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Impact of road grade on fuel consumption: Potential savings in Nablus, Palestine

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ABSTRACT

Energy consumption contributes to the transportation section with inherent impact in terms of delay, pollutions, and gas emissions. This work aims to assess the effect of road grades on gas emissions and vehicle fuel consumption in Nablus city. Traffic data in peak hours for thirteen representative segments was collected. Vissim was utilized to find the delay, emission, and fuel consumption, for the current situation compared with no grade scenarios. The average fuel consumption was about 14.4 and 12.4 L for the current conditions and assuming no grades, respectively. The average emissions (CO, NOx, and VOC) during the peak hours for the segments were about 264.1 g, 51.4 g, and 61.2 g with grades, and 227.9 g, 46.3 g, and 52.8 g assuming no grades. The maximum potential fuel savings was estimated in 2035 with about 9% by introducing hybrid and electric. The high potential fuel savings can encourage policymakers to adopt this policy in the future.

1. Introduction

Palestine as a developing country suffers from dramatical increasing in the toxic emissions due to the existing of huge fleet of private vehicles. According to Palestinian Ministry of Transport (Ministry of Transportation (MoT), 2022), the number of registered vehicles in 2021 was 435,584. The authors selected Nablus city as the case study for many reasons. Nablus is considered the third in terms of the number of vehicles after Ramallah and Hebron, and the second in terms of mountainous terrain after Hebron. Moreover, the complexity in geometric features is presented in a high grades with slopes up to 25% in specific sections. Finally, the increase in number of gasoline and diesel vehicles as there were 23,685 vehicles at the end of 2021 (MoT). The selected roads in the case study were carefully chosen in the western and middle parts of the city. From one side, the amount of traffic on these roads is the highest almost all the day as these roads serve vital traffic generations facilities such as universities, hospitals, municipal facilities, schools, etc. On the other hand, these roads are classified as arterials and have almost higher grades with some specific sections reach about 25%. This will in turn contribute to increasing the fuel consumption and accordingly will negatively impact the environment by producing different types of toxic gases and emissions. Consequently, the authors will investigate the relation between the type of vehicle in terms of fuel, traffic volume, and grades with the considerable quantities of transmitted emissions in the atmosphere including CO_2 and NO_2 emissions in the air which have dramatically increased over the last century.

Based on the collected database from the MoT, the number of electric and hybrid vehicles in Nablus city is still unpretentious. The introducing of electric and hybrid vehicles may affect the utilizing of current vehicles. The usage of electric and hybrid vehicles is compatible with Shin et al. 2012 who conducted a survey in South Korea considering the consumer preferences and usage of 250 households to analyze a future electric vehicles market. Moreover, the use of such vehicles has a good potential comparing with conventional ones due to; the dramatically increasing in fuel prices and governmental taxes and minimizing the CO_2 emissions.

In developing countries such as Palestine, the travel demands, and corresponding economic and logistics demands are continuing to rise. Accordingly, it is important to solve related problems related to gas emissions and increasing in fuel prices by introducing and adopting new national policies and regulations considering the hybrid and EV vehicles promotion and fuel economy. Although the impact of decarbonization by the promotion of the electric and hybrid vehicles will take long-term, the local government should take effective mitigation measures to

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reduce the GHG emissions (Shin et al. 2012). EVs usually depends on several parameters in energy consumption among them road topography, traffic, driver behavior, temperature, time, distance, acceleration, etc. (De Cauweret al. 2015). Manzieet al. 2007 declared that the increasing of oil prices requested the search for fuel efficient fleet like hybrid and electric vehicles. Recently, by the end of 2021. It is worth to mention that in Palestine, the total number of EVs in the West Bank is only 167 (1 in Nablus) and the number of hybrids is 699 (35 in Nablus) (Ministry of Transportation (MoT), 2022).

Newly, the lack in crude oil and the persistent need to minimize the emissions resulting from GHG, serious efforts and financial resources have been paid on improving and developing a potential, well-maintained, and sustainable transportation engineering system that concerns with minimizing dependency on oil and facing the challenges reflecting the change in climate. (Hassouna and Al-Sahili, 2020). In Palestine, the State of Palestine Palestinian Central Bureau of Statistics (2021) statistics indicated that the sum of emissions related to CO_2, CH_4, and N_2O resulted from transportation means was 2967.97, 1006.79, and 552.91thousand tons, namely about 65.6, 22.2, and 12.2 percent of the national CO_2 emissions, respectively (State of Palestine Palestinian Central Bureau of Statistics, 2021). The huge increasing in oil prices is another problem which faces the transportation sector in Palestine is. In 2021, the average rate per liter for gasoline was about USD 1.80, compared with USD 1.21 average world price. [PCBS Fuel Prices], which in turn means that in Palestine compared to the worldwide, the average fuel price equals about 150%.

Finally, this study is considered the first work which aims to assess the effect of road grades on gas emissions and vehicle fuel consumption in Nablus city. Traffic data in peak hours for thirteen representative segments was collected manually. Vissim software was utilized to find the delay, emission, and fuel consumption, for the current situation compared with no grade scenarios. On one hand, this study assesses the effect of gradient on fuel consumption and emissions, and on the other hand, it predicts the potential reductions in pollutants by taking into account the growing trend of buying and owning electric vehicles in the future.

2. Literature review

In the last 20 years, several studies investigated the impact and implications of grades and road profile on vehicles' fuel consumption and related transmitted emissions, especially in developed countries such EU and USA. However, in developing countries such as Palestine, these studies are still in early stages. Reviewed studies indicated the direct relationship between the quantity of emissions and the slope of roads. The following studies demonstrated the above-mentioned relation and implications in several countries around the world.

