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CONTENTS

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Investigation of pedestrian and vehicle level of service regulation for Hacettepe Sıhhiye campus

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Highlights

- Investigation sidewalks of Hacettepe Campus Children's Emergency Entrance
- Determination of LOS and PLOS Levels
- Different methods were compared
- Improvement of roads

Abstract

Roads and sidewalks of Hacettepe Campus Children's Emergency were investigated in order to determine the congestion in the "emergency zone" in this area and improvement effects to different road quality methods were discussed. Both level of service of roads (LOS) and sidewalks (PLOS) were studied by using different methods as Highway Capacity Manual (HCM), Landis and Australian methods. As the result of study, since the terrain in the region is not suitable for vehicles, the pedestrian path was narrowed to reduce the traffic on the vehicle road and significantly reduce the problem. In addition, the methods used in the PLOS calculation were found to be deficient in terms of applicability. When comparing the different methods AUSTRALIAN method more realistic results as it has more generalizable perspective than others in this study.

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1. Introduction

As can be known, the problems of human and vehicle traffic are increasing with the growing population day by day. Therefore, many studies and methods have been developed to solve the problems. Near of the vehicle transportation on roads walking on sidewalks, which is one of the modes of transportation, can have critical impacts on human life and traffic management [1]. Thus, sidewalks are of great importance to mitigate this situation and they separate vehicular and pedestrian traffic. As can be known, the term of level of service (LOS) is a qualitative measure used to assess the quality of service provided by road transport. In addition, the pedestrian level of service (PLOS) is a sophisticated metric designed to quantify the comfort and safety levels of existing and planned pavements. It provides an objective and robust assessment of how pedestrians perceive and respond to the road environment.

To avoid the problems, they should be determined based on important criteria such as the quality of sidewalks, their length and the distances between them, the roadway, etc. [2]. There are some studies in the literature about quality of level of service as can be seen in Table 1.

In this study, LOS and PLOS behaviors for roads and sidewalks were investigated with the traffic generated in the hospital area. Highway Capacity Manual (HCM) [3] used for LOS method and for sidewalks HCM, Australian and Landis methods were used. However, almost all of the methods do not address exactly the same points and their values need to be changed to adjust the evaluation criteria. Another aim of this study is improving road service capacity by reducing vehicle traffic and controlled the changing ranges of result by using various methods

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[4]. Provisions have been made on both the pedestrian and vehicular pathways to achieve the best possible result. This region is critical because of the school campus and the hospital region. There is no information that such a place has been studied in the literature. Thus, in order to obtain the data, 15-minute measurements were taken for one week. These measurements were used to determine the critical hours with high traffic volumes. The critical hours identified for more accurate and reliable results were measured again the next week. Using these methods, the LOS and PLOS values of the roads were determined. The fact that the roads in the region was single lane is one of the main reasons for this situation. The area has an "emergency entrance" and it is crucial for human life. Since our area is used as a campus and hospital entrance, there is increased traffic at the specified times. Additionally, in this article, a literature review was conducted and an attempt was made to find methods to analyze data in the region in the most appropriate way.

Table 1. Some literature studies

Number	Reference	Content
1	Mcleod et al. [5]	Methodology to Assess Level of Service on US-1 in the Florida Keys, Transportation Research Record 1398
2	Roess and Prassas [6]	Simplify communication of quantitative performance measures related to measures of central tendency such as LOS, average intensity
3	Margiotta et al. [7]	Simplified Highway Capacity Calculation Method for the Highway Performance Monitoring System
4	Mindell [8]	While macro problems are more considered in PLOS methods, micro problems are not considered. In this study, it draws attention to micro methods, and the study was driven by surveying the population through questionnaires.
5	Karatas et al. [9]	Examines changes in PLOS adjustments. Considers deficiencies using all 3 different methods
6	Bivina et al. [10]	A new method was established by noting the lack of classic
7	Zegeer & Zegeer [11]	Assess roadway performance including travel time, congestion, delay, etc.

2. Region Properties

This study was conducted in the hospital area of the Sıhhiye campus of Hacettepe University, which is a critical area in terms of pedestrian and vehicular traffic. The vehicular roads consist of two roads. 'A1' is the vehicle entrance road and 'A2' is the vehicle exit road (Figure 1). These roads have same width as 3 meters as can be seen in Figure 2.

There are two sidewalks, shown as "B1" and "B2" and "B1" sidewalk was measured as 8 meters. "B2" sidewalk was measured as 5.9 meters. The sidewalk 'B2' is narrower in one section because of the car parking.

Figure 1. Studied region by Google Map

Figure 2. Road and Pedestrian Paths

3. Methodology

In the study, pedestrians and vehicles were counted at 15-minute intervals for both sides between November and December 2021. LOS calculates the speed and quality of vehicle roads. In this case, a specific labelling is made by taking into account factors such as thickness, density, quality of the road and obstacles in the environment. In PLOS, the same elements apply on average. Factors such as the length of the pedestrian path, obstacles and distance from the roadway are effective. They are described as A, B, C, D, E, F. While "A" indicates the best and desired road grade, F corresponds to the worst and undesirable road grade. These ratings are based on the Highway Capacity Manual (HCM) [3] and the AASHTO Geometric Design of Highways and Streets. Table 2 shows the range of LOS grades.

LOS degrees in traffic are given below:

A: Free Flow: traffic flows above the posted speed limit. Drivers have physical and mental comfort.

B: Reasonably Free Flow: LOS-A values are the same, but drivers' maneuverability is limited.

C: Stable Flow: maneuverability is limited. Driver attention is required for lane changes. Minimal traffic congestion may occur.

D: Approaching Unstable Traffic Flow: traffic volume is slightly higher and speed is slightly reduced. Driver comfort level is low. There is a high volume of traffic on certain days.

E: Unstable Flow: maneuvering in the traffic flow is almost difficult. Drivers lack physical and mental comfort. Traffic is fluid, and speeds are constantly changing.

F: Forced/Breakdown Flow: The flow is almost at a standstill. Each vehicle moves slowly with the vehicle in front of it. Travel time is unpredictable.

Table 2: Changing principles of LOS values [3]

LOS	Density Range
A	Score < 7
B	7 ≤ Score < 11
C	11 ≤ Score < 16
D	16 ≤ Score < 22
E	22 ≤ Score < 28
F	Score ≤ 28

Steps of calculation can be summarized as below:

1) Determining the width of the road: if the width of the road is less than the appropriate width, the speed of free traffic is reduced.

2) Determination of the lateral distance of the right shoulder: since the reduction of the lateral distance reduces the psychological comfort of the driver, it has a negative effect on the flow speed.

(1)

3) determination of peak hour factor: it is the ratio between the hourly traffic volume and the ratio between the maximum 15-minute volume and the hourly traffic volume.

4) determination of the heavy traffic adjustment factor: heavy vehicles have a negative impact on the capacity of the road. Depending on this impact is the factor used in the calculation.

5) Determination of the flow rate: The resulting purchase value is calculated as follows.

6) Calculation of density and determination of LOS: The ratio of the calculated flow velocity to the average velocity gives the density. The appropriate LOS value is determined with the obtained density value.

PLOS calculations were made for three different methods as HCM, Landis and Australian methods. The number of pedestrians per minute is calculated. The highest value of the 15-minute measurements is taken and divided by 15 minutes. Then this value is divided by the length of the road to get a number. This numerical value is assigned a letter score using the PLOS scoring criteria as can be seen in Table 3.

HCM method for PLOS is a labelling method used to estimate the performance characteristics of the roadway used for pedestrians and transit passengers in each area [12, 13]. Together with the data obtained by applying this method on the Hacettepe Sıhhiye Campus.

Table 3: Sidewalk PLOS rating for HCM methods [14]

LOS	Density Range
A	0 < Score ≤ 5
B	5 < Score ≤ 7
C	7 <Score ≤ 10
D	10 < Score ≤ 15
E	15 < Score ≤ 23
F	Variable

The Landis method is another method of measuring the value of a sidewalk to pedestrians. This method evaluates the quality of pavement work, safety, and comfort. Factors such as on-street parking, bike lanes, the distance between the street and the sidewalk (width of the shoulder), and buffer areas are important. The greater the distance between pedestrians and the roadway, the safer the street. Equation 1 is used to calculate and Table 4 shows the levels.

$$PLOS = \begin{bmatrix} 1.2021 \times \ln \begin{bmatrix} W_{ol} + W_1 \\ +f_p \ x \ \%OSP \\ +f_b \ x \ W_b \\ +f_{sw} \ x \ W_s \end{bmatrix} \\ +0.253 \times \ln\left(\frac{Vol_{15}}{\mathrm{L}}\right) \\ +0.0005 SPD^2 + 5.386 \end{bmatrix} \quad (1)$$

W_{ol}=width of outside lane (ft)
W_1 = width of shoulder or bike lane (ft)
f_p = on-street parking effect coefficient
%OSP = percentage of segment with on-street parking
f_b = buffer area barrier coefficient
Wl = width of shoulder or bike lane (ft)
W_b = buffer width, which is the distance between edge of pavement and sidewalk (ft)
f_{sw} = sidewalk presence coefficient
Vol_{15} = average traffic during 15-min period
L = total number of through lanes for road or Street
SPD = average running speed of motor vehicle traffic (mph)

Another method of evaluating road use is the Australia method. In this method, the directions of the road to be improved can be determined. To determine the PLOS value, the calculation is made considering the physical factors, location and users. It is divided into eleven factors, which are assigned to three main categories. These are the factors that directly affect the quality of the road. According to the impact of the factors on the PLOS, a score is given according to the well-known rating system. Based on the score obtained, the PLOS value is defined according to the interval in which it is located. PLOS values are as follows, depending on the scores obtained as can be seen Table 5.

