyadh from a walled town to a metropolis with a significant population increase in the past fifty years and this rapid development has led to challenges such as congested traffic, longer travel times, and heightened safety concerns on highways [63].

Riyadh also follows tradition traffic management system and traffic is managed through traffic signals. Other problems include filled parking lots, corridors packed with traffic and signals don't function correctly.

The Kingdom of Saudi Arabia, and particularly the city of Riyadh, has a serious issue with the number of individuals who are killed or wounded as a result of traffic accidents [64]. The Riyadh Development Authority (ADA) has tasked to conduct a literature review on the execution of the activities of the most recent five-year highway safety policy and provided a new plan comprising action plans for the upcoming period of 2014 to 2019. This technique was carried out with considerable communication and coordination with all of the stakeholders engaged in the process [32, 65]. Based on the case studies of Jeddah and Riyadh, it is notable that the issue of traffic congestion can be solved through the implementation of an AI-powered traffic signal system focused on safety and hygiene measures within the transport system. This can be achieved by including traffic modeling, microscopic modeling, traffic control, and ITS technologies, coming up with feasible developments and strategies that address the traffic concerns and assist in the signal junctions. Moreover, understanding the initiatives taken by the two cities to improve traffic congestion through improved traffic signals can ensure that this study evaluates the integration of AI-powered traffic signals within the city of Dammam. This would align with the improvement of society's well-being and promotion of sustainable cities according to the UN Sustainable Development Goals (SDGs), minimizing pollutants and combating climate change while also preserving life.

5. DISCUSSION ON RESULTS

5.1 Analysis of existing ATS systems

The most common method of regulating access to important intersections is through the installation of a three-color signal at each road junction. A widely employed approach involves a double ribbon system, where specific time intervals are allocated for the main highway (green signal), the transitional phase (yellow light), and the lane closure (red light). Despite being the method with the lowest success rate, this approach is globally prevalent, with exceptions in a few affluent nations [12].

Major cities face a pressing issue with traffic congestion, stemming from factors such as a growing population leading to increased car numbers, overutilization of roads causing deteriorating conditions and more traffic jams. Ineffectiveness of public transit systems, poorly managed roads, driver behavior issues, and outdated signalized intersections contribute to the problem. The consequences include longer waiting times, irregular journey schedules, higher fuel consumption, increased transportation costs, and adverse effects on national profitability. Furthermore, congestion leads to elevated environmental pollution, noise, and vibration levels, impacting public health physically and psychologically, with subsequent repercussions for the ecosystem. Addressing these issues is crucial for sustainable urban development [66].

The existing traffic control method relies on synchronized traffic lights with insufficient green signal durations. To better regulate traffic flow, implementing real-time updating traffic lights at major intersections is proposed. The prevalent technologies for managing traffic flow at road intersections are traffic signal indicators and guidance applications. While navigation apps aid drivers in choosing less congested routes, they lack the capability to directly control traffic flow. In countries like India, the most frequently used signalized intersection type at road intersections is the traffic signal sensor [8].

The current traffic control system lacks adaptability to real-time driving conditions, leading to inefficiencies in transportation. Predetermined signal durations at intersections may cause delays in congested routes or allow unnecessary waiting time on less crowded lanes. This issue is particularly significant in Saudi Arabia and neighboring Gulf states, where rapid urbanization, limited public transport, and increased car ownership contribute to severe traffic congestion. The resulting problems include rising travel costs, environmental pollution, and a high economic toll, with an estimated $8 billion cost projected for traffic congestion in Riyadh. The rapid motorization in Saudi Arabia has also resulted in increased traffic accidents and fatalities. Traditional solutions such as expanding transportation infrastructure show limited effectiveness in relieving congestion, and alternative measures like bike-sharing systems and innovative roundabouts are being explored. Pricing based on congestion levels, travel demand management, anticipatory traffic prediction, and network optimization are identified as potential efficient strategies to mitigate the negative effects of traffic congestion [67-69].