Cicero-Fernandez et al. 1997 assessed through their project the high emissions produced from driving patterns on roads with zero to seven percent grades along arterial roads and freeways. The results revealed that the percentage of carbon monoxide (CO) emissions is directly proportional to the grades. In addition, roads with 35–55 MPH speeds and more than 3% grade generated high rates of hydrocarbon emissions. Wyatt et al. (2014) developed LiDAR-GIS Road grade emission model to have precise measure of CO2 emission. Sentoff et al. 2015 suggested that incorporating and measuring real-world road grade is an important factor to calculate emission rates, emphasizing that road slope should be considered in estimating emissions. They also developed a typology for driving style to account for the estimated differences in emissions due to driver variability. Moreover, they highlighted that the amount of such emissions varied from driver to driver. Safiarian and Mansourian, 2020, studied the effect of slopes on fuel consumption on freeways in Tehran. They developed an equation that generated an international rough index to measure fuel consumption. Faria et al. (2019) assessed the impact of road class, fuel consumption and slope on driving aggressiveness by the using real world monitoring data. They studied 17 gasoline light-duty vehicles and 29 diesel vehicles. The authors found that the rates of fuel consumption increased by 255% with grades and aggressive driving behavior.

Boriboonsomsin and Barth 2009 and Prati et al. 2015 assessed the effect of road grades (uphill and downhill) on fuel consumption considering light-duty vehicles and using an analytical approach. The results indicated that the road grade has an impact on fuel consumption. They found that flat roads save about 15% to 20% fuel compared with graded ones. Additionally, Prati et al. 2015 found that for uphill roads, emissions increased by 85% and 33% for CO2 and NOx, respectively. However, they found that there was an inverse trend for downhill with CO2 and NOx emissions decreasing by 60% and 45%, respectively. Gallus et al. 2017 studied the emissions resulted from different types of driving styles. They tested Gaseous emissions considering two test vehicles working by diesel. Route. The authors found that CO2 (65–81%) and NOx (85–115%) emissions presented a good correlation represented by linear relation with road slope ranging from 0 to 5% for all urban, rural and motorway parts.

The impact of both road grade and vehicle speed on fuel consumption and soot emissions was investigated by Gao et al. 2020. They found out that nitrogen oxides (NOx) and exhaust emission were constant and steady with fuel consumption rate, which was controlled by speeding up of the vehicle effect was aggravated by road grade. Moreover, they realized that when the road grade augmented from 0% to 4% then the fuel consumption doubled. When it comes to strict emission regulations it is important to consider that NOx and soot emissions as serious challenges.

Wang et al., 2015 studied the impact of different road gradient on changing fuel consumption under different speeds and different driving styles in Beijing. Founding that it is important to include the effects of road grade on the vehicle energy consumed evaluations and path choosing. Zhou and Jin (2017) argue road gradient have a major effect on predicting fuel consumption under real-world driving.

Several researchers developed models and solutions to reduce fuel consumptions and emissions such as Loulizi et al. 2018 who developed an analytical formulation that measures how road grade affects vehicle fuel consumption. This research concluded that when road grade increases from 5% to 6%, fuel consumption increases by 140%. The strong correlation between fuel consumption and road gradient inspired researchers to work it the other way around. Fan et al. 2022 tried to develop a method for acquiring road grades using fuel consumption as a main parameter. Considering the challenges in acquiring road gradients in road networks where design drawings are not available, this research developed a vehicle fuel consumption model to capture road grade-related fuel consumption difference based on data collected from large number of light duty vehicles. Hallmark et al. 2002 proposed a new mitigation measures and strategies associated with elevated emissions to be implemented. The main two strategies were to reduce the stop time at traffic signals and vehicle speed and acceleration with higher emissions. The main statistically significant variable in the study was road grade.

On the other hand, other researchers focused on studying buses' fuel consumption in relation to roadway grade, among them is Alam and Hatzopoulou 2014 who checked network congestion effect, passenger load, fuel type, and roadway grade considering bus emissions. They found that emissions are strongly affected by type of fuel, increasing passenger load, congestion, and most importantly road positive grades. Moreover, Keramydas et al. 2018 investigated how the fuel consumption and emissions of Euro VI hybrid-diesel public transport buses can be changed and influenced by road grade and speed, they tested this on different roads network in Hon Kong. Rosero et al. 2021 in their paper investigated and compared the effects of the loads of the passenger, road grade, and congestion level both on the real-world fuel and road grade (0%-4%) and how this influence consumption and emissions of urban buses. Moreover, they found out that emissions increased approximately 51% and 54% when road grade changes from 0% to 4% respectively. However, Yu et al. (2016) tested in china and argue that it was also found that the influence of passenger load on emissions is also related to road grade (although their case is flat). Other studies focused on trucks such as Svenson and Fjeld (2016) who quantified the effect of road curvature, gradient, and roughness for a 60-ton conventional logging truck. Moreover, Zhang et al. (2020) studied the state of the art of truck platooning fuel saving and how much road grade can contribute to this. Therefore, it becomes essential to take road slope into account as an important factor for developing driving strategies for fuel saving in truck platoons.

3. Methodology

Our study aims to investigating the effect of road grade on emissions and fuel consumption as well as assessing potential savings in Nablus City, Palestine. The city lies between two mountains and has steep terrain. PTV Vissim was used to simulate the quantity of delay, fuel consumption, and emissions (CO, NOx, and VOC). The authors used different scenarios considering uphill and downhill grades as well as no grade case. In Fig. 1, research methodology steps are presented in order to achieve the research objectives.