Table 4: Sidewalk PLOS rating for Landis methods

LOS	Density Range
A	0 < Score ≤ 1,5
B	1,5 < Score ≤ 2,5
C	2,5 < Score ≤ 3,5
D	3,5 < Score ≤ 4,5
E	4,5 < Score ≤ 5,5
F	5,5 ≤ Score

Table 5: Sidewalk PLOS rating for Australia methods

LOS	Density Range
A	132 ≤ Score
B	101 < Score ≤ 131
C	69 < Score ≤ 100
D	37 < Score ≤ 69
E	Score ≤ 36

4. Result

The objective of the study is that Hacettepe Sıhhiye Campus, which is a significant region in terms of passenger and vehicle traffic, is both a school and hospital area, so the passenger and vehicle traffic increases at certain hours and days. It was observed that vehicle traffic increases at certain times, but this causes difficulties in transportation. Therefore, efforts are being made to prevent this by making improvements in the area.

Table 6 was prepared according to LOS by HCM method. When different road widths were used for various times, it can be seen that road service quality was changed from D to A. As another word, widening of the road was sought as a solution for these problems. Therefore, an attempt was made to eliminate this problem as much as possible by increasing the number of lanes on the road. Firstly, the service quality of the road was evaluated. To improve the vehicle and the pedestrian street were widened with certain narrowing. The first condition of the vehicle street consists of a single lane with 3 meters widening. The pedestrian path is 8 meters. Based on the measurements, sections of the pedestrian path were taken in half meters and added to the vehicle road. It is assumed that a two-lane road is created when the vehicle road is 6 meters long, and a three-lane road is created when it is 9 meters long. As a result of the improvements to the vehicle road, the changes in the PLOS values of the road were examined as can be seen in Table 7, 8, 9 and 10 [15,16]. The changes in PLOS values were analyzed using three different methods. Briefly, by narrowing the sidewalks and adding to roads width results of the various methods were compared. Thus, improving effects and changings on the methods were analyzed.

First, the vehicle counts of the road were recorded for one week and the LOS values were calculated. The critical hours were determined by considering the values where the traffic volume is higher than normal. The next week, the LOS values were calculated again for these critical hours. Since the area is a frequently used location by the public and the superstructure is being widened to accommodate the widening of this road, the superstructure data was used. Using these data, the PLOS values of the road were measured. These values were determined using the HCM, Landis, and Australia methods [17]. The following tables show the PLOS values of the road according to the HCM and Landis methods.

Table 6: LOS values depending on the length changes in the vehicle path

Road Width (m)	Road Type	Time										
		08:00-09:00	09:00-10:00	10:00-11:00	11:00-12:00	12:00-13:00	13:00-14:00	14:00-15:00	15:00-16:00	16:00-17:00	17:00-18:00	18:00-19:00
3	A1	D	D	D	C	C	D	D	C	C	B	B
	A2	B	A	B	B	B	C	C	B	C	D	B
3.5	A1	C	C	C	B	B	C	C	B	B	A	A
	A2	A	A	A	A	A	B	B	A	B	C	A
4	A1	C	B	C	B	B	C	B	B	A	A	A
	A2	A	A	A	A	A	B	B	A	B	C	A
4.5	A1	C	B	C	B	B	C	B	B	A	A	A
	A2	A	A	A	A	A	B	B	A	B	C	A
5	A1	C	B	C	B	B	C	B	B	A	A	A
	A2	A	A	A	A	A	B	B	A	B	C	A
5.5	A1	C	B	C	B	B	C	B	B	A	A	A
	A2	A	A	A	A	A	B	B	A	B	C	A
6	A1	B	A	B	A	A	A	A	A	A	A	A
	A2	A	A	A	A	A	A	A	A	A	B	A
6.5	A1	B	A	B	A	A	A	A	A	A	A	A
	A2	A	A	A	A	A	A	A	A	A	B	A
7	A1	B	A	B	A	A	A	A	A	A	A	A
	A2	A	A	A	A	A	A	A	A	A	B	A
7.5	A1	B	A	B	A	A	A	A	A	A	A	A
	A2	A	A	A	A	A	A	A	A	A	A	A
8	A1	B	A	B	A	A	A	A	A	A	A	A
	A2	A	A	A	A	A	A	A	A	A	A	A
8.5	A1	B	A	B	A	A	A	A	A	A	A	A
	A2	A	A	A	A	A	A	A	A	A	A	A
9	A1	A	A	A	A	A	A	A	A	A	A	A
	A2	A	A	A	A	A	A	A	A	A	A	A
9.5	A1	A	A	A	A	A	A	A	A	A	A	A
	A2	A	A	A	A	A	A	A	A	A	A	A
10	A1	A	A	A	A	A	A	A	A	A	A	A
	A2	A	A	A	A	A	A	A	A	A	A	A

When the Table 6 compared, it can be seen that 'A1' which is the vehicle entrance road is more crowded and LOS values are worse than 'A2' which is the vehicle exit road at morning times. However, when the road widening was changed from 3m to 3.5m, LOS values were improved form D to C. Nevertheless, generally, after 8 m road width, the LOS value was completely improved and LOS values were A for all times.

The 15-minute measurements were taken between 8-14 November between 8:00 am – 7:00 pm. The length of the roadway was measured and certain measures were taken. Sidewalk results can be seen in Table 7.

When Table 7 values were compared, it can be said that for both B1 and B2 sidewalks PLOS values were A for HCM and Landis methods, but Australian method gave different solution as C for all times. In order to improve the road quality sidewalks were narrowed. Sidewalk widths were changed as from 8 m to 1 m. After the expansion of the roadway, there is almost no traffic obstruction at any hour. Since the area cannot be increased, the pedestrian walkway is shortened in order to widen the roadway. For this reason, taking into account the narrowing of the road, comparisons were made according to the methods HCM, Landis and Australia. The critical hours were determined based on the values measured in the first week. In the following week, the sidewalk values were recalculated in the methods as Table 8.

Table 7: PLOS values for pedestrians. [November 9,8am-7pm]

Time	Sidewalk	HCM	Landis	Australia
08:00-09:00	B1	A	A	C
	B2	A	A	C
09:00-10:00	B1	A	A	C
	B2	A	A	C
10:00-11:00	B1	A	A	C
	B2	A	A	C
11:00-12:00	B1	A	A	C
	B2	A	A	C
12:00-13:00	B1	A	A	C
	B2	A	A	C
13:00-14:00	B1	A	A	C
	B2	A	A	C
14:00-15:00	B1	A	A	C
	B2	A	A	C
15:00-16:00	B1	A	A	C
	B2	A	A	C
16:00-17:00	B1	A	A	C
	B2	A	A	C
17:00-18:00	B1	A	A	C
	B2	A	A	C
18:00-19:00	B1	A	A	C
	B2	A	A	C

Table 8: PLOS values depending on the length of the pedestrian path using the Highway Capacity Manual (HCM)

Side	Width														
	8 meters	7.5 meters	7 meters	6.5 meters	6 meters	5.5 meters	5 meters	4.5 meters	4 meters	3.5 meters	3 meters	2.5 meters	2 meters	1.5 meters	1 meter
B1	A	A	A	A	A	A	A	A	A	A	A	A	A	A	B
B2	A	A	A	A	A	A	A	A	A	A	A	A	A	A	B

Looking at the Table 8, 9 and 10, changes were shown every half-meter on the pedestrian path and the vehicle road. When all the results are considered, the quality of the pedestrian road decreases, and the road quality increases on the vehicle road. The total length in the field is 11 meters. The most suitable interval is the interval where the length of the vehicle road is 7.5 meters, and the pedestrian path is 3.5 meters. Accordingly, this road value increases from 'D' to 'B' at the most important hours. However, the pedestrian sidewalk decreases from 'B' to 'C'.

Table 9: PLOS values depending on the length of the pedestrian path using the Landis Method

Side	Width														
	8 meters	7.5 meters	7 meters	6.5 meters	6 meters	5.5 meters	5 meters	4.5 meters	4 meters	3.5 meters	3 meters	2.5 meters	2 meters	1.5 meters	1 meter
B1	A	A	A	A	A	A	A	A	A	A	A	B	B	B	B
B2	A	A	A	A	A	A	A	A	A	A	A	B	B	B	B

Table 10: PLOS values depending on the length of the pedestrian path using the Australia Method

Side	Width														
	8 meters	7.5 meters	7 meters	6.5 meters	6 meters	5.5 meters	5 meters	4.5 meters	4 meters	3.5 meters	3 meters	2.5 meters	2 meters	1.5 meters	1 meter
B1	C	C	C	C	C	C	C	C	C	C	D	D	D	D	D
B2	C	C	C	C	C	C	C	C	C	C	D	D	D	D	D

When literature studies were compared with this study the importance of the study can be seen more. For illustrated this, Wibowo and Nurhalima [18] investigated the situation of pedestrian walkways in certain regions for Bandung Technology Institute and a study was conducted to improve the service quality of pedestrian walkways. Three different methods were used as HCM, Trip Quality and Australian. According to these methods, there are very different PLOS values on the pedestrian way. In this study, the value of HCM method is 'A', the value of Tripquality method is 'C' and the value of Australian method is 'D'. While the Tripquality and Australian method are more realistic results, the HCM method is insufficient for the pedestrian walkway. As a result of the study, it was concluded that factors such as "surface quality/maintenance, effective width, support facilities" should be more appropriate to increase the level of service of pedestrian paths. In this study, Hacettepe Sıhhiye study, it was planned to improve the effect of pedestrian and vehicle streets on each other. Since the values of vehicle streets have a higher value, more vehicle streets were improved. Due to the unsuitability of the terrain, the widening of the vehicle road will lead to the narrowing of the pedestrian road. Therefore, the relationship between them was established and the degree of mutual influence was considered. In this process, 3 different methods were used for the values of the pedestrian paths. HCM, Landis and Autralian methods were studied. The value is "A" for HCM method, "A" for Landis method and "C" for Australian method. Considering the methods, the Australia method provides realistic results. Generally, when the results of the studies were compared it can be said that HCM method does not provide adequate results. When the parameters used in the method were only pedestrian density and roadway length are used. However, factors such as the quality of the sidewalk (e.g., pits, soil) and obstacles on the sidewalk (signs, trees, structures, bike lane) are not considered for calculations. Thus, this method can be inadequate in most cases and does not provide realistic results.

