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Autonomous vehicles will spur moving budget from railroads to roads

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Received 20 December 2022
Revised 17 April 2023
Accepted 23 June 2023

Abstract

Purpose – Nowadays, transportation authorities in various countries are in tension as to whether to invest in railroads or roads. There are arguments for each side, and in the end, each transportation authority reaches a kind of balance between the investments. This study aims to anticipate how autonomous vehicles will influence this decision.

Design/methodology/approach – The roads' capacity in the era of autonomous vehicles is assessed and research has concluded that the anticipated increase in road capacity will encourage transportation authorities to invest much more in roads than in railroads.

Findings – The appearance of the autonomous vehicles will significantly change the balance in favor of the roads, because the roads' capacity will be increased substantially so the roads will be able to accommodate many more vehicles.

Research limitations/implications – Currently, autonomous vehicles are still very rare.

Practical implications – The impact of autonomous vehicles on the decision whether to build more roads is explained.

Originality/value – The study explained why the transportation authorities in the various countries will be more inclined to switch to road construction and why the transition to more roads and fewer railroads will likely be done gradually as more autonomous vehicles enter service.

Keywords Saturation flow rate, Congestions, Autonomous vehicles, HOV lanes, Double-decker road

Paper type Viewpoint

Introduction

Even though in many places in the world, car users experience extensive traffic congestion, it is usually difficult to gain support for increasing road capacity. Many transportation authorities advocate using rail systems or alternatively living near the job, so people will be able to use bicycles or even walk to their job. In spite of this, self-powered green intelligent highways have been emerging recently (Minea and Dumitrescu, 2022) and these green highways will make the roads more sustainable and environment friendly (Brice, 2018). Moreover, in several cases, highways have a significant role in promoting regional green technological innovation (Hu *et al.*, 2022).

Analysis of several experimental roads shows that even quite plain and simple adjustments in roads' pavement design such as using recycled materials can bring about various substantial environmental and eco-friendly improvements resulting in much more sustainable construction (Lee *et al.*, 2013). In addition, novel thermoelectric and piezoelectric energy-harvesting systems can make use of the huge thermal energy of moving vehicles to generate electricity instead of generating electricity by burning carbon Lallmamode and Al-Obaidi (2021).

Yet, many transportation authorities accept as true that it does not make a difference how much road capacity is added, and this additional capacity will be quickly refilled to congested levels. Other transportation authorities like The Austrian Transportation Ministry believes that there is no reasonable area left to expand current highways without heavy negative effects on their environment (France 24, 2021). In addition, even though many of the new highways are designed with more concern for esthetic issues, some people believe the highways harm many sights and views (Khan *et al.*, 2004).

International Journal of Intelligent Unmanned Systems

2049-6427
DOI 10.1108/IJIUS-12-2022-0142

All of these concerns are genuine and legitimate; however, if France, which is a country with one of the most developed rail systems, is examined, it can be seen that the rail system cannot be a comprehensive solution for mobility. The percent of the total passenger transportation in France is only 9% after one of the most massive investments in rail systems in the history of transportation (US Embassy in France, 2018). Moreover, it has been claimed that coronavirus disease 2019 (COVID-19) along with autonomous vehicles may put an end to rail systems in isolated territories (Wiseman, 2021a).

In some other countries, there is a smaller demand for transportation and less capital to invest in transportation infrastructure; thus, they can invest in only one kind of infrastructure. As a result, they will often select the roads that can provide a more wide-ranging solution (Wiseman, 2022).

Therefore, roads are essential and loss of mobility because of not providing enough highway capacity is harmful. The ability of moving ourselves and transferring merchandise quickly from one place to another substantially influences our quality of life and our opportunities. Efficient and effective highway network enables many more options of education, various jobs, numerous shopping possibilities and leisure activities. Employers can select their employees from a wider list and stores can choose from a wider catalog where to buy their goods. Also, people who need a professional service like a plumber or electrician will have a wider range of potential service providers.

In regions with a high-quality road network, residents' quality of life and the businesses thrive and prosper, whereas residents' quality of life in regions with a poor road network is at a low level and businesses have been having a hard time surviving. Therefore, increasing road capacity is significant and important (Samuel and PooleRobert, 2006).

