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Smart Reversible Lanes in Dubai

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SMART REVERSIBLE LANES IN DUBAI

By

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Abstract:

There is no doubt that transportation is one of the most important elements in any city and its development. However, traffic congestion is hurdle to any transportation system and especially in top cities like Dubai. Traffic congestions have many reasons like traveling from suburban to the city center for work and study, and relaying mostly on private vehicles. The impacts of traffic congestions reach beyond the increase in travel time, it also increase gas consumption, and affect people's health negatively.

One of the most practical ways to ease traffic congestion is using Reversible lanes (RL) which are lanes that can change travel direction based on the traffic congestion and increase road capacity in different times of the day. RL proved its effectiveness to ease traffic congestion in many cases around the world.

RL was applied on Alittihad road that witnesses a heavy traffic congestion in rush hours in different times of the day. RL was applied starting from Mulla Plaza intersection and for 2 km. After collecting data and doing the calculations, the results came that applying RL will reduce traffic congestion and traffic volume, as a result, the travel time will reduce and driving speed will increase.

Smart application were introduced to RL in this paper to increase the efficiency of the solution and to have advantages such as predicting the traffic jams ahead and control the RL system accordingly. In addition to sending and receiving signal from autonomous vehicles that will be used more in the future and might replace the private vehicles.

Acknowledgement:

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Secondly, I would like to thank my husband, my mother and father, and my family, for supporting me in this whole journey, and helping me whenever I needed it.

By their help, I was able to put this project together, from a simple idea that once crossed my mind, to a real project that I believe it can help my country grow and develop.

Chapter 1:

Introduction

Transportation plays a fundamental role in our lives, affecting both the industry and the economy growth. However, the growth in transportation sector comes with cost as well, transportation sector include infrastructure, land use, factories, and vehicles. The impact on the environment is the most critical, in which transportation is responsible of generating 25% to 30% of the world greenhouse emissions [1].

Traffic congestion is another disadvantage that comes with transportation, which increase its drawbacks. There are many potential interconnected causes for traffic congestion, such as travel behavior that include time, route, mode of travel, etc., which is affected by other factors like economy and land use patterns. [2]

Traffic congestion can increase the level of fuel consumption, increase environmental impact of greenhouse emissions, increase noise pollution, lead to health problems and negatively affect quality of life, in addition to losses in time and money.

Dubai, based on World's Best Cities 2020 Report, ranked 6^{th} in 2019, comparing with 2018 that ranked 9^{th} [3]. And despite being one of the world top cities and destinations, wide highways and good infrastructure, Dubai struggle with traffic congestion, which is mostly due to people's travel behavior. The travel behavior characteristics of people that drive in Dubai is unique, people tend to relay mostly on private vehicles to commute from one point to another that comes as a result of many reasons, the foremost is culture and extreme weather condition. In addition, and based on Dubai Statistics Center the number of permanent residents in Dubai is 3,192,275 people, however, additional 1,190,000 people commute every day from other emirates to Dubai for working purposes. The last number increased by 80,000 comparing with 2016 [4]. I believe that this number will increase dramatically in 2020 due to Expo 2020 that Dubai will host.

People travel behavior cause a road condition called Tidal Flow, the term "Tidal Flow" is used to describe uneven directional traffic flow that is due to people traveling in the morning from suburban areas to the city for work, schools, etc., however, the direction of

traffic flow is reversed in the evening, when people head back to their homes. Tidal Flow causes traffic congestions that are hard to mitigate because of people travel behavior described above that is almost impossible to change. There are many ways that is used to ease traffic congestion, however, in this paper, I will explore the ability of using Reversible lanes in Dubai.

One of the most practical and efficient way to ease traffic congestion caused by Tidal Flow or uneven directional traffic flow is to use Reversible lanes (RL). Reversible Lanes (RL) are "One or more lanes are designated for movement one-way during part of the day and in the opposite direction during another part of the day" [5]. There are other terminology that is associated with reversible lane operation that are similar or describe the same methodology, such as convertible lanes, managed lanes, contraflow operation, and tidal flow in which it can be used to describe the rush-hour road condition and describe the method or reversing the lanes.