5. Conclusion

The aim of the study is determining by comparing the methods of LOS and PLOS and solving the traffic problem at the pediatric emergency entrance of Hacettepe Sıhhiye Campus. The results of this study can be summarized as follows:

Vehicle street LOS values were determined using the literature study. These values were used to determine the critical hours of the road with the heaviest traffic. According to the results, LOS values appear at "D" value during important hours as especially mornings. This situation is at a level that cannot be resolved with traffic regulations and lighting. Therefore, roadway width was changed. Since there is no suitable area because of it is at the center of the city and a hospital area, the widening was made as narrowing the sidewalks. When the roadway was expanded above a certain level, the value could be increased from "D" to "B". However, despite the changing of the pedestrian sidewalk, optimum performance could not be achieved on the vehicle road. Widening dimensions could be critical. When investigating by using three different PLOS methods, it can be said that HCM method can be generally inadequate. However, considering both pedestrian and vehicle traffic behaviors, Australian Method can give more optimum results.

Comparing studies in literature about street improvements, it can be highlighted that there are not many studies that are categorized by pedestrian routes. Especially, hospital areas behaviors can have critical effects. However, due to the inadequacy of some of the methods used, it has been determined that new and more compatible methods are needed for each area. Considering the inadequacy of these studies in the literature, the needing for this study can be significant.

Declaration of Interest Statement

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.

Author Contribution Statement

E. Cicek: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – Original Draft, Writing – Review & Editing; **T. B. Ozdemir:** Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Software, Visualization, Writing – Original Draft; **O. Kaplan:** Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Software, Visualization, Writing – Original Draft; **T. Yusel:** Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Software, Visualization, Writing – Original Draft; **M. O. Punar:** Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Software, Visualization, Writing – Original Draft.

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Research Article

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Sustainable production of WMA with pine gum wax modification

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Highlights

- Lower stripping resistance caused by the S® was increases by addiction of PGW
- PGW modified samples perform rutting resistance better than S®-WMA samples
- PGW modified S®-WMA reduced fatigue resistance more than S® samples
- Better low temperature cracking resistance performance by addiction of PGW

Abstract

Warm mix asphalt (WMA) (S®-WMA) produced with Sasobit® (S®), a widely used organic admixture, shows a significant increase in softening point value and a decrease in stripping resistance. These two characteristics of S®-WMA are considered as some problems to be solved. Therefore, this study was established to evaluate possible solutions to these two problems through another modification process. In this study, it was investigated whether modifying S®-WMA using a previously unstudied product, pine gum wax (PGW), could be a solution to the problem. In this context, WMA was produced with S® at 1, 2 and 3 in percent by mass of bitumen. As PGW has not been previously used as an additive to modify S®-WMA, it was added within a limit of 1% (by bitumen mass) for initial investigation. Physical and rheological standard tests were performed on each sample to demonstrate the change in properties of S®-WMA produced with 1% PGW compared to S®-WMA. The results indicated that the addition of 1% PGW to S®-WMA resulted in a significant reduction in softening point and an improvement in stripping resistance compared to S®-WMA. Thus, it seems that the use of PGW could be a potential solution for the two mentioned problems. It can also be pointed out that modifying the S®-WMA specimen with PGW without compromising its properties can help in an efficient, economical and environmentally friendly solution. However, due to the use of PGW, more in-depth research is required.

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1. Introduction

Hot mix asphalt (HMA) generates high amounts of greenhouse gas emissions during the production and construction process, causing environmental pollution [1]. It also endangers occupational health and safety due to its high working temperature. During the production and construction processes, HMA requires high temperatures of 150 °C and higher and a significant amount of heat energy, usually derived from fossil fuels [2]. Environmental contamination caused by the high amount of emission gases from fossil fuels, a major cause of global warming, has motivated researchers to search for solutions for high-temperature HMA production. In addition, growing social environmental awareness and sensitivity has also accelerated this solution process. In this context, research scientists have long been interested in the production of HMAs at lower temperatures on the principles of energy efficiency, cost effectiveness and environmental friendliness [3]. Therefore, researchers have developed a new asphalt technology known as warm mix asphalt (WMA) for the production and construction of a sustainable, cost-effective, ecological and energy-efficient flexible pavement as well as providing technical advantages. Over time, the use of HMA technology is gradually being replaced by WMA technology [4].

WMA technology intends to improve workability by reducing viscosity and decrease fuel consumption by lowering the processing temperature. As compared to HMA, WMA enables processing at lower mixing and compression temperatures of 100-135 °C or lower [5]. Thus, it preserves the environment by minimizing greenhouse gas emissions and contributes to

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occupational health and safety by ensuring a lower working temperature in the workplace [6].

Nowadays, there are a number of widely used WMA technologies with different levels of efficiency for a common objective [4]. These are categorized as (1) chemical, (2) foaming and (3) organic hot mix technologies [7]. There are many additives developed for use in WMA production. Some of them are Revix, Evotherm, Cecabase RT, Interlow, ZycothermTM Rediset ® LQ for chemical techniques; Licomont ® BS, Asphaltan A, Asphalt B, Sasobit ® and Ecoflex for organic hot mix; and Advera®, Zeolite, Aspha-min for foaming [8]. The organic WMA technology used in this study is mostly used in the transportation sector [9, 10]. This technology aims to significantly decreases the viscosity of the binder by blending WMA additives with some modified bitumen or HMA [11-13]. In this technology, after the additive is added to the bitumen, it is crystallized during cooling, leading to a harder binder. The best known and commonly used organic additive used in this study is Sasobit® produced by the Fisher-Tropsch (FT) process [14], where FT is produced by a process using natural gas [15].

Instead of presenting a detailed individual literature summary, it is important to highlight the outputs of the review articles in which hundreds of studies are cited to provide a broad perspective on WMA characteristic characteristics. Some of the reviewed review papers can be illustrated as those presented by Cheraghian et al [16], Diab et al [17] Sukhija and Saboo [18], Prakash and Suman [19], Abdullah et al [20], Guo et al [21]. All of them presented the advantages and disadvantages of WMA technology and categorized the advantages into environmental, economic and technical categories. The use of WMA technology is mainly attributed to environmental benefits, which include the minimization of energy use and the amount of greenhouse gases due to the lower thermal treatment than with HMA. It has been reported that the use of WMA can result in a reduction of greenhouse gases (Carbon dioxide, Sulphur dioxide, Nitrogen dioxide, Carbon monoxide, etc.) from the use of fossil fuels by between 10% and 70% and the amount of energy used in WMA production can be up to 20% less than that used in HMA processes. A reduction in WMA production and coating construction costs of between 10% and 40% can therefore be achieved, depending on parameters such as technology, product type and quantity. Cost savings can be achieved by improving occupational health and safety by working at lower temperatures and then improving the performance of workers. Apart from the environmental benefits, there are also some technical benefits that can be expressed as the follows: (1) Enhanced workability throughout the entire construction phase. (2) Extending the construction season and enabling work in cold weather conditions. (3) Reducing the time required to open the pavement to traffic by enabling faster curing following pavement construction. (4) Permitting longer distances and transportation times between the construction site and bitumen plants due to low temperature operation; (5) Demonstrating a significant increase or decrease in binder and mixture performance.

Excessive increase in softening point and low moisture resistance are two problems for (S®-WMA). In the perspective of numerous existing studies [9, 22-31], solutions can be on the basis of modifying the WMA with supplemental additives. To address these problems, S®-WMA was prepared with S® with a 1% increase from 1% to 3% (by weight of bitumen). For the modification of S®-WMA, Pine Gum Wax (PGW) was used, which has not been used in any WMA preparation before. Apart from being an organic product like S®, the main reason behind the use of PGW is due to the fact that it exhibits some physical and mechanical properties similar to bitumen. Consequently, as a preliminary preparation for the use of PGW, only 1% (by weight of bitumen) was added to each S®-WMA produced at each S® ratio for modification purposes. Last but not least, the properties of the new S®-WMA were analysed through a series of physical and rheological test methods.

2. Material and Method

2.1. Material

In the production of S®-WMA and PGW modified S®-WMA specimens, 70/100 penetration grade base bitumen obtained from Batman refinery was used. Also, the aggregate used in this study to investigate the peel resistance of the produced WMA specimens was basalt. The reason for using basalt is its wide use in the region and the stripping resistance can be seen more clearly. Table 1 and Table 2 show the properties of the base bitumen and aggregate.