Induced demand

There is a known debate over the expansion of road infrastructure and about "Induced demand." Induced demand is a controversial term arguing that every new road will be quickly filled up with new traffic, i.e. there will always be a flood of new drivers that will use the new road as soon as the new road is open, immediately jamming the road over again. This theory is regularly used as a reason why expansion of road infrastructure will not alleviate traffic congestions.

Actually, the term "Induced demand" is not used only in roads and vehicles. The same term is also used in several other issues, e.g. hospitals and patients. It has been argued that every new hospital and new beds for patients will be quickly filled up with new patients (Seyedin *et al.*, 2021). However, it is unlikely that governments will not build new hospitals when there is a growth in the population, even though some of the patients do not actually need to be hospitalized. On the one hand, better service in hospitals will improve public health. On the other hand, this better service could entice additional unsolicited patients into the hospitals which would impose additional burden on the health system. The same dilemma also exists regarding the expanding of roads. On the one hand, more roads will contribute to a healthy and growing economy. On the other hand, there will be an addition of vehicles that will travel on the new roads whose contribution to the economy is nil, but the construction and maintenance of the road will impose additional burden on the transportation system.

The induced demand concept is debatable in several issues (Mokhtarian *et al.*, 2002).Yet, it is unquestionable that there is a minimum of roads that should be paved in order to maintain a vivid economic environment which, in turn, will generate high quality of life.

Autonomous vehicles

An emerging issue that should be taken into account and analyzed when considering road expansion is the new technology of autonomous vehicles. Investing in road expansion can be open to discussion if the road capacity is going to be substantially expanded by the usage of autonomous vehicles.

Autonomous vehicles are self-guided vehicles that can maneuver and prevail over driving difficulties without any human driver assistance by employing a number of dedicated devices (Wiseman, 2020). These devices will provide the autonomous vehicles the ability of monitoring their surroundings and coming to a decision in real time how to handle each situation. Currently, the autonomous vehicles are anticipated to go on the roads the public is now familiar with and also with the same traffic signs.

The road capacity and flow rate in the roads will significantly be improved by the autonomous vehicles mainly because of two attributes.

(1) Shorter safety distance between vehicles and

(2) The variance between the velocities of the vehicles will be much smaller.

There are other aspects to the entry of autonomous vehicles into the transportation market. When autonomous vehicles are available, the level of service of autonomous vehicles will be much better than the level of service of trains. Therefore, a significant share of train passengers will move to autonomous vehicles and increase the number of passengers on the roads. It has even been argued that the number of train passengers moving to autonomous vehicles will be so large that the inevitable result will be the collapse of the railway companies or at least a collapse of a significant part of the railway companies (Wiseman, 2018, 2019a). Therefore, there might be more passengers traveling on the roads.

In Richter *et al.* (2022), the authors argue that different cities will benefit unequally from autonomous vehicles implementation. Cities with well-developed public transport systems and small travel routes can barely benefit from autonomous vehicles. On the other hand, cities with poorly developed public transport systems can significantly benefit from autonomous vehicles, so the impact of autonomous vehicles on the decision whether to build more roads depends on the type of the city.

Methodology

In order to examine and analyze the road expansion necessity, the number of vehicles per hour traveling on a road should be assessed compared to the saturation flow rate (Qi and Hu, 2020). A number of research studies have been conducted to calculate the saturation flow rate, that is to say the maximum number of vehicles that can go through a single road lane in one hour (see, for example, Bonneson *et al.*, 2006; Bester and Meyers, 2007). According to Bonneson *et al.* (2005), Florida Department of Transportation (FDOT) specifies 1,950 vehicles per lane per hour as the saturation flow rate; nonetheless, they acknowledge that 1,950 vehicles per lane per hour is not accurate. Essentially, the numbers of this threshold essentially range from approximately 1,600 to 2,300 vehicles per lane per hour. The number of maximum vehicles per hour per lane is usually denoted as VPHPL.

When many vehicles arrive and the number of the vehicles is about to exceed the VPHPL, the number of the vehicles will not succeed to go beyond the VPHPL and congestion will ensue; therefore, the speed will be substantially reduced. In Ali *et al.* (2010), the authors show that the speed can be reduced by up to 70% when the number of the arriving vehicles is 4,000.