This method can be used in many situations that causes traffic congestion in one way of the road, like rush hours, accidents, bottleneck areas, big events and occasions, and for processions.

The biggest advantage of RL is utilizing and increasing the capacity of the available roads in the most efficient way and with minimal cost. In addition, RL can be used on roads that cannot be expanded, due to economic or geographic limitation, especially in bridges and tunnels.

Chapter 2:

Goals and outcomes

The goals and outcomes of this paper is to introduce the idea of applying reversible lanes in the roads of Dubai. Although Reversible Lanes operates around the globe, the idea is still considered new in the context of Dubai and never been used despite the instant benefit and low cost of implementation.

The second part is to explore the feasibility of implementing RL in one road section in Dubai, and that will be determined after studying RL and road characteristics, and consulting some experts in the field, the method will be by using calculation of traffic volume over road capacity.

The third goal of this paper is to introduce smart application to RL in the using it as the main control system to the RL and in intention of increasing the efficiency of RL and optimize it.

Chapter 3:

Literature Review

Reversible lane in Beijing – China

Beijing is the capital of China, and the center of its culture and politics. It is located on the north side of China, with a population of 20,462,610 according to 2010 census [6]. It one of the most important cities in China, not only because it is the capital, but also because the historical events that the city hold. Beijing is the second largest city in terms of GDP, and the hub of the most and largest headquarters of China's state-owned companies. In addition, the two top education institutes in China are located in the city, which is Peking University and Tsinghua University.

Beijing aims to be a "world-class harmonious and livable city" by 2035, which was published in Beijing Overall Urban Planning (2016-2035) that was released by Beijing Municipal Authorities. [7]

Figure 1: *Beijing City Profile [9]*

Chaoyang District is one of the important development areas in Beijing, and home of around 120 headquarters of multinational companies, which form 70% of the capital total number. [8]

Chaoyang road is one of the important roads in Beijing; it is the main radial line in the eastern part of the city [10]. Chaoyang road is a two-way with 8 lanes, with 4 lanes inbound and 4 lanes outbound. A reversible lane was implemented in the road to solve the tidal flow situation; the total length of the reversible lane is 2.3 km. The speed of the road is 60 km/h and the theory road capacity is 1730 pcu/h. The results of implementing RL in Chaoyang road was positive, "It is thus obvious to improve the possible road capacity of the out the city by 25.3%, increase the average travel speed by 7.50%, reduce the average unit vehicle delay by 15.25% , and improve the traffic condition in road network conspicuously" [10].

I-70 Reversible Lane Georgetown to Floyd Hill

This paper is a feasibility study on applying RL on the road of 70 (I-70) between the Eisenhower Johnson Memorial Tunnel (EJMT) and Denver in Colorado, United States. The road have traffic volume increase by 1.5% to 1.8% every year, and a typical Tidal Flow congestion in certain times of the day and due to several reasons such as high traffic flow from other entrances to the road, slow-moving vehicles, tourist heading to tourists