Table 1. Properties of bitumen

Test methods	Unit	Standard	Results
Penetration (at 25°C)	0.01 mm	EN 1426	85.7
Softening Point	°C	EN 1427	50.5
Flashing Point	°C	EN 22592-b	240.0
Ductility (at 25°C)	cm	EN 13589	103.8
Viscosity (135 °C)	cP	ASTM D4402	405.6
Viscosity (165 °C)			112.3
Solubility	%	EN 12592	99.4
Density	g/cm³	EN 1087	1.032

All the results are presented for each test specimen, taking into account a series of nomenclature according to the principle given below.

- Base Bitumen: BB
- Sasobit® S
- Pine Gum Warm Wax: PGW
- Modified Bitumen with S + X (%): S-X
- Modified Bitumen with PGW + X (%): PGW -X

- Modified Bitumen with combination of S and PGW + X (%): SPGW-X

where, X is the rate of Sasobit® as a percentage by mass of bitumen.

Table 2. Properties of bitumen

Test methods	Unit	Standard	Results
Water Absorption (Coarse)	%	EN 1097-6	2.22
Water Absorption (Fine)		EN 1097-6	8.79
Unit Weight (Coarse)	g/cm3	EN 1097-6	2.63
Unit Weight (Fine)		EN 1097-6	3.08
Unit Weight (Filler)		EN 1097-7	2.72
LA Fragmentation Resistance	%	EN 1097-2	18.95
Weathering Resistance		EN 1367-1	8.15
MD Abrasion Resistance		EN 1097-1	9.94
Polish Stone Value	PSV	EN 1097-8	56.79
Flakiness Index	%	EN 933-3	11.92
Mytilene Blue	MB	EN 933-9	1.75
Stripping Test	%	EN 12697-11	40-45

3. Method

3.1. Physical test methods

Within the scope of physical test methods, penetration, softening point, rotational viscometer tests and Nicholson stripping tests were performed on bitumen samples. In addition, the thermal sensitivity of each sample was determined using the penetration index developed based on the penetration and softening point test results.

Penetration test method: The test helps researchers to ensure adequate consistency of bituminous binder. It is used to determine the hardness or consistency of bitumen. The EN 1426 standard [32] was followed to perform the test on test samples in this study.

Softening point test method: The test helps researchers to ensure adequate fluidity before it is used for a variety of road applications. It is used to determine the temperature at which the bituminous binder reaches a certain softening phase. EN 1427 standard [33] was followed to test samples in this study.

Rotational viscometer test method: The test helps researchers to measure the apparent viscosity of bituminous binders at different temperatures. The test is applied under controlled temperature provided by thermal chamber and rotational rate. The tests were conducted on the samples according to ASTM D 4402 standard [34]. Considering the viscosity data provided at different temperatures, usually 135 and 165°C, it is possible to estimate the mixing and compaction temperatures of asphalt binders. In this study, viscosity tests were carried out for each unaged sample at the specified temperatures. The viscosity values defined for the determination of mixing and compression temperatures of bitumen samples are 170 ± 20 centipoise (cP) and 280 ± 30 cP, respectively [35].

Nicholson stripping test method: This test is based on coating a defined size and quantity of aggregate with a certain amount of bitumen and keeping the test specimens prepared in this way in water at a constant temperature for a certain period of time to determine whether they strip or not by visual analysis. The EN 12697-11 standard [36] was followed for implementing the test in this study.

3.2. Rheological test methods

The rheological properties of bituminous binders are presented in the Superior Performance Asphalt Pavements (SuperPAVE) system developed by the Strategic Highway Research Program [37]. Within the scope of testing defined in the SuperPAVE system, there are test methods that measure the rheological properties of bitumen samples. These test methods are as follows: (1) Dynamic Shear Rheometer (DSR), (2) Bending Beam Rheometer (BBR), (3) Rolling Thin Film Oven (RTFO) for short-term aged samples and (4) Pressure Aging Vessel (PAV) for long-term aged samples [38, 39].

Dynamic Shear Rheometer-DSR: It is one of the main machine systems used in SuperPAVE. The test is performed within a uniquely designed logical framework and analyzed with a dedicated software program. The test is performed on unaged, short- and long-term aged bitumen samples. Complex shear modulus (G*) and phase angle (δ°) are the two parameters obtained from the test. The phase angle means that bitumen specimens are elastic as they approach 0° and viscous as they approach 90°. The interrelationships developed between G* and δ° provide information on the structural performance of the bituminous binder, including rutting and fatigue resistance. The rutting factor is determined by G*/Sin(δ°), while the fatigue factor is calculated by G*. It is calculated with Sin(δ°). The SuperPAVE system determines limit values taking into account different aging conditions. These limit values are defined as 1000 Pa (1 kPa) and 2200 Pa (2.2 kPa) in the G*/Sin(δ°) for non-aged and short-term aged specimens, respectively, and 5 × 106 Pa (5000 kPa) for G*.Sin(δ°) for long-term aged specimens. Testing of DSR was performed on the specimens in accordance with EN 14770 [40].

Bending Beam Rheometer-BBR: The system of the machine is used to determine low temperature properties through thermal cracking and relaxation. The test is applied to long-term aged bitumen samples. The BBR test has two test parameters, creep stiffness (St) and m-value. St is the quotient of the bending stress and bending strain under the specified load, while m-value is the slope of the creep stiffness at 60 seconds. As with the DSR, the limit values are defined as a maximum of 300 MPa for St and a minimum of 0.300 for m-value. The test temperature that satisfies both two limit values is labelled low temperature resistance or thermal cracking. Testing is performed on specimens following the EN 14771 standard [41].

Table 3. Physical test result

Test method	BB	S-1	S-2	S-3	PGW	SPGW-1	SPGW-2	SPGW-3
Penetration (0.01. mm)	85.7	58.1	49.5	49.0	81.5	58.0	51.8	50.8
Softening Point (℃)	50.5	62.5	67.1	69.0	51.4	61.8	65.6	67.7
Penetration (dmm)	70.2	50.0	44.8	30.6	45.7	36.3	35.7	29.2
Softening Point (℃) (After short-term Aging)	59.3	65.5	69.6	71.0	62.0	62.3	67.7	69.2
Mass Loss (%)	0.45	0.25	0.30	0.40	0.60	0.71	0.43	0.60

Rolling Thin Film Oven-RTFO: Bitumen during mixing, transportation and compaction undergoes some aging process, referred to as short-term aging. It is possible to simulate aging under laboratory conditions using the Rolling Thin Film Oven (RTFO) test method. The test system consists of a specially designed rotary oven, standard open-end glasses and an air supply compressor. The testing occurs under a defined speed and temperature by blowing hot dry air from the open end into the specimen, which exposes the specimens spread as a thin film on the glass. The test is conducted according to the EN 12607-1 standard [42].

Pressure Aging Vessel-PAV: Long-term aging is the aging process occurring from the production of bitumen samples until the end of their service life. As with RTFO, it is possible to collect long-term aged bitumen samples under laboratory conditions. The testing systems consist of a container, a dry air supply compressor and a set of sample plates. The test can be at 90, 100, 110 °C under a pressure of 2.1 kPa. In this study, the testing was carried out according to EN 14769 standard [43].

3.3. Modification process

The bitumen modification procedure below was determined in the light of previous studies [9, 17, 26-29, 44-46].

Step 1. The bitumen needs to be liquefied and in this respect the base bitumen was heated at 160 ± 5 °C for 60 minutes.
Step 2. 500 grams of heated bitumen was then transferred into metal cans.
Step 3. The cans (filled with bitumen samples) were placed one by one on a heater running at 140 ± 5 °C.
Step 4. S® and PGW additives were mixed into the bitumen in the specified proportion and mixed for 30 minutes with a propeller mixer at 500 rpm.
Step 5. The modified bitumen was mixed again for the next 10 minutes with the mixer running at 100 rpm to ensure successful bitumen modification through homogeneity.
Step 6. Finally, the modified bitumen samples were transferred for testing.

4. Results and Discussion

4.1. Physical test methods

Results of physical tests of bitumen including penetration, softening point tests and analysis of the penetration index based on these tests. Also, the mass loss of the base and short-term aged specimens is presented in Table 3.

From the results shown in Table 3, the penetration value of the specimens decreased as the S® content increased significantly. Though the addition of PGW at 1% (by weight of bitumen) decreases the penetration, the rate of decrease is much lower than that with added S®. Together, the use of both additives in the bitumen resulted in a slight increase in the penetration of the samples. However, the addition of PGW to the base bitumen increases the softening point value. PGW addition, compared to the other, results in a significant decrease. This prevents the excessive rise of the softening point observed in the S®-WMA specimens. For all specimens, the mass loss after short-term aging is below the allowable limit of 1%. Short-term aging leads to an increase in hardness, which results in a decrease in the penetration value and an increase in the softening point value.

The rotational viscosity test results were determined at two temperatures, 135℃ and 165℃, and the calculated mixing and compression temperature ranges are given in Table 4.

Table 4. Viscosity and mixing-compaction temperature results

Samples	Viscosity (cP) 135 °C	Viscosity (cP) 165 °C	Mixing Temperature (°C)	Compaction Temperature (°C)
BB	405.6	112.3	157.1-161.1	144.8-150.9
S-1	345.4	101.1	154.1-159.0	139.3-146.7
S-2	284.8	95.5	150.0-156.4	131.0-140.5
S-3	252.5	81.6	146.0-153.0	124.9-135.4
PGW	366.4	100.8	154.9-159.4	141.4-148.1
SPGW-1	309.6	96.1	151.8-157.4	134.9-143.4
SPGW-2	344.8	89.5	153.2-157.9	139.1-146.1
SPGW-3	355.6	88.3	153.6-158.1	140.1-146.9

As mentioned earlier, the secondary motivation that led to the establishment of this work was to overcome the problem of stripping of S®-WMA specimens. To overcome this, 1% of PGW was added to S®-WMA due to some of the inherent properties of the bitumen such as stickiness, oily structure and temperature sensitivity. The stripping resistances of both S®-WMA and SPGW bitumen samples are reported, and the results and post-test sample images are shown in Figure 1. One can see from Figure 1 that the S® modification reduces the stripping resistance of the base bitumen as the rate increases. On the other hand, the addition of PGW significantly increases the stripping resistance of the base bitumen.