Equation no. 1 gives the VPHPL:

$$VPHPL = \frac{1}{\frac{R}{3{,}600} + \frac{L}{V}} \tag{1}$$

where

R is the average reactive time of human beings in seconds;

L is the average length of vehicles in meters + margin of safety and

V is the minimum velocity of the vehicles going on the road in meters/seconds.

Different people have different reaction times. For example, older people have a longer reaction time on average; however, age is not the only factor that affects reaction time (Hultsch *et al.*, 2002). The average reactive time of human beings is 1.3 s (Summala, 2000). The average length of vehicles is 4.5 meters. It is considered in this length also the margin of safety that is also usually taken by drivers Xu *et al.* (2017.

A road is considered jammed when the minimum velocity of the vehicles going in the road in question is getting to 30 km/hr or less (Treiber and Kesting, 2013). According to these data and equation (1), VPHPL is 1,956 which is very similar to the number of FDOT, i.e. 1,950.

When it comes to autonomous vehicles, the reaction time is much smaller. According to Xu *et al.* (2012), the reactive time of an autonomous vehicle is about 100 milliseconds.

If the numbers of autonomous vehicles are put in equation (1), a VPHPL of 5,625 will be obtained, which is 187% better than the VPHPL of human driven vehicles, and with advanced tools of communication between autonomous vehicles and infrastructure that are nowadays developed (Zawodny and Kruszyna, 2022), this ratio can be even higher. The other parameter that has been mentioned above is a smaller variance between the velocities of the vehicles which in addition to the VPHPL can offer a much better utilization of roads. Therefore, the dilemma of whether to invest in railroads or roads significantly changes. Since the roads will be able to accommodate many more cars, the expediency of investing in the roads increases.

High occupancy vehicle lanes

Another different way of endeavoring to solve the congestion problem could be High Occupancy Vehicle (HOV) lanes. The cost of shifting a general purpose lane into a HOV lane is usually much smaller than adding road lanes, so it should be analyzed when and where HOV lanes can be successfully implemented vs when and where more funds should be allocated in order to construct additional road lanes.

The aim of HOV lanes is encouraging drivers to carpool (Cohen *et al.*, 2022). The incentive is the permission to go in the HOV which is almost at all times much less congested. These carpooled vehicles will reduce the number of vehicles going on the road, and as a result, the congestion will be alleviated (Giuliano *et al.*, 1990).

Therefore, according to this method, some paint buckets are all that is needed to solve the problem of traffic congestion on the roads. However, there is difficulty in the rationale of this method. Drivers will have a real incentive to shift to the HOV lane only if there is a significant difference between the travel time on the HOV lane and the travel time on the general purpose lanes. In order to achieve such a significant difference between the travel times on the different lanes, the general purpose lanes must be considerably congested, and congestion in the road is needed to reduce congestion in the road, which seems to be a questioned model as was discussed, explained and reasoned in (Dahlgren, 1998).

This irrationality is an essential factor when assessing the productivity of HOV lanes (Shewmake, 2012), because if HOV lanes are capable of reducing congestions only if congestions in the road persist, are HOV lanes actually productive? That is to say, when employing the HOV scheme, congestions are an inexorable outcome; therefore, the HOV scheme's productivity in eliminating traffic congestion is doubtful (Dahlgren, 1995).

Moreover, since many major highways pass through several cities, they are used by many professionals such as electricians, plumbers, etc. in addition to couriers who bring goods to the customer's home. All of these people drive a vehicle without additional passengers and turning their lanes into HOV will cause them significant damage, will increase the price of their service and in actual fact will harm the economy of the area.

Similar roads in the USA have adopted a policy of easing the rules of HOV lanes in response to their unproductiveness such as permitting the use of one passenger for a fee or a permit to drive an environmental-friendly vehicle. On other USA roads, HOV lanes have been annulled. At any rate, in the USA all the HOV lanes including the lanes that allow individual drivers for a fee or eco-friendly vehicles are only 0.08% of the roads in the USA (Wiseman, 2019b).

The COVID-19 has made the concept of HOV even more ineffective because people are afraid to carpool as they want to avoid getting infected by the virus. It is unclear whether the pandemic and its psychological effects are over. It can be assumed that someday in the future the emotional effects of the COVID-19 will evaporate; however, currently the pandemic still discourages people from carpooling (Wiseman, 2021b).