5.2 Suitable systems suggested for Dammam

Traffic congestion is most likely to occur at intersections within urban areas, particularly during peak traffic times, contributing significantly to fatalities and collisions [66]. As essential components of the urban transportation network, intersections are crucial, and ensuring their smooth operation is vital for effective and safe circulation throughout a city. Failing to control traffic flow at intersections can lead to chaos across the city, emphasizing the necessity of advanced traffic control systems. The choice between stop signs and signal lights depends on traffic volume, with the former suitable for low traffic and the latter for significant urban traffic. Signalized traffic management systems, employing either a flow-triggered or fixed control approach, are used based on network flow demand. A flow-triggered system is preferable due to varying traffic levels throughout the week, making predetermined interactive elements less effective [4].

The varying traffic conditions necessitate the use of different methods to activate traffic lights at intersections. Multiple transportation performance metrics, also known as performance measures (MOEs), facilitate the evaluation of the organizational effectiveness of signalized intersections. Examples of frequently used MOEs for assessing pedestrian crossing service levels include vehicular postponements, halts, journey time, bandwidth, vehicular capabilities, waiting times, average gas mileage, and total automobile exhaust (e.g., CO, NOx, HC). Other commonly used measures for operational effectiveness include queue lengths, travel times, bandwidth limitations, parking issues, and travel times. Numerous recent studies have focused on enhancing these MOEs at both the junction and infrastructure levels [70].

The methods employed for managing traffic lights at signalized intersections play a crucial role in determining the overall quality of operating conditions. Historical research has primarily focused on optimizing message time length, convergence phasing series, and compensation to improve various performance measures such as vehicle delay, travel duration, number of stops, buffer size, gas mileage, and air pollution. Previous efforts centered on minimizing time spent waiting at intersections. Early recommendations used analytical and statistical likelihood-based approaches, but their reliability in situations of varying traffic density was questionable. Adaptive traffic management systems, utilizing advancements in information and communication technologies like 5G and IoT, have been proposed as solutions to unpredictable and congested traffic flow. These systems, employing heuristic and modeling-based methods, are considered more effective, robust, and accurate in addressing the non-linear and diverse properties of traffic flow at signalized intersections. However, heuristic-based research in this area often focused on single or bi-objective methods rather than simultaneously addressing multiple purposes [62].

5.3 Potential challenges in the implementation of ATS

Implementing automatic traffic signal systems in a large city presents multifaceted challenges. The biggest challenge is to cross financial hurdles. due to high initial costs. Ensuring compatibility with existing infrastructure demands substantial upgrades or replacements. Integrating diverse data sources, such as sensors and cameras, necessitates sophisticated management systems. Regulatory hurdles must be cleared, alongside educating the public about system benefits. Cybersecurity risks mandate robust protective measures. Coordinating traffic management efforts across departments is crucial. Sustained maintenance is vital to system longevity, demanding dedicated resources and personnel. Addressing these challenges (Figure 3) effectively is essential for successful implementation and operation.

Once the financial and regulatory approvals are obtained, pilot study should be performed. This involves deploying the technology on a smaller scale in a specific area or route within the city to assess its feasibility, effectiveness, and impacts. The pilot study allows city officials and engineers to observe how the system performs in real-world conditions, identify any potential challenges or issues, and gather feedback from stakeholders, including residents, commuters, and businesses.

It provides valuable insights into the practicalities of implementing the technology on a larger scale and helps refine strategies and approaches for broader deployment.

Concurrently, conducting research is crucial to gather data, analyze trends, and assess the potential benefits and drawbacks of automatic traffic signal systems. This research may involve studying existing traditional traffic systems and comparing the advantages with the pilot implementation. The main objective is to study the new system and improve its efficacy in terms of congestion hotspots, accident data, and environmental impacts. The concurrent research helps better decision-making, develop evidence-based strategies, and establish benchmarks for evaluating the effectiveness of the technology.