The main followed steps are:

- Data collection. The qualitative data was collected from the field and represented by the traffic volume counts and the calculated peak hour volumes. The second type of data was the quantitative. The main sources of such data were the Ministry of Transport (MoT), Palestinian Center Bureau of Statistics (PCBS), Nablus municipality, Ministry of Local Government (MoLG), and topography and grades utilizing GIS. It is worth to mention that that traffic volumes were collected manually which was a challenge in terms of accuracy and minimizing encountered errors. From our experience, collecting traffic data manually can be challenging due to several factors. One of the main difficulties is safety concerns, as data collectors may be required to work in a busy and potentially hazardous traffic environment. In addition, traffic data collection is often time-sensitive, as it needs to be collected during specific time periods, such as during peak hours, which can be limited and challenging to access. The data collection process itself can be time-consuming, especially if large amounts of data need to be collected, and it may require additional staff, increasing the overall cost of the project. Human error is also a risk in manual data collection, and the repetitive and tedious nature of the process can lead to boredom and fatigue, further increasing the risk of errors in the collected data. The quality of the data collected through manual methods may also be impacted by factors such as the expertise and experience of the data collectors, and the clarity of the data collection instructions.
- Data Analysis. The main two components which were addressed are fuel consumption and gas emissions (CO_2, NOx, and VOC) in the targeted roads considering both uphill and downhill grades.
- Results. Developing and validation the model which describes the amount of emissions and fuel consumptions. In addition to the developing what if analysis (scenarios) in the case of using electric or hybrid vehicles considering level, uphill, and downhill grades.
- Conclusions and recommendations and perspectives for future development.

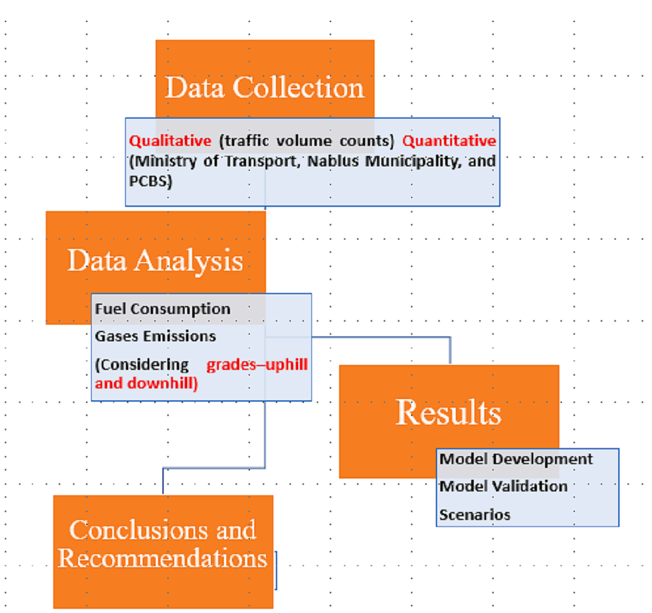

Fig. 1. Research methodology.

The main two steps (data collection and data analysis) are illustrated under the methodology section. However, the third and fourth steps are illustrated in the next main sections of the research.

3.1. Data collection

The authors referred to several sources in this study by collecting a large amount of data from Ministry of Transport, Nablus Municipality, the Palestinian Central Bureau of Statistics (2021), in addition to field traffic volume data collected. The selection of roads in the study area was based on functional classification, importance, grading, serviceability, mobility, speed, etc. The main collected data was peak hour volume, vehicle classification in terms of private cars, taxies vehicles, and heavy duty, in addition to the grades of the targeted roads. Moreover, the data included the number of licensed vehicles in Nablus governorate up to end of 2021 in terms of type of fuel (gasoline and diesel), engine force, manufacturing date, etc. Table 1 shows the percentage of each type based on vehicle classification. Moreover, Fig. 2 illustrates the targeted roads in the case study based on their ID. The case study was selected based on the characteristics of Nablus municipality in terms of geometric complexity in terms of mountainous terrain and due to the fact that Nablus is considered the economic capital of the North of West Bank. Moreover, the number of vehicles has been increased dramatically since 1994 (the establishment of the Palestinian Authority).

The classification of vehicles based on the type of fuel is illustrated in Fig. 3. From Fig. 3, it is clear that the majority of the registered vehicles use gasoline with about 58.60% followed by diesel with about (41.30%), and finally hybrid and electric vehicles with about (0.10%), These statistics indicate that the pollution and emissions are expected to be source of threat for public health and will badly impact the local national economy through the considerable quantities of fuel consumption.

The trend of number of vehicles based on fuel type (gasoline and diesel) from 1980 to 2020 is presented in Fig. 4. It is clear that the number of both types is increasing dramatically which in turn will result in more emissions and pollutions.

As stated before, the terrain of Nablus city can be described as hilly to mountainous. The grades reach about 25% in specific locations. Accordingly, the expected amount of fuel consumption and gas emissions is huge. The topography map of Nablus city is presented in Fig. 5.

Table 2 illustrates the collected traffic volumes on the target roads in Nablus city. The traffic volumes were collected manually. The assigned

Table 1
Percentage of vehicles based on their classifications.