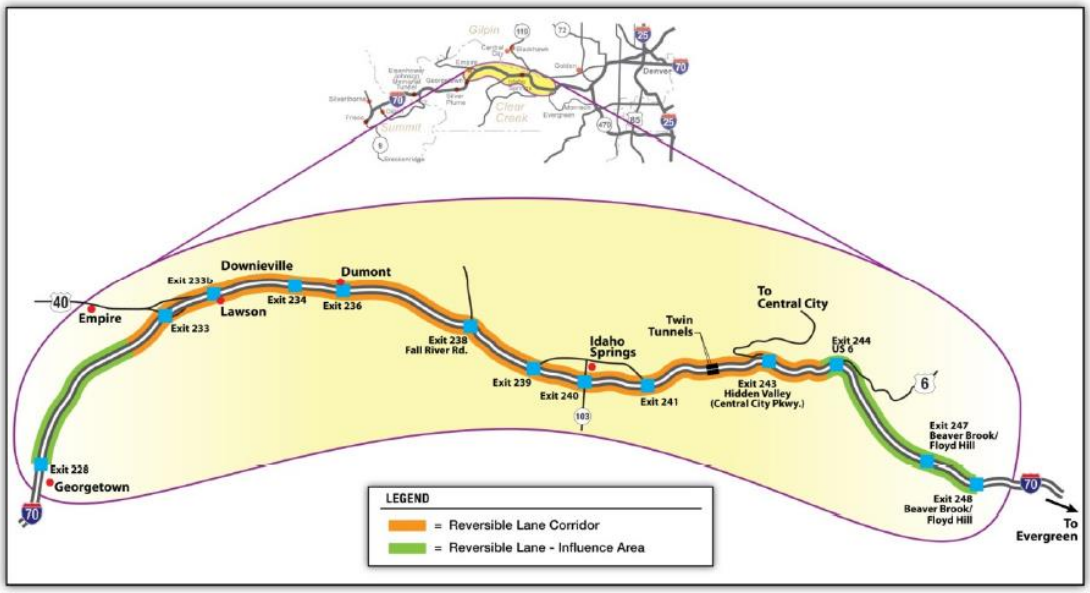

Figure 2: *Reversible Lane Study Area [11]*

attractions, and narrow shoulders and tight curves of the road. It is expected for traffic volume to increase 10% in 5 years.

This road condition leaded to several other consequences, it increase the travel time to 79 minutes, which is double the time needed without traffic congestion. In addition to causing traffic accidents and delaying emergency services.

Due to the above reasons, Colorado Department of Transportation (CDOT) is studying the feasibility of applying RL to overcome the challenge of traffic congestion on the road. The study mentioned reasons behind considering RL as a solution to resolve the problem such as it was successful solution in many other roads that experienced the same road condition, and the desire of immediate traffic congestion relief.

CDOT determined the location of RL to be 13 miles long that will begin west of Empire Junction and end east of the Hidden Valley interchange.

The expected results of implementing RL on the traffic volume that it will push the 10% threshold in 5 years to be in 5 to 10 years. The saving time of drivers will decrease by 38 minutes, which represent 13% improvement on the current total-person travel time. [11]The road consist of 4 lanes, 2 on each site, the operation of RL will be by moving the center barrier to leave three lanes on one side and 1 lane on the other, using movable concrete barriers or transfer machine. The transfer machine is used to move concrete barrier and travel by 10-20 miles per hour, this mean that it takes 3 hours to complete moving all barriers along the 13 miles on speed on 10 mph.

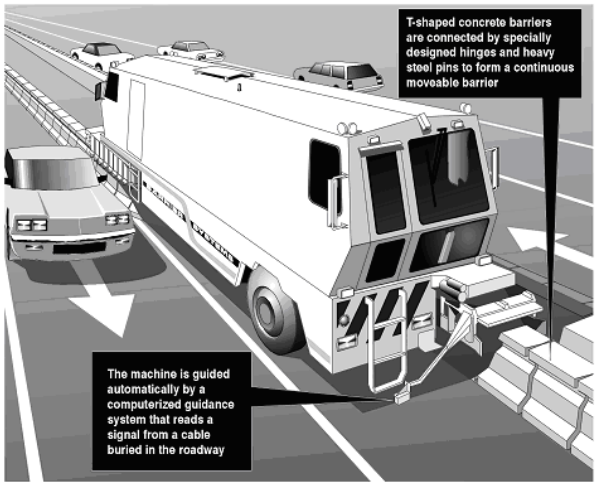

Figure 3: *Moveable Barrier Technology - Freeway Management and Operations Handbook [23]*

Effects of reversible lane implementation, a case study simulation

The paper goal is to design RL and evaluate it using simulation on a program called Synchro. The study started by establishing the road artery that was in Sibui city, home of

147245 inhabitants, and have 21 districts. The selected road was one of the main artries that feeds an important industrial area in Sibui.