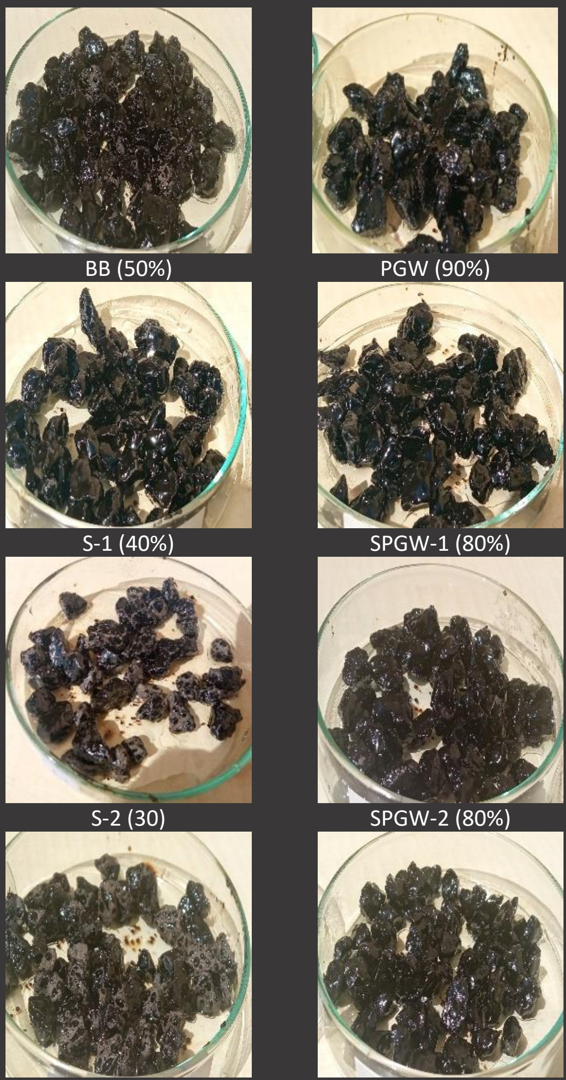

Figure 1. Nicholson stripping resistance results

4.2. Rheological test methods

Under constant and/or variable loading and high temperature conditions, the prepared untreated, i.e. unaged, short-term and long-term aged specimens were analysed by DSR. Furthermore, the long-term aged specimens are subjected to BBR tests at the specified temperature. Besides, RTFO and PAV tests are used to provide short- and long-term aged specimens, respectively. DSR test results for all specimens under different aging conditions are given in Figures 2 to 4.

The DSR test results presented in Figures 2 and 3 show that the rutting resistance of the bitumen samples increased with S® modification. As the S® content increases, the rutting resistance also increases. In this sense, the highest value was determined for the highest content ratio in the additive, whereas the addition of PGW decreases the rutting resistance. The lowest rutting resistance performance of SPGW bitumen samples is seen for SPGW-1.

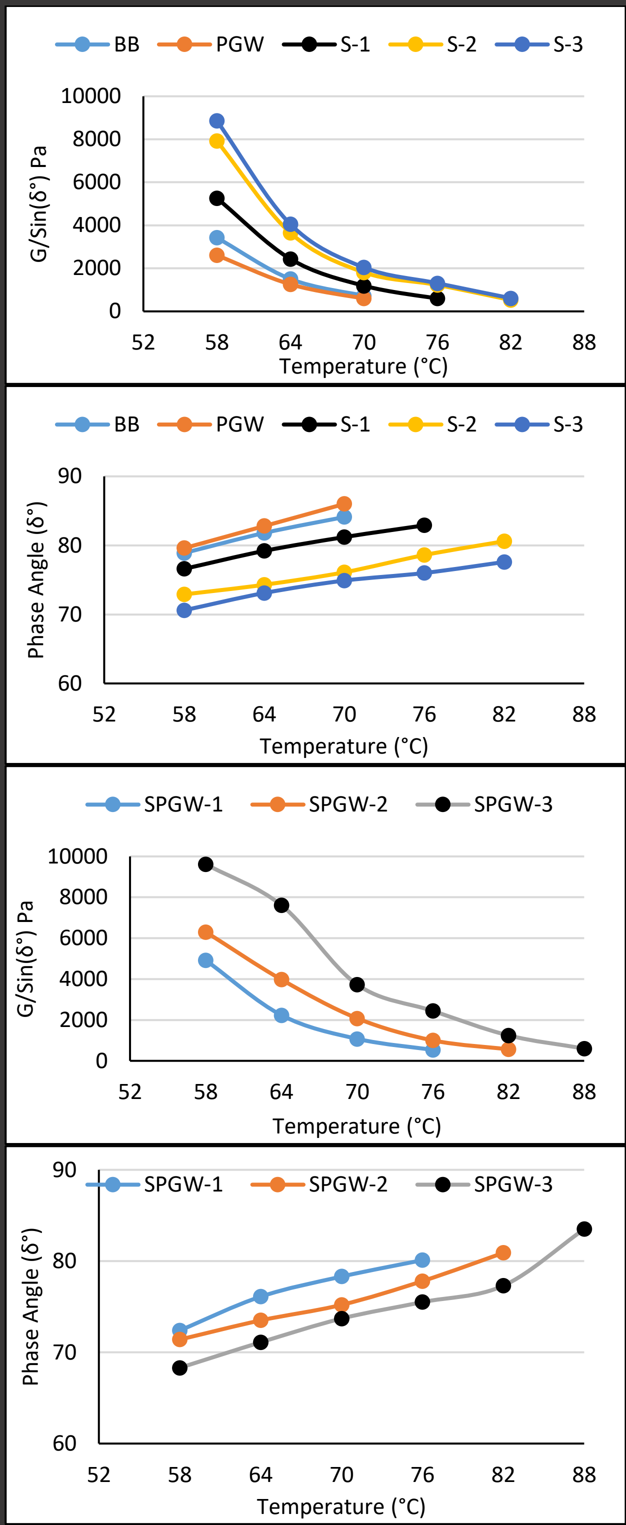

Figure 2. DSR results for unaged bitumen samples

The DSR results given in Figure 4 show the fatigue resistance of the specimens. The fatigue resistance of the modified bitumen decreases with the addition of S® and this becomes more pronounced as the rate increases. There is, however, a modification that does not significantly change the performance of the PGW modified one. The reduction in the fatigue performance of the bitumen, on the other hand, is more pronounced for the SPGW specimens.

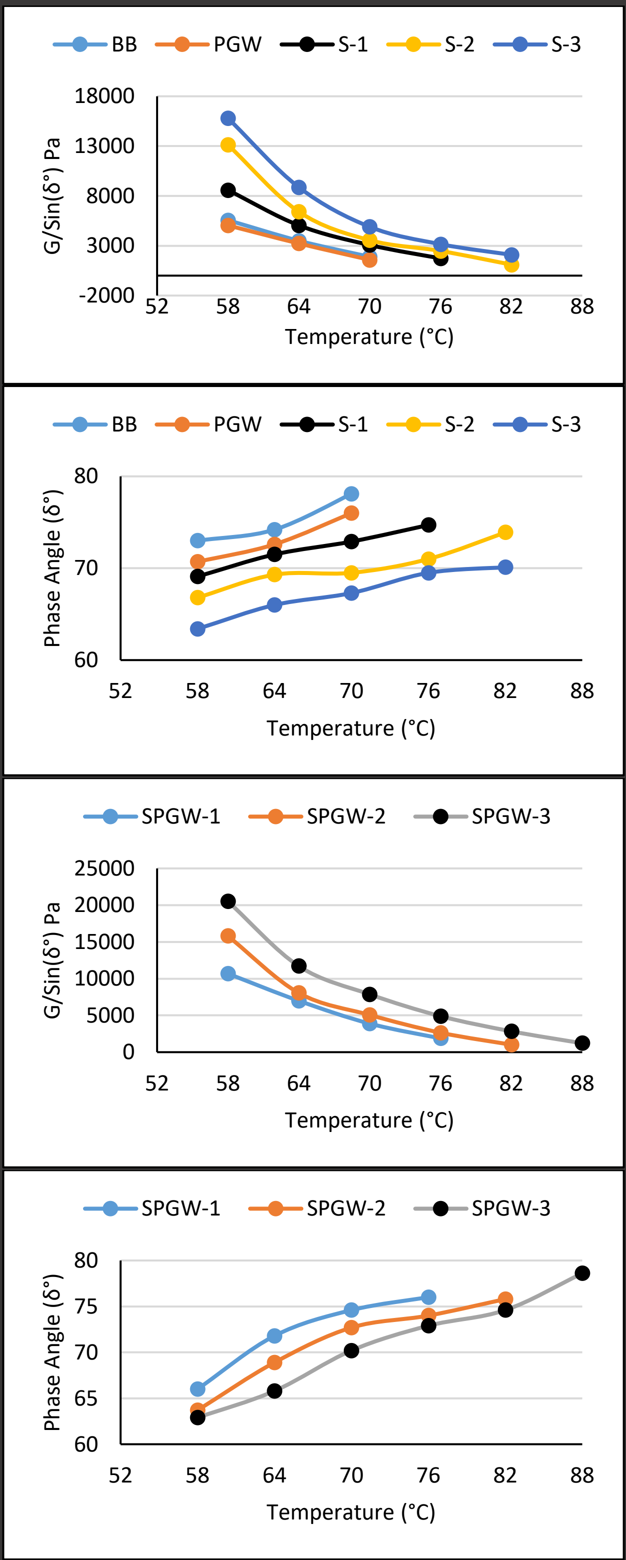

Figure 3. DSR results for short-term aged bitumen samples

For the whole study, BBR tests were only carried out at -18°C. Because, the temperature at which all specimens satisfy the requirements (the limit values are defined as a maximum of 300 MPa for St and a minimum of 0.300 for m-value) as specified in the SuperPAVE system. Therefore, no further BBR testing at different temperatures was required to ensure an adequate test temperature that met both parameters. It is seen from the test results presented in Figure 5 that all specimens met the minimum St and m-value criteria.