No.	Vehicle Class	Percentage
1	Private	65.51%
2	Taxi	27.26%
3	Heavy duty	7.23%
Total		100%

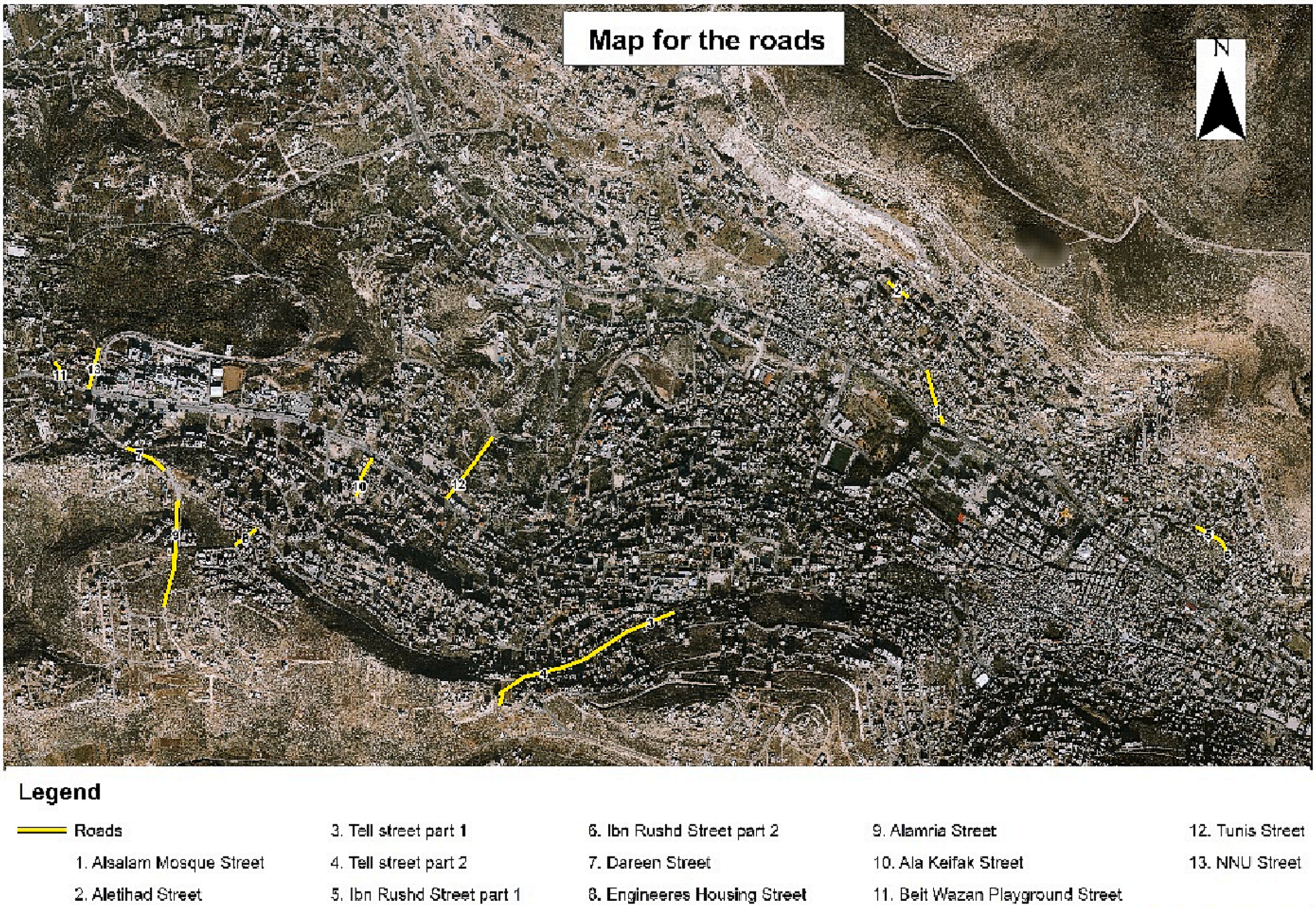

Fig. 2. A map illustrated the targeted roads with ID.

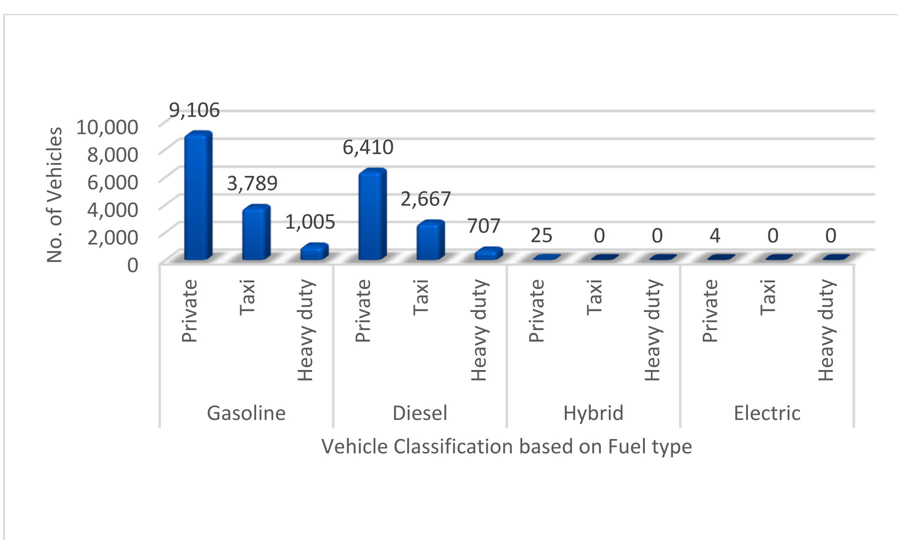

Fig. 3. Number and percentage of registered vehicles based on the type of used fuel.

hours were based on the peak time for each road. Thirteen vital and important roads were selected with different grades and classifications. The traffic volumes were collected in the morning and afternoon peak hours in the targeted roads for both uphill and downhill considering three main vehicle classes include private, taxi, and heavy duty. The length of segments was variable and measured grades were based on the change in slope.