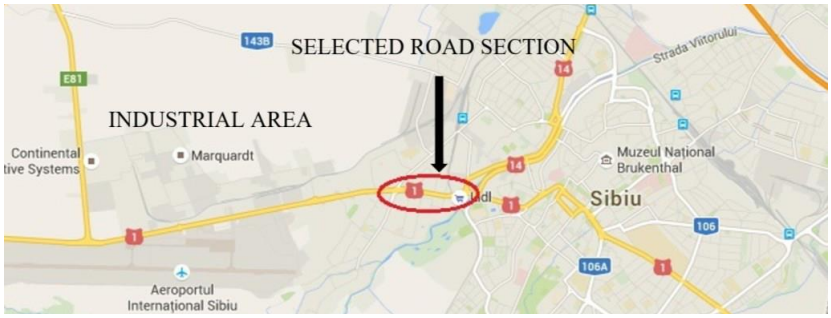

Figure 4: *Selected road artery. [12]*

The second part was collecting data from the selected road, the data collected showed that the traffic congestions starts at 16:30 to 18:00 that is when employee from the industrial area head home. In addition, the data included the number of vehicles entering the intersection from each arm and the type of vehicles entering the intersection. The results where analyzed and computed to measure delay and the corresponding level of service (LOS), which was very low. The data were used generating simulation of applying RL to the road.

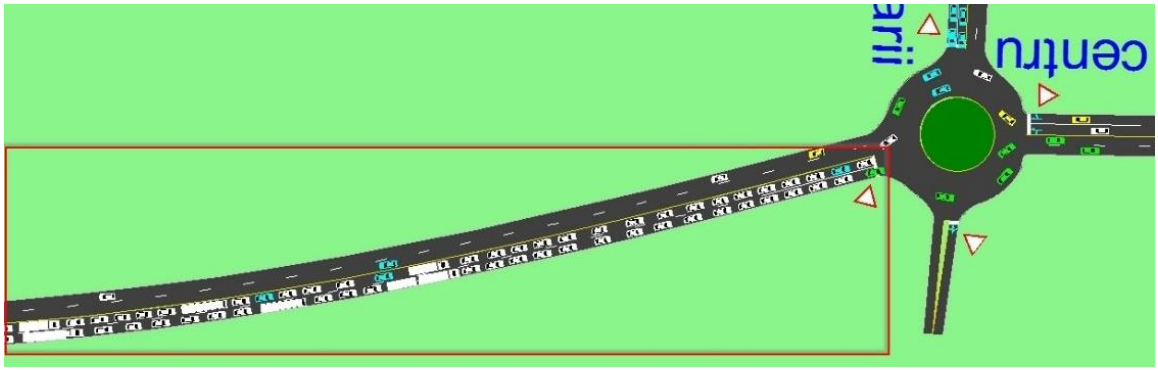

Figure 5: *Simulation of the real traffic situation and validation of the model [12]*

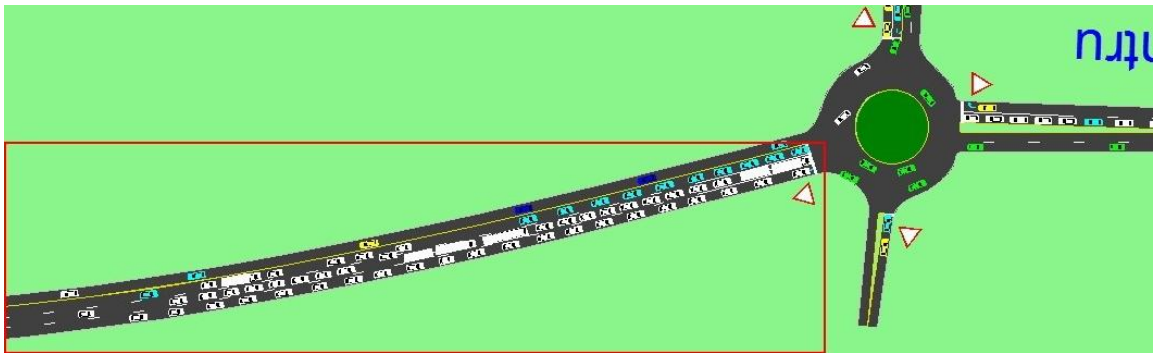

***Figure 6**: Simulation of the proposed solution [12]*

After conducting the simulation on Synchro, the results were not satisfactory and the first solution attempt will be rejected because it showed that LOS was improved in one of the area, however, the LOS also decreased in another area. The paper suggest that using RL can be successful in the area with more reconfiguring of the geometry of the intersection to transform it into feasible solution. [12]

Chapter 4:

Methodology

In order to explore the ability of implementing RL on roads of Dubai, I will start by choosing a road section with tidal traffic characteristics. The first characteristic is unbalanced traffic flow in a two ways road, in which one-way experience high traffic flow while the opposite way have a minor traffic flow. The second characteristic is that traffic flow decrease and change through the time of day, however, this traffic flow change is constantly regular and periodic, with at least 25 percent decrease of the operating speed during congested hours [13]. Third is that the road have limited land space for expansion or economically it is not applicable to expand the roads.