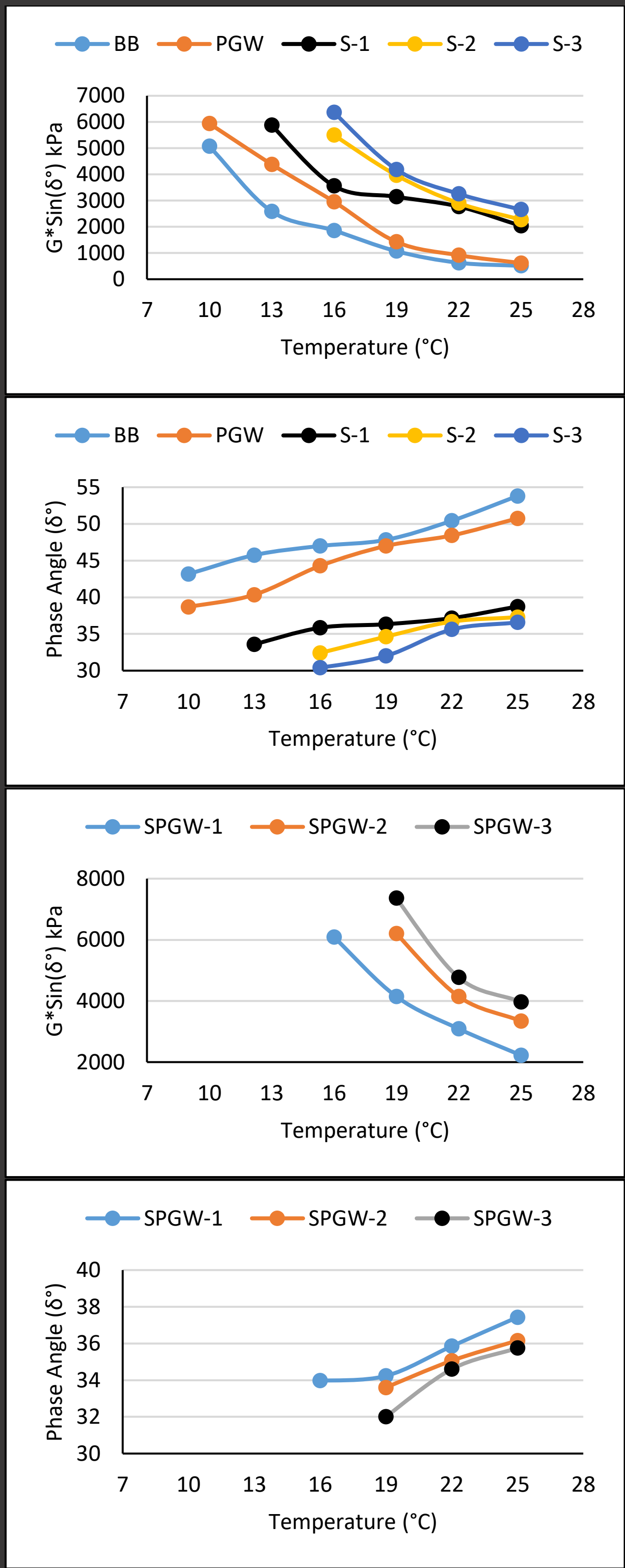

Figure 4. DSR results for long-term aged bitumen samples

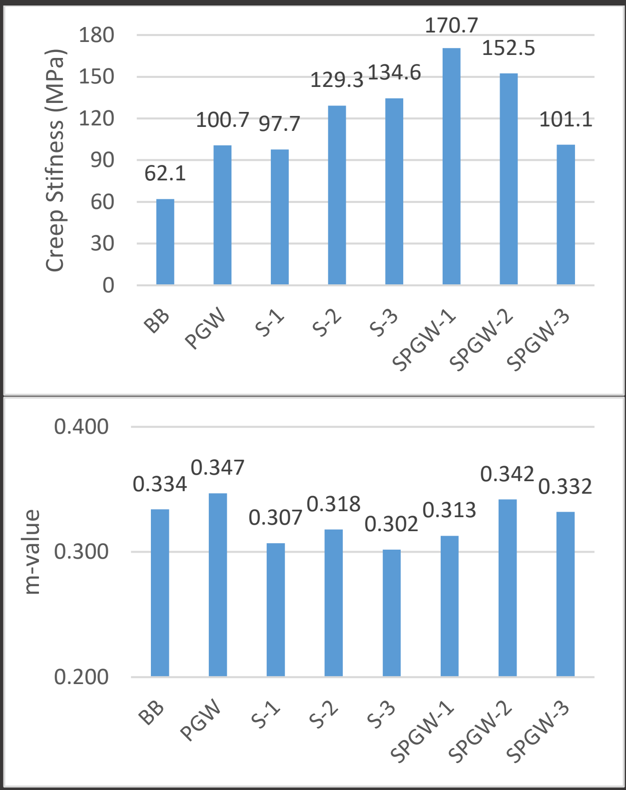

Figure 5. BBR test results

The classification based on the SuperPAVE system is determined by the degradation temperatures determined by the DSR test applied to unaged and short-term aged bitumen samples, as well as the temperature determined by the BBR test applied to long-term aged samples. In this context, Table 5 is provided to illustrate the SuperPAVE-based classification of each bitumen sample.

Table 5. SuperPAVE classification for bitumen samples

Samples	High temperature Grade	Low Temperature Grade	SuperPAVE Classification
BB	64	- 18	64-18
S-1	70	- 18	70-18
S-2	76	- 18	76-18
S-3	76	- 18	76-18
PGW	64	- 18	64-18
SPGW-1	70	- 18	70-18
SPGW-2	76	- 18	76-18
SPGW-3	82	- 18	82-18

5. Conclusions

In the present study, a possible solution to the two common problems of S®-WMA bitumen (excessive increase in softening point and decrease in peel resistance) was investigated. In this context, S®-WMA bitumen samples prepared with different proportions of Sasobit® additives were modified using 1% PGW, a commercial industrial product that has not been studied before, as far as can be seen from the available literature. To this end, Sasobit® additives were used in 1% increments up to 3% (by bitumen weight) to modify 70/100 penetration base bitumen for WMA production. A series of physical and rheological properties characteristics of the bitumen samples were determined by the standard test methods. Consequently, the following can be pointed out.

- A significant decrease in penetration results occurred with the S® modification, but the decrease in penetration was realized with the addition of PGW.
- The softening point showed an excessive increase with the S® modification, but a significant decrease in softening point was obtained with the addition of PGW.
- The low stripping resistance caused by the S® modification increased with the addition of PGW.
- The specimens with PGW showed less rutting resistance than the S®-WMA specimens.
- The fatigue resistance of PGW modified S®-WMA decreased more than that of Sasobit® modification.
- The low temperature cracking resistance performance of SPGW specimens is better than that of S®-WMA specimens.

Altogether, this study shows that adding 1% PGW additive to S®-WMA can help to produce an innovative, effective, environmentally friendly and sustainable product. Overall, this study shows that the addition of 1% PGW additive to S®-WMA may help an innovative, effective, environmentally friendly and economical solution to overcome the excessive increase in softening point and low stripping resistance.

From existing studies, it can be seen that PGW has not been used before in WMA production, especially not in WMA produced with S®. For this reason, as a preliminary study, the PGW utilization rate was kept low at 1%. As such, the scope of future studies may include the use of PGW at higher rates. The analyses in the study were limited to a series of physical and rheological tests and analysis methods. It is suggested that the study be expanded in the future to include chemical, image processing and/or microscopic analyses to gain a deeper understanding of the relationship between the materials. Furthermore, the production of WMA blend samples was beyond the scope of the present study. Therefore, future studies are needed to investigate the structural and functional performance of WMA blend samples within the parameters defined in this study.

Declaration of Interest Statement

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

Author Contribution Statement

İ. Gökalp: Conceptualization, Formal analysis, Methodology, Resources, Supervision, Validation, Writing – Original Draft, Writing – Review & Editing; **R. Yani:** Data curation, Formal analysis, Investigation, Resources, Visualization, Writing – Original Draft.