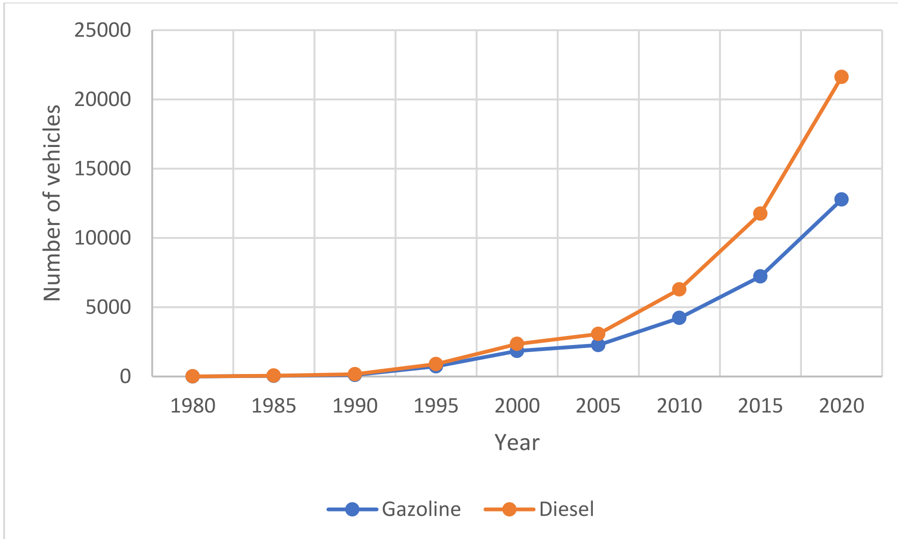

Fig. 4. The trend of registered vehicles considering type of fuel.

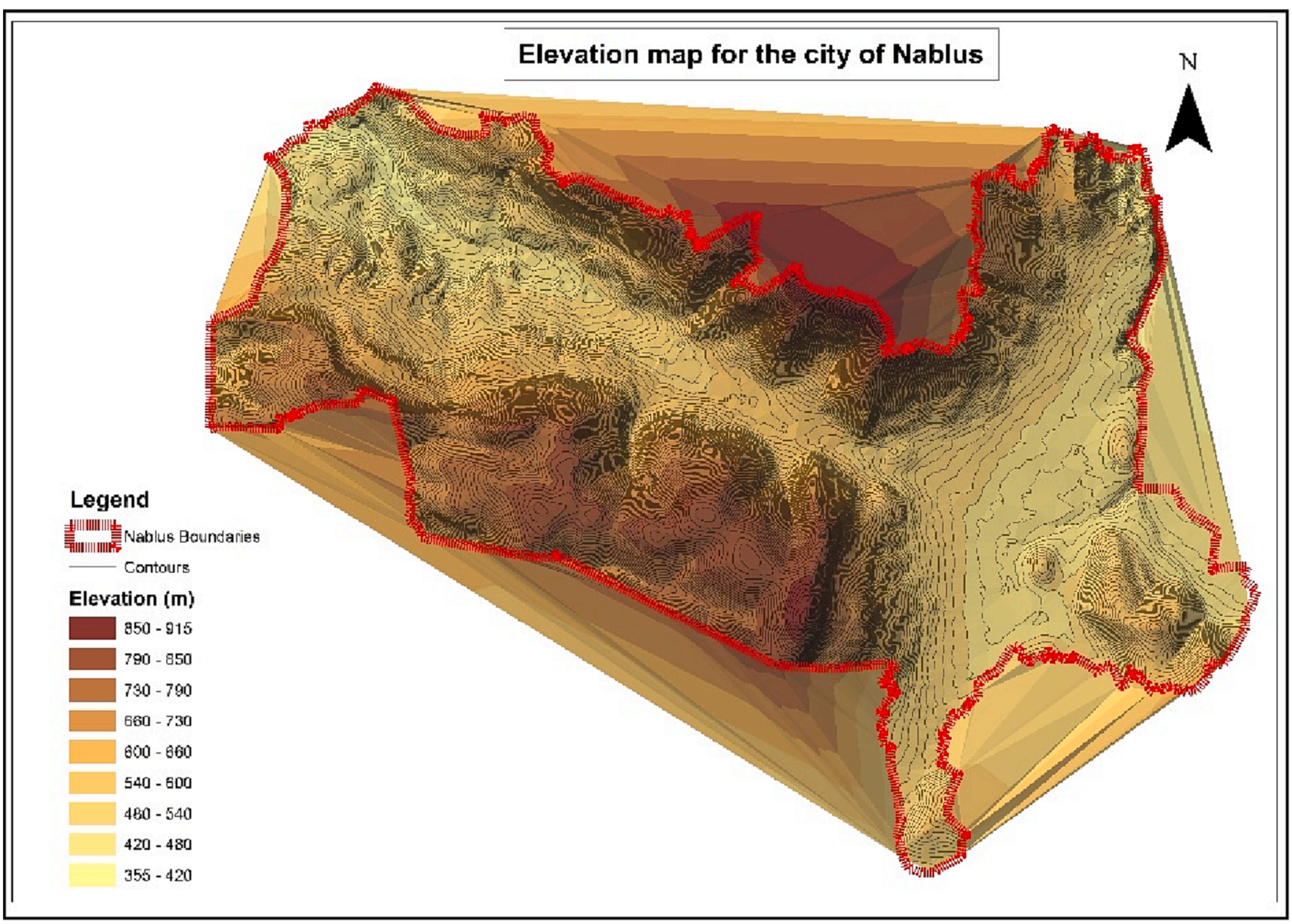

Fig. 5. Topography map of Nablus city.

3.2. Data analysis and simulation

PTV Vissim is a widely used microscopic simulation software for modeling “multimodal transport operations and belongs to the Vision Traffic Suite software” (Ramadhan et al., 2019). Vissim provides the best options for engineers to test many traffic scenarios realistically and accurately before implantation. Vissim is nowadays used worldwide by public agencies, private sectors including consulting and engineering firms, and researchers in academia (Ramadhan et al., 2019; Stevanovic et al., 2009; Park and Schneeberger, 2003; Ziemska, 2021; Alshayeb

Table 2
Summary of collected dataset.