As a conclusion, in Ma and Wang (2019) the authors suggest replacing the defectively operated HOV lanes with exclusive lanes for autonomous vehicles. In the first stage of transformation, only one lane (almost always there is just one HOV lane) will be opened to vehicles equipped with autonomous driving technology, whereas other vehicles will not be permitted to enter it. Next, when more autonomous vehicles emerge, more lanes can be gradually shifted to autonomous vehicles' traffic.

Double-decker roads

There is no extensive use of autonomous vehicles yet; however, capacity augmentation of roads can be also achieved by other means. One of them is double-decker roads. In this section, the concept of double-decker roads is examined.

Railroads usually take smaller space than a road and even in the autonomous vehicle era, and there will be a need to widen roads in order to add new lanes; however, some obstacles can get in the way. Sometimes there are buildings in close proximity to the road which leave no area to construct additional lanes. In some other cases, the terrain nearby the road is unpavable.

The alternative option for widening the road is constructing one or more road decks above the current road. Usually the upper level of road enables signal-free driving which is suitable for drivers who want to drive the entire road from one side to the other, whereas the lower level of the road has traffic signal and traffic lights which enable the vehicles to turn right or left as is implemented for example in (Shukla, 2022).

The model of expanding roads by building another level is not new, and actually, it can be said that the concept of double-decker roads is even very old with interesting experiences.

The first double-decker road was built in Manhattan along the Hudson River in New York City in 1929. The road was called Miller Highway named for Manhattan borough president from 1922 to 1930 – Julius Miller (Panero and Botha, 2011).

Miller was an ardent supporter of roads. He believed that constructing many roads will significantly ease the traffic congestion in New York City. Before the construction of Miller Highway, Miller had already widened many roads and also removed a number of railroads in order to free up space for more road lanes.

There has been no previous experience in this type of construction, and so many mistakes were made in the road construction; actually, as a result, the standards of the road were quite poor. The drainage of the road was insufficient and inadequate, so many large and deep puddles were generated. Also, some pieces of the road fell off from time to time due to the poor standards. Additionally, because of lack of adequate knowledge, corrosive salts were used to get rid of snow, ice and frost from the road in winters. These corrosive salts augmented the decay of this low standard road.

In 1973, a dump truck fell from the road. This accident instigated a discussion whether to renovate the poor road or to just give up the road and demolish the structure. Since the structure was in a poor condition at any rate, it was decided to dismantle the road (Leidner, 2014).

Even though Miller Highway was a failure, many lessons have been learned from the mistakes made in its construction. Nowadays, many double-decker roads are constructed throughout the world. The standards of the new roads are much higher. They have been lasting for many years and they are much safer than the old Miller Highway.

To this day, there are several transportation authorities in the world that have already put into service double-decker roads or even multi-decker roads with the aim of alleviating the traffic jams and congestion they have in their territories.

For example the city of Seattle in Washington, USA is a large city of more than 4 million residents. Yet, Seattle is located amid many water bodies like inlets of the Pacific Ocean, lakes and streams which make the city dense and challenge the capability of widening the roads. So a main section of the main highway of Seattle (I-5) is a double-decker road with the aim of coping with the intense traffic of Seattle (de Cani *et al.*, 2019). Figure 1 shows a double-decker section of I-5 in Seattle.

In other cities, it was decided to build a double-decker road only at certain points with very busy traffic, when each section of such a double-decker road is only a few hundred meters long. Such a short additional road decker is typically called a flyover. In Indonesia, for example, the solution of short double-decker road sections, i.e. flyovers is common (Saraswati and Gunari, 2021). Some other transportation scholars even suggested that a road can be called highway just if all of its junctions have flyovers on top of them (van Nes, 2021).

There are also double-decker roadways in the USA in other places such as Austin, Texas and Chicago Illinois (Al-Kodmany, 2021). In Chicago, there are even some triple-decker roads. In addition, there are double-decker roads in other countries in the world, e.g. in Kobe, Japan; Seoul, South Korea; Manila, The Philippines; Teheran, Iran; Bandar Lampung, Indonesia; Delhi, India and in many more places.

Nowadays, the construction of double-decker roads is not a policy of only developed countries. As mentioned above, non-developed countries like The Philippines, Iran and Indonesia also construct double-decker roadways.