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Research Article

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Investigation of the road network structure around rail transit stations

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Highlights

- Road network connectivity around rail transit stations were examined
- Road network connectivity scores were evaluated for different buffer zone sizes
- Stations near the high-density areas revealed a higher connectivity score

Abstract

This study examined the connectivity of road networks around rail transit stations in İzmir, Türkiye, using intersection density and connected node ratio metrics. The analysis was conducted within 800 m, 600 m, and 400 m catchment areas around these stations, which were considered reasonable walking distances. Rail transit stations and road networks were digitized using ArcGIS Pro software. The research identified variations in connectivity scores among different stations and buffer zones. Stations in high-density areas like Konak and those near the ferry port showed higher connectivity scores, indicating well-integrated street networks that support multimodal transportation. In contrast, stations such as Ataşehir and Mavişehir, where intersection densities were lower, demonstrated significant connectivity challenges, underscoring the necessity for targeted urban planning interventions.

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1. Introduction

Enhancing rail transit station connectivity is regarded as a key strategy for i) reducing the high intensity of traffic flow due to the private vehicles [1], ii) promoting sustainable urban mobility, and iii) creating more liveable cities [2,3]. To decrease the private car use, cities have aimed to expand their rail transit networks, strategically positioning stations to facilitate connections with other environmentally friendly transportation modes and enhance multimodal connectivity [1,4-5]. Friedrich et al. [6] stated that rail transit systems are regarded as the core of public transportation system in China, improving the road network connectivity of the cities. According to the Song et al. [7], establishing a new rail transit network resulted in an increase of 25% of urban road network connectivity. Yang and Liang [1] stated that 57.5% of rail transit stations in Wuxi, China had low connectivity. The connectivity of the stations was assessed in terms of average transfer time, interchange demand, comfort and interchange information services. In addition to these, evaluating the rail transit station connectivity has been evaluated for the different purposes such as the integration of non-motorized modes such as bicycles for first/last mile travels. For example, Guo et al. [8] investigated the impact of the several independent variables for the frequencies of bicycle-metro system integration. The intersection density, is a way of measuring the connectivity score, was found significant variable affecting the number of bicycle-metro integration. In contrast, Wu et al. [9] investigated the impact of the connectivity level of road network near the stations for bike-metro integration in Shenzhen, China. Different buffer zone size was trained but it was not found significant variable.

In addition to the aforementioned studies, it is crucial to outline the connectivity level of the road network around rail transit stations in terms of various buffer zones and metrics. This aspect has not been comprehensively discussed in the literature, highlighting the need for further exploration which is the focus of this research. The Light Rail Transit (LRT) network in İzmir serves as a vital component of the city's public transportation system, linking various neighbourhoods and facilitating the movement of people across the urban landscape. Despite the evident importance of these networks, there is a need for comprehensive studies that assess their effectiveness

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in enhancing connectivity and accessibility within the city. This study focuses on the evaluation of the road network connectivity around the two rail transit stations serving in İzmir, Türkiye. Two connectivity measures were selected from the literature and the results concluded about the current stations connectivity level. The results will inform urban planners and policymakers about the areas where connectivity can be enhanced, ultimately contributing to a more efficient and accessible urban transportation system.

2. Methodology

The methodology section is composed of two main subsections. Firstly, the study area is introduced, followed by the evaluation process of road network connectivity around rail transit stations.

2.1. Study area

In this study, the Konak and Karşıyaka trams in İzmir province were examined. The Konak tram is located in the Konak district, one of the central and busiest areas of İzmir. The tram line is 12.8 kilometers long and comprises 19 stations (Figure 1). It runs from Fahrettin Altay Station, a major transportation hub, to Halkapınar Station. Along its route, the tram passes through significant locations such as Konak Square and the historic Kemeraltı Bazaar. The Karşıyaka Tram serves the Karşıyaka district, which is located on the northern shore of Izmir Bay. The total length of Karşıyaka tram is 8.8 km and it has 14 stations and passes through various residential areas, commercial districts, and transportation hubs. It serves between Ataşehir and Alaybey stations (Figure 1).

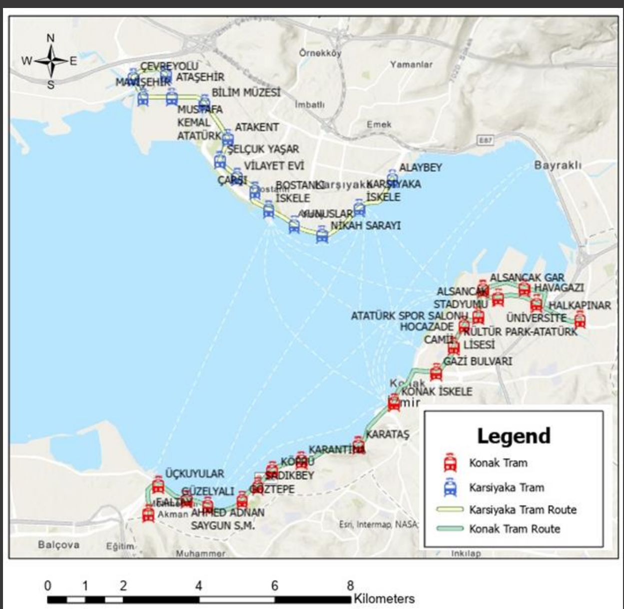

Figure 1. LRT routes in İzmir, Türkiye

2.2. Evaluation process of the road network around rail transit stations

ArcGIS Pro software was utilized to digitize the rail transit stations and road network data. Three different catchment areas (buffer zones) were defined, considering reasonable walking distances of 400 m, 600 m, and 800 m. These values were selected based on studies in the literature. For example, Li et al. [10] conducted a study to investigate the best catchment area using the metro ridership data of the six cities in USA, concluding that the catchment area of rail transit stations was in between 600 m -1200 m. El-Geneidy et al. [11] stated that the typical walking distance to rail transit stations is generally around 800 m. However, this value was found to range from 400 m to 900 m for North American cities [12]. Kim et al. [13] preferred to take 400 m, while 600 m catchment area was taken in studies [14-16].

An example buffer zone of each station for the 600 m is illustrated in Figure 2. Sea regions have been removed from the area of the buffers. The road network topology was examined. Intersection and dangle nodes, as well as the number of links within each buffer calculated automatically in ArcGIS Pro software (Figure 2). Two metrics from the literature were chosen for connectivity analysis: intersection density [17-21] and Connected Node Ratio (CNR) [17,22]. Intersection density measures the number of intersections per unit area, with higher densities generally indicating greater connectivity [17]. The CNR is calculated by dividing the number of street intersections by the total number of nodes (intersections plus cul-de-sacs). In other words, the number of real nodes divided by the total nodes (real + dangle). A higher CNR indicates that more nodes are interconnected, signifying a more connected network [17]. These metrics were derived separately for each station within the selected buffer zones.

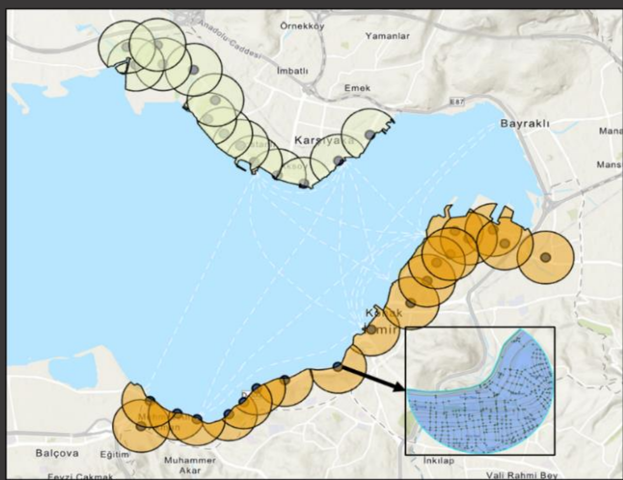
Figure 2. Illustrations of 600 m buffer zones of rail transit stations

3. Results and Discussions

The intersection density results for various buffer zone sizes around each station are summarized in Table 1. For Karşıyaka tram, the highest intersection density is observed at Bostanlı İskele, a value of 365.7 at 400 m. This indicates a very dense and well-connected street network at close proximity, further supported by high values of 267.2 at 600 m and 222.1 at 800 m, reflecting excellent connectivity across different distances.

Table 1. Intersection density values for different sizes of buffer zones

No	Name	400m	600m	800m
	Karşıyaka Tram			
1	Yunuslar	169.43	158.61	170.08
2	Nikah Sarayı	77.39	76.24	109.54
3	Karşıyaka İskele	122.93	143.44	157.15
4	Bostanlı İskele	365.67	267.15	222.05
5	Alaybey	235.66	193.21	201.94
6	Çarşı	195.18	192.97	188.49
7	Vilayet Evi	163.48	169.27	177.26
8	Selçuk Yaşar	332.47	306.57	264.07
9	Atakent	300.41	292.67	279.90
10	Bilim Müzesi	101.46	90.19	117.87
11	Mustafa Kemal Atatürk	69.63	66.31	85.55
12	Mavişehir	89.41	70.60	79.92
13	Çevreyolu	58.49	68.46	69.14
14	Ataşehir	59.68	91.96	53.22
	Konak Tram			
1	Alsancak Gar	165.12	142.23	134.89
2	Halkapınar	155.18	142.36	130.81
3	Havagazı	148.05	100.91	77.94
4	Alsancak Stadyumu	79.58	109.64	109.50
5	Konak İskele	391.69	317.02	295.50
6	Gazi Bulvarı	212.87	212.21	202.84
7	Karataş	248.93	237.40	259.86
8	F.Altay	137.27	117.60	125.83
9	Karantina	178.45	208.27	189.40
10	Ahmed Adnan Saygun	107.69	106.63	128.87
11	Göztepe	110.82	181.12	168.70
12	Güzelyalı	169.28	173.10	170.73
13	Köprü	106.03	149.21	148.96
14	Sadıkbey	69.22	75.02	115.48
15	Üçkuyular	148.51	78.43	64.34
16	Kültür Park-Atatürk Lisesi	121.36	109.64	117.25
17	Hocazade Camii	149.21	162.69	158.47
18	Üniversite	109.42	104.34	96.57
19	Atatürk Spor Salonu	127.32	129.98	146.72