Street ID	Grade (%)	Length (km)	Time	Uphill			Downhill			Total
				Private	*Taxi*	*Heavy-duty*	*Private*	*Taxi*	*Heavy-duty*	
1	18	0.2	1-3PM	881	451	44	679	524	56	2635
2	16	0.1	1-3PM	704	262	59	565	207	52	1849
3	18	0.4	10-12AM	596	281	119	153	86	20	1255
4	21	0.4	10-12AM	556	266	117	141	80	22	1182
5	11	0.1	1-3PM	925	294	156	174	85	19	1653
6	19	0.2	1-3PM	265	56	32	241	53	28	675
7	20	0.2	7-9AM	235	79	24	223	61	32	654
8	11	0.1	1-3PM	276	67	29	271	62	18	723
9	12	0.3	7-9AM	273	89	16	266	116	13	773
10	8	0.2	8-10AM	53	9	2	62	13	1	140
11	7.5	0.1	1-3PM	141	28	20	120	17	3	329
12	13	0.3	8-10AM	678	507	22	831	391	38	2467
13	13	0.3	1-3PM	482	135	29	442	108	43	1239

et al., 2022). Vissim has various features, such as traffic flow modeling, vehicle delay analysis, vehicle queue length analysis, multiclass vehicle simulation, fuel and emissions analysis, as well as including the effect of geometric road parameters including grades. There have been several and different studies that used Vissim to simulate traffic conditions of real scenarios for fuel consumption and emissions including (Ziemska, 2021; Alshayeb et al., 2022). Vissim allows for considering "mutual interactions generated by groups of traffic users moving on the same road network" (Ziemska, 2021), which is essential in our study. Vissim is based on the Wiedemann model as a car-following model. The vehicle following another vehicle "reaches its maximum speed then it slows down and accelerates to keep a safe distance from the vehicle in front of it" (Ziemska, 2021). In this study, Vissim was used to build a series of simulations for the 13 streets that are part of the study considering two scenarios: using their real grades, and assuming no grades. During these simulations of the two scenarios, we reported the results of delay, fuel consumption, emissions of CO, NOx, and VOC for the traffic passing through each of the 13 streets. For each street, we reported the results considering the uphill and downhill and using the traffic counts for each of them, which was collected as shown in Table 2. To build and execute the model, we followed these steps:

- The roads with the grades and lengths were mapped;
- We added vehicle counts on an hourly basis as shown in Table 2;
- The different vehicles classes were added based on Table 1;
- Allowable speeds on individual sections were assigned and speed zones were created for areas, where it is believed that vehicles are not supposed to exceed lower speeds than the allowable; and
- Measurement points for fuel consumption, emissions, and delay were added.

Based on five simulation runs, the results were averaged. The model made is considered to reflect the existing state of the study area.

4. Results and analysis

The results of simulations are shown with respect to the analysis of delay, fuel consumption, and emissions of the thirteen segments with their grades and assuming no grades. For each segment, we reported the results for the downhill lane, uphill land, and the total impact on the segment. We found the generated emissions based on the analysis of nodes on Vissim for the three gases considering CO, NOx, and VOC in addition to the fuel consumption on the microscopic level. First, the effect of the road slopes on delay, fuel consumption, and emission in the city is presented. The analysis showed the results for the current state (with grades) and is compared with the assumed state (no grades). In the end, potential savings in fuel consumption and emission is presented if hybrid and electric vehicles were adopted as a policy by the policy-makers in the coming years.

From the results of the simulation, the results vary based on the segment. It depends on different parameters such as traffic volume, the queue, the road grade, percentage of heavy-duty vehicles, and the length of the segment. While it is evident that the outcomes on uphill terrain tend to be greater than those on downhill terrain, the extent of the difference is also influenced by the factors mentioned previously. A statistical Student's *t*-test was implemented to assess the importance of the differences between grades and no-grade results. In all cases, we found that the p-value is less than 0.001 indicating that results with grades have significantly higher delays, fuel savings, and emissions than the no-grade results.

Delay is considered a significant factor in determining the level of service at the segments as well as a parameter that can be used in traffic signal timings design and optimization for nearby signalized intersections. Fig. 6 shows the impact of road grades on the delay at the segments. We found that the average delay for the 13 segments is about 35.5 sec for the current state and about 27.9 sec assuming no road grades in the segments. In the case of segment12, the maximum value of the delay was found to reach about 85.0 sec during the two-hour under study.

The effect of road grade on fuel consumption was evaluated for the segments during the two-hour under study. Fig. 7 shows the fuel consumption and the reduction percent at each segment with grades and assuming no grades. We found that the average fuel consumption was about 14.4 Liters and 12.4 Liters for the current segment state and assuming no grades, respectively. We also found that the average reduction in fuel consumption considering no road grades is about 19%. However, the maximum value for fuel consumption was in case of segment 1 with about 33.3 Liters. The highest reduction percentage was in case of uphill section in segment 12 with about 37%, if no grade is assumed. We further investigated the relationship between road grades and reduction in fuel consumption. We found that there is a seemingly a linear relationship, where reduction in fuel consumption increased when road grades increased as presented in Fig. 8. We found that there is a relatively strong relationship (R^2 is estimated about 0.89) and equation (1) represents the relationship as follows:

$$ReductionPercent = 0.019RoadGrade - 0.061 \quad (1)$$

The effect of road grade on emissions including CO, NOx, and VOC were evaluated for the segments during the two-hour under study. Fig. 9 shows the three types of emissions at each segment with grades and assuming no grades. We found that the average emissions for the 13 segments are about 264.1 g, 51.4 g, and 61.2 g with grads; and 227.9 g, 46.3 g, and 52.8 g assuming no grades for CO, NOx, and VOC, respectively. In case of segment 1, it has the highest emissions with about 611.5 g, 119.0 g, and 141.7 g for CO, NOx, and VOC, respectively during the two-hour study.