To implement RL successfully in any road section, there are some traffic requirements that we need to consider and measure to assess the feasibility of implementing RL. The most important parameter is measuring the traffic volume quantity and distribution [13]; the ration of directional traffic volume will determine the number of lanes and the length. American Association of State Highway and Transportation Officials (AASHTO) suggest 65 percent or more traffic volume in one direction during peak hours indicate the need of implementing RL [14]. While the Manual on Uniform Traffic Control Devices (MUTCD) suggested the range from 66 to 75 percent of traffic volume justify the same [15]. The cost and complexity of the traffic control, the agency that is responsible in implementing and controlling RL, the purpose and goal behind the project, and the functional type of the road, are all factors that can determine and influence the overall planning.

Control and enforcement is another important factor that we need to take into consideration for applying RL, it is used to communicate information to the drivers and to indicate which road to use. There are many control methods used around the world in which it varies from one country to another. However, Manual on Uniform Traffic Control Devices (MUTCD) included number of controls like pavement marking, signs, and signals. The number and type of method used can be determined by the road function and speed limit. Similarly, the method of adding physical barrier depend on the road

function and speed limit, physical barrier can be cones, concrete barriers, or even robotics.

Policies and guidance need to be generated and published to control the design and implementation on RL, enhance the effectiveness of RL and insure the safety of all stakeholders. These policies should include things like design regulation for every road type, the methodology of using the lanes of how and when to use it, types of vehicle allowed to use RL, types of signals and enforcement used, and other regulation.

No regulations should compromise the right of pedestrians on the road or parking areas in front of shops, if using parking areas is necessary, parking hours should be included on the policy.

Applying Reversible lane on Al Ittihad Road:

After commuting in different highways and roads in Dubai in the peak hours, I chose to apply RL method to a road section on Al Ittihad Road. This section experience high traffic congestion in three peak hours, morning, noon, and evening. There are several reasons for the traffic congestion in this area, first is the limitation in expanding the roads due to land use limitations. Second is that Al Ittihad road is one of the main highways used by people that live outside Dubai and commute daily for work and study purposes, which is estimated to be above 1 million people [4]. Third is that it leads to Shaikh Zayed Road that is a vibrant economical and commercial location with several malls, many retail shops, and center of many big companies. These reasons makes it a good location to apply RL.

Figure 7: *The location of applying RL on the map – Reference GoogleMaps*

The below pictures show the traffic congestion in that area:

Figure 8: *Al Ittihad Road [16]*

Figure 9: *Ittihad Road [17]*

I determined the area where I will apply RL, it will start from after Mulla Plaza intersection and it will be 2 km long.

After my meeting with some expert in the RTA, I found this information:

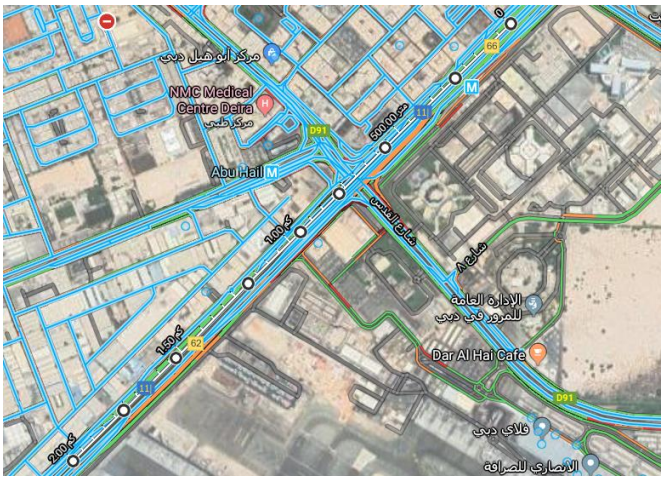

Figure 10: *Length of proposed reversible lane – Reference: Googlemaps*

- The number of vehicle entering through Al Ittihad road from Sharjah to Dubai is around 100,000 vehicles that is the average daily traffic (ADT) in a regular average day.
- The morning peak hour is from 7am to 8 am.
- The morning and evening peak hour each makes 12% of the average daily traffic.
- This mean that 12% of 100,000 is 12,000 vehicles per hour use the road, divide this by the number of lanes 12,000 / 6 = 2000 vehicle per hour per lane.
- The theory road capacity is 1800 vehicle per hour, which mean that the road take more than its capacity and result traffic congestions.
- Traffic volume can be calculated by dividing volume over capacity, based on Traffic Data Computation Method report, “V/C ratio is an indicator of quality of traffic operations on a segment. It also indicates how close a roadway is operating to its capacity. V/C ratios are used to perform capacity and LOS, intersection, or geographic boundary analyses. … For LOS analysis, HCM uses the v/c ratio as a main indicator. As the v/c ratio get close to 1, traffic operations in and upstream of the segment are negatively affected” [18], in this case, by dividing 2000/1800 the number exceed 1, which justify the traffic congestion in that area.

After applying reversible lanes and open two lanes from the minor flow lane to the major flow lane the calculations will be as following:

- 12,000 vehicle per hour / 8 lanes = 1500
- 1500 / 1800 = 0.83 traffic volume

If we opened 3 lanes instead of 2:

- 12,000 vehicle per hour / 9 lanes = 1333
- 1333 / 1800 = 0.74 traffic volume

The same calculations applies for the evening rush hour, with a slight deference which is the number of vehicles is less, and that is 95,000 thousand.

- 95,000 vehicles / 12% = 11,400 vehicle per hour in the evening rush hour.
- 11,400 / 6 lanes = 1900 vehicle per hour for each lane
- Traffic volume is 1900 / 1800 = 1.05
- After applying RL with 2 lanes extra: 11,400 / 8 lanes = 1425 vehicle per hour each lane.
- Traffic volume in this case will be: 1629 / 1800 = 0.79

If we opened 3 lanes:

- 11,400 vehicle per hour / 9 lanes = 1267
- 1267 / 1800 = 0.70 traffic volume

From the above results, we can clearly see that applying RL into this intersection will allow more capacity to the vehicle entering Dubai form Al Ittihad road, and therefor ease the traffic congestion.

The table below summarize the results:

Table 1: *Traffic volume results*

	Morning Rush hour (7:00am – 8:00am) south west	Evening Rush hour (7:00pm – 8:00pm) north east
Traffic volume (before RL)	1.1	1.05

Traffic volume (after RL – 2 extra lanes)	0.83	0.79
Traffic volume (after RL – 3 extra lanes)	0.74	0.70

Suggested signals and enforcement:

To indicate the drivers of road condition, there are number of methods that needs to be considered:

1. Road pavement that indicate the beginning and end of the reversible lane.
2. Overhead signals that show the status of the lane and the travel direction.
3. Barrier transfer machine that moves concrete barriers.
4. Road LED signals that can indicate the travel direction based on its color.

Additional work:

Applying RL on Al Ittihad road requires some additional construction work such as removing the isolation belt on the road, and removing the lights from the middle of the road (if available) to relocate them to the side of the road.

Smart applications to control RL system:

ITS or Intelligent Transportation Systems are advanced technology that support the transportation and increase the level of safety, mobility, and increase the efficiency. Over the past decade, ITS developed many technologies such as smart signs, smart controls, smart cameras, and many other technologies.

In this section, I will list some of ITS technologies and tools that will be used to control RL and increase its efficiency.

Big Data:

One of the best tools that can be used to optimize RL is using Big Data technology. Big Data is “To qualify datasets too large to be contained or processed using the resources of a typical personal computer or the analytical capacity of commonly used spreadsheet applications” [19]. The importance of big data comes from its ability to “provides insights we could not discover by analyzing data on smaller scale” [20]. In different words, Big Data show patterns in our lives that we could not notice and discover problems and present it in a simple way to resolve.