Considering all the subjects discussed above, the results in other locations in the world that double-decker roads have been implemented should be looked at with the aim of realizing what the potential gain of a road expansion is. Three double-decker projects in three different countries are explored:

Source(s): The image was taken from Google Earth

Figure 1.
Double-decker section of I-5 in Seattle

In Tokyo, Japan there is a double-decker expressway between Itabashi junction and Kumanocho junction which crosses the Central Circular route (*C2*) and route no 5. The double-decker road was built because of intense traffic congestions, and indeed, it succeeded in reducing the travel time from 66 min to 41 min (Ministry of Land *et al.*, 2008).

Another successful double-decker road has been implemented in The Philippines. This double-decker road of 18-km called "Skyway 3" was opened in 2021. The road links Southern Luzon Expressway (SLEX) to Northern Luzon Expressway (NLEX). The project was a great achievement as it succeeded in reducing the travel time from SLEX to NLEX from 3 h to only 20 min (Quadra-Balibay, 2021).

Additional instance of double-decker road's success is The Santa Cruz–Chembur Link Road in India connecting the Western Express Highway (WEH) in Santa Cruz with the Eastern Express Highway (EEH) in Chembur. The road effect appeared to be substantial as the travel time was reduced from 50 min to 20 min (Ranjan, 2014).

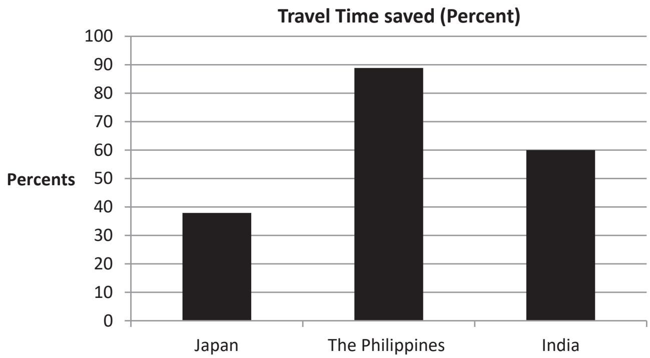
The results of the travel time saved by implemented double-decker roads are summarized in Figure 2.

The decent impact that the double-decker road had on the travel time can be a valuable indication that capacity augmentation of roads is a worthwhile and an advantageous solution to traffic congestions.

In some places in the world, a double-decker road has been constructed as a part of a land bridge. A land bridge is a route enabling the moving of cargos on the land between seaports on either side of a landmass, such as the land bridge in Israel (Wiseman and Giat, 2016). However, some of these land bridges have to pass over paved roads that already serve many people like the proposed land bridge in Thailand (Chalermpalanupap, 2021); so instead of making a long detour around the road, the Ministry of Transportation of Thailand decided to construct an additional decker of road lanes above the existing road (Wangkiat, 2017).

Even though double-decker roads are usually more expensive to build than conventional roads, there are several reasons why this kind of road has been chosen in more than a few locations.

(1) Double-decker roads are safer – the likelihood of finding pedestrians or wildlife in the upper level is significantly lower. Even though it is commonly illegal and dangerous for pedestrians to cross busy highways, there are sometimes pedestrians who decide to cross these highways. Building an upper level for these highways instead of an expansion of the lower level will make the distance one has to go in order to cross the lower level from one end to the other shorter.



Source(s): Authors work

Figure 2. Travel time saved by implementing double-decker roads in several locations

(2) Many congested roads are surrounded by many nearby buildings that should be purchased and demolished to make way for a would-be road expansion (Mawlana *et al.*, 2012). The acquisition and demolition costs of the nearby structures can be higher than the extra budget needed for building an upper level.

(3) If the terrain is hilly, it can sometimes be very expensive to level or carve a path through the hills.

Concisely, the governments of small countries with small areas that can be dedicated for roads should consider road expansion differently. Instead of looking just right and left, they should also look up.

(4) Nowadays, the balance between constructing new highways so as to enhance economic development and nature conservation is intense. The ability to construct more road lanes above the existing road lanes can leave more land for nature conservation uses (Nogués and Cabarga-Varona, 2014).

To conclude, railroads indeed take less space; however, this disadvantage of the roads can be alleviated by double-decker roads as an advantageous solution to traffic congestions.