Potential fuel consumption savings were assessed by assuming a scenario, where the policymakers adopt introducing and incentivizing

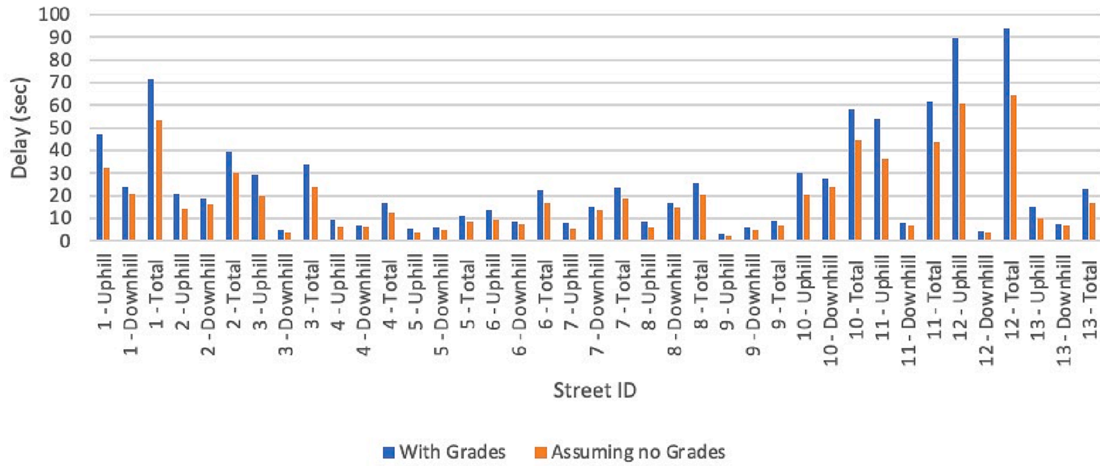

Fig. 6. Delay at each segment with grades and assuming no grades.

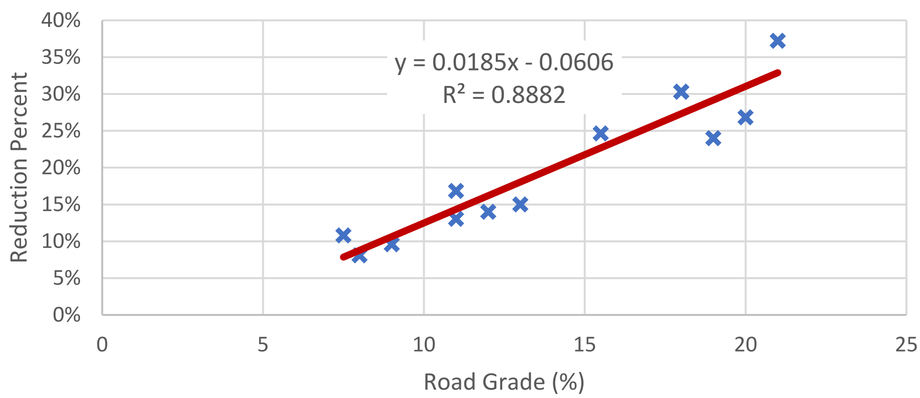

Fig. 7. Fuel consumption and reduction percent at each segment with grades and assuming no grades.

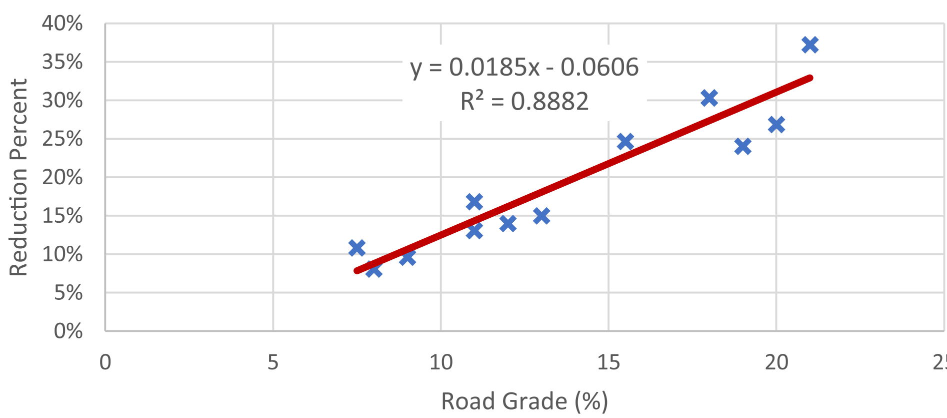

Fig. 8. Relationship between reduction percent and road grade.

hybrid and electric vehicles. The current transportation situation in the City of Nablus is still mainly based on the use of conventional vehicles powered solely by an Internal Combustion Engines (ICE) that use gasoline (about 58.60%) or diesel (about 41.30%). There are several reasons for this trend including the lack of governmental tax incentives for electric/hybrid vehicles, absence of real investment in the needed infrastructure, as well as due to unpredictable political conditions. We assumed that if the government incentivized the public to replace ICE vehicles with hybrid and electric ones, the distribution of vehicles in the city by type will pick up the global trend between 2023 and 2035 (Hassouna and Al-Sahili, 2020), which is also the case in nearby countries including Jordan (Shalalfeh et al., 2021).