Similarly, in transportation, if we manage to gather and combine different sets of data, potentially, we will be able to spot patterns and problems in our transportation and resolve it. This can be applied in RL, by gathering information about our travel behavior, roads capacity, and traffic information, we will be able to know exactly when and how to implement reversible lanes.

Internet of Things (IoT):

Another technology of ITS that can be used in RL is the Internet of Things (IoT), the IoT “is when entire systems of physical goods and household objects become connected and can be monitored and adjusted in real time” [21]. With the emerging of 5G or the fifth generation of the internet network, IoT applications became possible and real. In Transportation, IoT can be used in autonomous vehicles by using sensors that can communicate within the vehicle itself, and with the vehicles around it. Autonomous vehicles will be able to drive in a constant way and speed that will eventually ease the traffic congestions. In addition, vehicles can read RL signs and use the lanes based on the information received from the signs.

Robotics:

Robotics are also one of the smart application that are currently used in controlling RL. Robotics are used as moving barriers, by reading directly from the road information using IoT, which will significantly decrease the implementation time of moving the barriers.

Figure 11: *The automated guardrail system used in Shenzhen. [24]*

This method is currently used in Shennan road in China, calling it the "lane robot", based on Wang Le, Traffic Police head office, the new "lane robot" decreased the morning rush-hour that used to finish at 10 am, and decrease it to finished at 9 am. [22]

Proposed scenario of Smart Reversible Lanes:

This scenario is a combination of multiple ITS that will be used to control and enforce RL like IoT, Big Data, and Robotics, which will aid to take RL to new level in which the technology will create a harmony between vehicle, road condition, and RL that will deliver a seamless journey.

The scenario will start by collecting information that will not only be limited to traffic information, data will include road condition, number of vehicle entering the city and using the lane, accidents, events that will take place in the city, and even weather as it play a big role in traffic congestion if it was raining or foggy. Taking variety of data in the system enable us to control RL in the most optimized way and come up with better results and solutions. This information will be analyzed by Big Data systems, and based on the analysis we will determine how to control the reversible lanes. Using IoT, all devices including RL signals, robots barriers and autonomous vehicles will be able to receive, read this information, and move accordingly.

Using this scenario in RL will enhance the efficiency of the method and will help deliver better results by predicting traffic congestions, easing it, and reduce travel time.

Chapter 5:

Conclusion

This review of the traffic management used in RL to add capacity to highly unbalanced congested roads during rush hours especially roads with expanding limitation, showed a success in many places around the world, with high level of people acceptance and low implementation cost and safety impacts. In fact, some studies showed an improvement in accidents rates after implementing RL [13]. The advantages of using RL was the result of all the papers that I discussed in the literature review section, which was studied and implemented each in different ways, whether as real life implementation, calculations, or simulation. The results emphasize the importance and usefulness of the method.

Taking advantage of the road by taking extra capacity from the minor flow way and add it to the major flow way not only improved the utilization of the roads, it increases people happiness by allowing them reach their destination faster, improves their lifestyle and health, and decrease gas consumption wasted in traffic jams. The benefits also reach the economic and business sector, especially deliveries and cutting costs on constructing additional lanes. This was proved in this paper after applying RL to a particular section of Al Ittihad Road in Dubai, which is consider a main highway used by people who live outside Dubai to commute for work and studying purposes. After applying RL on Al Ittihad Road, it was found that the traffic volume is very high and cause traffic congestion, but with RL, the traffic volume reduced and eased the traffic congestions.

In addition to RL, I introduced applying smart technologies to increase the efficiency of the method. The whole scenario of smart RL include using several new smart technologies such as Big Data, Autonomous vehicles, IoT, and Robotics.

Smart applications are still under development and we are still not able to benefit from them due to many reasons related to security issues, however, once these technologies are fully reliable, it will be used intensively in transportation systems and in RL systems to increase the effectiveness of implementing and controlling it.

Cities should be more open to use unconventional solutions such as RL to mitigate traffic congestions, and put more effort and funding in studying it instead of pumping millions on road expansion. Roads will always get more congested over the time with the grow of traffic volume due to several reasons, such as the absence of regulations controlling the ownership of private cars, lack of public awareness and willingness to use public transportation, and underutilization of available resources.

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