Conversely, Ataşehir records the lowest intersection densities across all distances, with values of 59.7 at 400 m, 92.0 at 600 m, and 53.2 at 800 m, suggesting significant connectivity challenges and a less integrated street network that may impede accessibility. Atakent station shows consistently high average intersection densities, with values of 300.4 at 400 m, 292.7 at 600 m, and 279.9 at 800 m, indicating a robust and well-integrated urban network that facilitates better mobility and accessibility. In contrast, Mavişehir has the lowest average intersection densities, with values of 89.4 at 400 m, 70.6 at 600 m, and 79.9 at 800 m, pointing to a less dense street network and highlighting potential areas for connectivity improvement. Regarding the Konak tram stations, Konak İskele, Gazi Bulvarı, and Karataş stations show higher intersection density values. These stations are located in areas predominantly characterized by commercial and residential zones. Konak İskele exhibits the highest intersection densities across all buffer zones with 295.5 at 800 m, 317.0 at 600 m, and 391.7 at 400 m. This makes it the most connected area, suggesting excellent connectivity and potential for pedestrian movement. Karataş, with consistently high intersection densities of 259.9 at 800 m, 237.4 at 600 m, and 248.9 at 400 m, indicates robust connectivity and strong urban integration. Alsancak Gar station, with intersection densities of 134.9 at 800 m, 142.2 at 600 m, and 165.1 at 400 m, shows moderate connectivity, supporting good accessibility without being overly dense. Halkapınar station, exhibiting intersection densities of 130.8 at 800 m, 142.4 at 600 m, and 155.2 at 400 m, indicates a balanced level of connectivity. Sadıkbey station, with lower intersection densities of 115.5 at 800 m, 75.0 at 600 m, and 69.2 at 400 m, suggests poorer street network connectivity and potentially lower accessibility. Üçkuyular station, displaying the lowest intersection densities with values of 64.3 at 800 m, 78.4 at 600 m, and 148.5 at 400 m, indicates significant challenges in connectivity. Additionally, Intersection density values were visualized using color-coded maps (Figure 3) where green indicated high intersection density and red indicated low intersection density. These maps were created for each buffer zones around the stations. The maps helped in visually interpreting the spatial distribution of intersection density and identifying areas with varying levels of connectivity.

CNR values for Karşıyaka Tram stations varies from 0.67 to 1.00, with the latter indicating well-structured road networks (Table 2). While the Nikah Sarayı station has a lower CNR value, Mavişehir and Mustafa Kemal Atatürk stations each has a value of 1. It is important to note that, despite the lower intersection density values around these stations, the CNR results were very high. Therefore, relying on a single metric to evaluate connectivity is not robust. On the other hand, Nikah Sarayı stations has both lower intersection density and CNR; hence further improvements are necessary to enhance the connectivity to this rail transit station. For the Konak Tram station (Table 2), it can be concluded that CNR scores of the station are very close to the 1.00, indicating the perfect structured road network. Alsancak Stadyum station has a lower CNR score, whereas Köprü and Üniversite stations have the highest scores. However, for the Alsancak Stadyum station, increasing the buffer zone size results in a higher CNR for this station.

4. Conclusions

This study provides a thorough evaluation of the connectivity of the road network structure around the Light Rail Transit Stations serving in İzmir, Türkiye. Two different metrics were selected, intersection density and connected road ratio (CNR) for this purpose. By assessing intersection densities and CNR within 800 m, 600 m, and 400 m buffer zones around each tramway station, the research highlights significant variability in urban connectivity. This approach provides insights into connectivity levels and identifies areas for potential improvements. Stations such as Bostanlı İskele, Selçuk Yaşar, and Atakent exhibit higher intersection densities, indicating well-connected road networks. In contrast, stations like Mavişehir, Çevre Yolu, and Ataşehir have lower intersection densities, suggesting areas where connectivity improvements are needed. For areas with low intersection densities, urban planning efforts should focus on improving the street network to enhance connectivity and accessibility. This could include adding more intersections to create a more integrated street network.

Table 2. CNR values for different sizes of buffer zones

No	Name	400m	600m	800m
	Karşıyaka Tram			
1	Yunuslar	0.91	0.93	0.91
2	Nikah Sarayı	0.67	0.74	0.85
3	Karşıyaka İskele	0.87	0.94	0.93
4	Bostanlı İskele	0.91	0.93	0.94
5	Alaybey	0.92	0.93	0.92
6	Çarşı	0.94	0.96	0.95
7	Vilayet Evi	0.96	0.95	0.96
8	Selçuk Yaşar	0.98	0.98	0.97
9	Atakent	0.97	0.95	0.96
10	Bilim Müzesi	0.86	0.88	0.89
11	Mustafa Kemal Atatürk	1.00	0.99	0.97
12	Mavişehir	1.00	0.95	0.92
13	Çevreyolu	0.94	0.91	0.92
14	Ataşehir	0.88	0.94	0.92
	Konak Tram			
1	Alsancak Gar	0.90	0.90	0.91
2	Halkapınar	0.90	0.90	0.91
3	Havagazı	0.96	0.94	0.87
4	Alsancak Stadyumu	0.73	0.83	0.88
5	Konak İskele	0.93	0.92	0.92
6	Gazi Bulvarı	0.97	0.94	0.93
7	Karataş	0.96	0.96	0.96
8	F.Altay	0.95	0.96	0.98
9	Karantina	0.92	0.96	0.96
10	Ahmed Adnan Saygun	0.91	0.93	0.93
11	Göztepe	0.94	0.96	0.94
12	Güzelyalı	0.92	0.90	0.93
13	Köprü	1.00	0.99	0.99
14	Sadıkbey	0.95	0.94	0.96
15	Üçkuyular	0.98	0.98	0.95
16	Kültür Park-Atatürk Lisesi	0.97	0.98	0.98
17	Hocazade Camii	0.99	0.99	0.97
18	Üniversite	1.00	0.98	0.94
19	Atatürk Spor Salonu	0.94	0.96	0.96

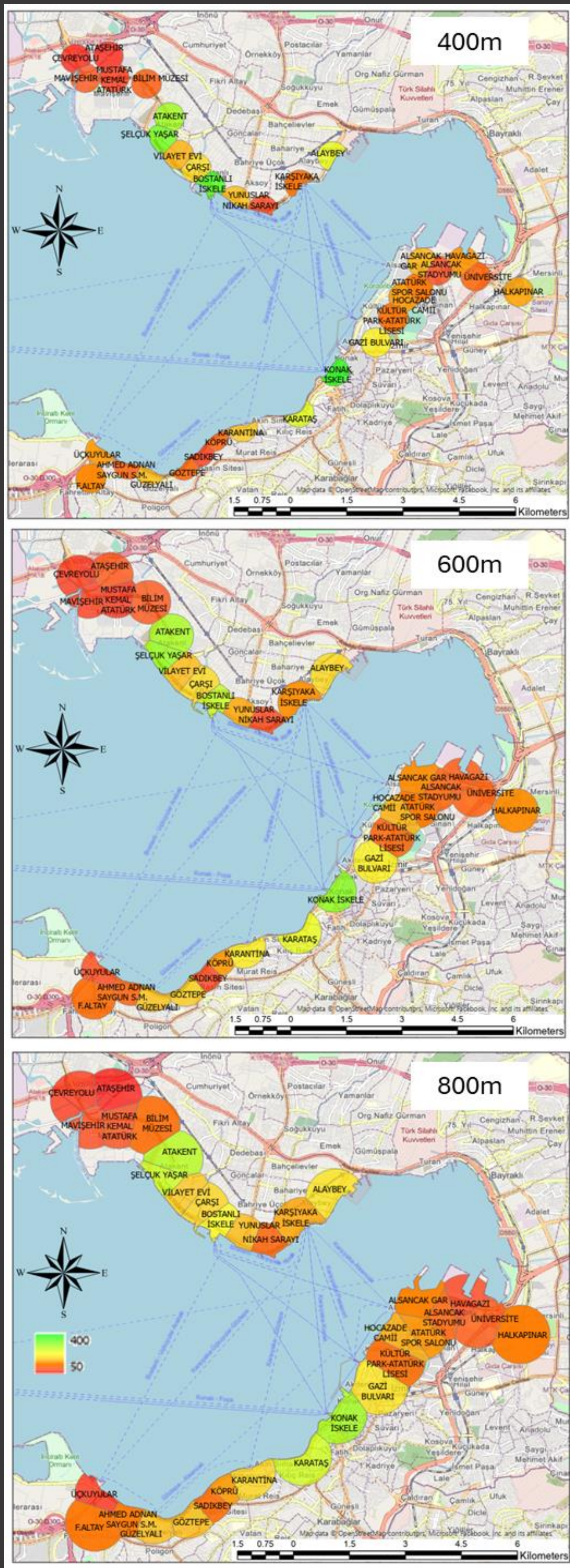

Figure 3. Coloured visuals of intersection density values for the different sizes of buffer zones

Declaration of Interest Statement

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.

Author Contribution Statement

O. Altintasi: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Supervision, Writing – Original Draft, Writing – Review & Editing; **A. Kundakci:** Data curation, Formal analysis, Investigation, Software, Visualization, Writing – Original Draft, Writing – Review & Editing.

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