Using the results of fuel consumption for the thirteen representative road segments, we argue that we can predict the potential savings in fuel consumption from 2023 to 2035 using simulation. We used Vissim to simulate the proposed scenarios and to find the results. Fig. 10 shows EVs and hybrid assumed trends in Nablus and potential saving in fuel consumption. We extracted the trends based on several reports and references including (Chen et al., 2022; Tung et al., 2020; MacDonald, 2016; BloombergNEF, 2021; Kapustin and Grushevenko, 2020). We found that a 5.0% reduction on fuel consumption may be viable on average every year. We argue that this percentage can be further

Fig. 9. Emissions at each segment with grades and assuming no grades.

proliferated when considering that more EVs and hybrid vehicles will be used and when it is used on gentler road grades as recommended. The maximum potential fuel savings will occur in 2035 with about 9.0%. Introducing EVs and hybrid vehicles not only leads to fuel consumption savings but also to avoiding all the types of gas emissions including CO, NOx, and VOC emissions, which can be significantly reduced per year in the City of Nablus. From these results one may conclude that the high potential fuel savings found each year by introducing and incentivizing

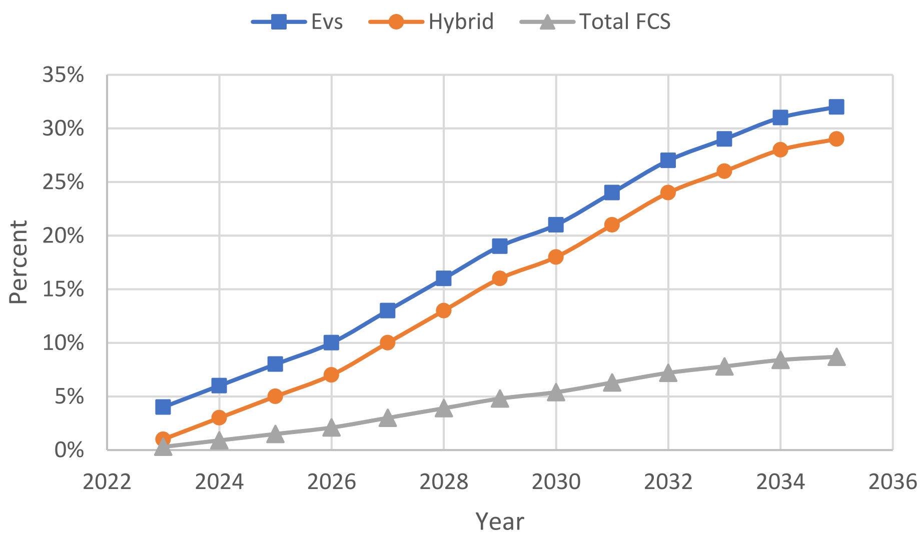

Fig. 10. EVs and hybrid assumed trends in Nablus and potential saving in fuel consumption.

EVs and hybrid vehicles is important to draw policymakers' attention towards adopting this policy in the near future.

5. Conclusion

This study investigated the impact of delay, fuel consumption, and emissions including CO, NOx, and VOC using Vissim simulation for thirteen segments in Nablus city. The percentage of heavy-duty vehicles, queue, peak hour traffic volumes, length of uphill and downhill segments, grades, and fuel type (gasoline, diesel, hybrid, and electric) were used in the simulation process. Results revealed that the amount of delay, emissions, and fuel savings were directly proportional with increasing road grades. The average delay for the thirteen segments was about 35.5 sec considering current situation and 27.9 sec assuming no road grades. Regarding the average fuel consumption, 14.4 L and 12.4 L for the current conditions and assuming no grades, respectively. The average reduction in fuel consumption considering no grades was about 19%. However, the highest reduction percentage was in case of uphill section with about 37% which was illustrated by the strong correlation ($R^2 = 0.89$) as shown in equation (1).The average emissions (CO, NOx, and VOC) during the peak hours for the thirteen segments were about 264.1 g, 51.4 g, and 61.2 g with grades, and 227.9 g, 46.3 g, and 52.8 g, respectively assuming no grades.

The potential fuel consumption savings were assessed for the period from 2023 to 2035 by assuming a scenario where the policy makers adopt introducing and incentivizing the use of hybrid and electric vehicles. On average, a 5% of fuel reduction is expected to be achieved every year. The maximum potential fuel savings is expected in 2035 with about 9% by introducing hybrid and electric vehicles which in turn will contribute to minimize the gas emissions (CO, NOx, and VOC) in Nablus city. Finally, we conclude that the high potential fuel savings found each year by introducing and incentivizing hybrid and electric vehicles is important to draw policymakers' attention towards adopting this policy in the near future. The impact of road grade on fuel consumption can provide valuable insights for policymakers and researchers, enabling them to make informed decisions on transportation planning, vehicle efficiency, environmental impact, energy demand forecasting, and urban design.

Results show that different road grades can influence fuel consumption rates in cities, which characterized with mountainous terrain. Nonetheless, collecting more data from other areas in the same city will enrich the results and provide more insights toward fuel savings. Moreover, including other strategies such as incentivizing the use of micromobility and public transportation would also provide a more comprehensive analysis on future consumption savings. Still, the impact of road grades and potential savings provides new insights as cities attempting to become more sustainable. This can also be useful to define and implement proactive strategies.

CRediT authorship contribution statement

Amjad Issa: Conceptualization, Data curation, Visualization, Writing – original draft, Writing – review & editing. **Zahraa Zawawi:** Conceptualization, Investigation, Project administration, Resources, Visualization, Writing – original draft, Writing – review & editing. **Huthaifa I. Ashqar:** Conceptualization, Formal analysis, Methodology, Software, Validation, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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