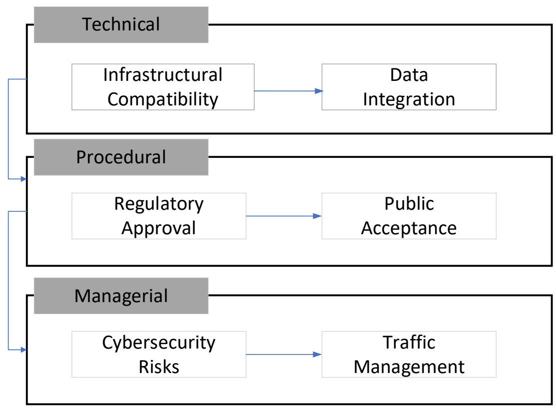

Figure 3. Challenges in the implementation of new ATS system

6. CONCLUSION

6.1 The need for ATS in Dammam

Urban businesses confront the challenging responsibility of controlling and minimizing the impacts of congestion, a problem worsened by the increasing number of vehicles within metropolitan networks. This surge in traffic has resulted in congestion at intersections and long lines of waiting cars, especially during peak periods. The resulting economic, environmental, and health impacts underscore the need for effective solutions. The expansion in population exacerbates problems with traffic lights, leading to frequent accidents and increased time spent in traffic. To address these challenges, new approaches must be developed, balancing efficiency, cost-effectiveness, and intelligence. Traditional traffic control systems are primarily based on pre-programmed, reactive, and local techniques, and are thus not very effective. In contrast, an autonomic system that uses automated planning techniques is easily configurable and modifiable, capable of reasoning about the future implications of actions that change the default traffic light behavior. An Automatic signal system/Automatic traffic signal system in big cities for managing traffic is a better solution for traffic chaos. By using Automated traffic system, congestion, long delays and pollution can be minimized.

6.2 Technologies used

To rapidly control traffic, a system has been suggested that evaluates recordings made by real-time recording devices. The purpose of this analysis is to inform the framework's decision on the most efficient flow of traffic. Counting the volume of traffic may show the total number of automobiles, thus using that information to allocate a set period to the flow of traffic might be one way to accomplish this goal. After that, the data would be used to feed an automated system that calculates the ideal timing for vehicles to pass at a certain intersection. It was also observed that windows software based on visual modeling and a fuzzy inference system was designed to build and instantly deploy a traffic light management system.

Microsoft Windows was used to complete this task. They also compared the planned application to that of a standard lighting device and found that it was both more effective and more profitable. An inferential loop detector and probabilistic reasoning system were suggested by Huang et al. [40]. The distribution of peak hours to cars for an efficient release from the intersections is attributable to probabilistic reasoning technology, which in turn may be directly attributed to the use of impedance loop detectors for accurate traffic data. Both of these technological developments have also been responsible for additional problems.

Based on the study conclusions, it would be adequate to consider the effectiveness of AI-powered traffic signals for improvement of transport congestion in Dammam, utilizing the major findings to understand what policymakers should implement and establish in their planning. Future research will focus on incorporating studies on government activities to implement smart city projects like traffic signals in the city, evaluating the urban landscape and how it can benefit.

Results from using this strategy to the issue of traffic management showed that it was quite efficient. It was planned to use wireless communication technology to collect accurate traffic data at a junction and then allocate the required clearing times among the various lanes of traffic. Their research is where the idea was originally put forth. Vehicles used in the operation did not need to be outfitted with any specialist equipment for this procedure to be a success, so that was another plus. A novel method, the "Adaptive traffic signal control system," was also seen to be developed. This approach relies more on GSM services to carry out its goals, such as informing drivers and passengers about traffic patterns through SMS. Additionally, this approach has made more extensive use of GSM services to achieve its aims. Additionally, sensors were installed at intersections to detect whether it was safe to proceed after clearing the connection. Results showed that the efficiency of this method was much greater than that of traditionally controlled traffic signals.

6.3 The best methods suggested for DMA

The traffic highlights the urgent issue of major city traffic congestion and identifies various factors contributing to the problem. The increasing population and the corresponding rise in the number of vehicles are cited as primary causes of road congestion. Poorly planned roadways, inefficient public transportation, errant drivers, and outdated signalized junctions further exacerbate the situation. The consequences of traffic congestion include wasted fuel, unpredictable travel times, increased gas expenses, and a negative impact on the nation's economic output. The adverse effects extend to public health and the environment. The current traffic light system is criticized for its inefficiency, with signals not timed optimally, leading to longer waiting times. Real-time traffic updates are suggested as a solution to regulate vehicle movement, and technologies like traffic signal indications and guidance apps are mentioned. In countries like India, traffic signal sensors are commonly used, but they often result in inefficient transportation networks. The paper emphasizes the need for the development of an AI-based autonomous and real-time system for better road transport management that also collects real-time data to train its AI model to further adapt to the increasing traffic and changing traffic behavior, aiming to mitigate the negative consequences of congestion and fulfill the sustainability objectives of Vision 2030 of Saudi Arabia and contribute to meet UNO's SDGs.

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