Findings and results

The suggestion assumptions and model were examined on Road no 4 in Israel. Road no 4 is the longest highway and one of the longest roads in Israel. The total length of the road is 201 km. The road runs from the border of Israel and Lebanon in Rosh Hanikra passing along the coastal plain of Israel to the Gaza Strip. Until 2005 the road continued to Rafah and the Egyptian border, but due to the Oslo Accords, the road now ends at the Erez checkpoint on the Gaza Strip border.

Road no 4 is one of the busiest roads in Israel. The National Roads Company of Israel continuously monitors the road and its traffic. Once in a while decisions are made by The Israel Ministry of Transportation and The National Roads Company regarding renovations and changes to the road. The common decisions are to construct interchanges in the most congested intersections. The vision of The National Roads Company is to replace all the intersections in the road by interchanges.

Adding lanes in order to alleviate traffic congestions are also unexceptional decisions (Gutman, 2021). In the congested sections adding a fourth lane is certainly considered necessary; however, these sections are passing near buildings in close proximity which leave no area to construct additional lanes; so instead of demolishing buildings in order to free up space for more lanes of the road, a better solution will be to construct a double-decker road.

The main section of highway no 4 in Israel from the intersection with Route 67 to the intersection with Route 7 has been examined. The length of the section in question is 91 km, whereas the length and the number of lanes in each subsection are detailed in Table 1 (Isreal Roads, 2017).

The number of vehicles per hour traveling on this section of road no 4 is 4,552 (Bar-Gera *et al.*, 2015). This section is constantly jammed and the below model explains the whys and wherefores for these traffic jams in road no. 4.

In the above section about autonomous vehicles, a model for the VPHPL has been provided. In this section another model that is more suitable for traditional vehicles is provided with the aim of measuring the VPHPL using other parameters:

Equation no 2 VPHPL:

Sub-section	From	To	Length (km)	Number of lanes
Northern section	Interchange with Route 67	North Kfar-Saba interchange	44	2
Central section	North Kfar-Saba interchange	Interchange with Route 20	31	3
Southern section	Interchange with Route 20	Interchange with Route 7	16	2

Source(s): Authors' work

Table 1. Length and number of lanes in the subsections

$$VPHPL = \frac{v \cdot t}{\sum_{i=1}^{n} d_i l_i} \tag{2}$$

where:

v is the number of vehicles per hour in the road;

t is the total length of the road in km;

n is the number of sections in the road;

d_i is the length of section i in km and

l_i is the number of lanes in section i.

According to (2) the VPHPL in this section, road no 4 is 1,945 which is approximately the saturation flow threshold according to FDOT that as was mentioned above specifies 1,950 vehicles per lane per hour as the saturation flow rate. In other words, the road is completely congested, and if more vehicles arrive, they will only increase the delay because the flow in the road is at its maximum capacity. The model results are unsurprisingly reflected in reality and can be seen for example in Figure 3.

As was pointed out in the previous section, double-decker roads can be a good solution for road expansion in urban areas; however, the obvious question is why investing in double-decker roads when the road capacity is going to be considerably extended? In Gates (2023), Bill Gates anticipates that the day autonomous vehicles will be widely available "is coming sooner rather than later." For now, however, only two companies offer driverless-taxi rides to the general public – Waymo in a part of Phoenix, Arizona and Cruise in a part of San Francisco; nevertheless, they seem to be the first robin that is a precursor of spring. Therefore, it is unreasonable to invest a significant amount of budget in new infrastructure during this decade and to realize in the next decade that the investment was superfluous because the road capacity has been significantly augmented.

Conclusions

In the era of the autonomous vehicle, there will be a significant increase in the amount of vehicles that can move on the road at any given time. This increase will boost the attractiveness of road construction, compared to railroad construction. Therefore, the transportation authorities in the various countries will be more inclined to switch to road construction because

Figure 3.
Congestion in road no. 4

Source(s): https://www.ynetnews.com/articles/0,7340,L-4947509,00.html

that way their budget will be used in a better way. The transition to more roads and fewer railroads will likely be done gradually as more autonomous vehicles enter service.

As has been shown, capacity augmentation of roads can improve the transportation level of service. In the meanwhile, the impact of autonomous vehicles by other means of capacity augmentation of roads can be assessed; however, in the future when abundant autonomous vehicles will travel on the roads, it will be possible to observe the real impact of autonomous vehicles and provide more exact numbers with the aim of analyzing more accurately the autonomous vehicles' efficiency.

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