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GIS Based Bus Stop Optimisation for Sakarya Public Transportation System

Hakan Aslan*¹ and Hakan Kocaman

ABSTRACT

In today's world, the needs for transportation have increased and the existing solutions have become insufficient in response to the demand especially with the increase of urban life and the widespread urbanisation. For this reason, local authorities aim to improve urban public transportation services, one of the effective in-city transportation solutions, in order to solve the current needs of transport and reduce or regulate the current traffic intensity. In this study, geographical information system (GIS) was used to analyse the relationship between the bus routes and related stops being offered by Sakarya Metropolitan Municipality (SBB) public transportation service along with the population living in the region to evaluate the level of available current service to the population in each region. An alternative optimisation for the locations of bus stops was presented through a proposed model by comparing the results obtained from the existing positions.

Keywords: GIS, Urban Public Transportation, Bus Stop Spacing Optimization

1. INTRODUCTION

It has become a necessity to support urban transportation strategies with public transportation systems due to some basic reasons such as the increase in individual car ownership, the development of cities and growth in population.

In public transportation, the biggest share in our country and in many developing countries belongs to bus related transportation systems. Proper arrangements for urban bus transportation will increase the demand for public transport and the quality of urban life by reducing the rate of private vehicle use. The intensity of the use of private vehicles on the road is seen as the most important cause of traffic congestion and air pollution in many cities [1].

The negative impact of transportation related environmental issues for the mobility of people in

metropolitan cities can be reduced by encouraging bus-based public transportation systems. This will play a very significant role to increase the attractiveness and quality of urban life [2].

Moving from one location to another is a human activity and using public transport is a main alternative to do so. Public transportation is an indispensable component of the social economy and plays a key role in spatial relations between locations. It represents a basic service and creates valuable connections for all cities by providing diversified activities, economic vitality, socially and environmentally sound conditions [3]-[4].

Farewell and Marx stated that 400m should be considered as the maximum walking distances simply because of the fact that lesser walking times are more preferable by people compare to longer in-vehicle times. As a result of this, they stated that public transportation systems could be

* Corresponding Author

¹Sakarya University, Faculty of Engineering, Department of Civil Engineering, haslan@sakarya.edu.tr

more attractive in case of reducing walking times to access to the bus stops [5].

Fletterman formulated Bus Stop Location Problem as a two objective optimisation model. While the first objective was to minimise the total walking distances for bus users to get the bus stops, the second objective was to have minimised number of stops for the whole system. In this way, he tried to balance the required access distances and the in-vehicle travel time [6].

An iterative algorithm suggested by Chien and Schonfeld is used to optimise a grid system to minimise total cost through bus route and stop spacing along with headways optimisation [7].

Jahani et.al., proposed a multi objective constrained integer programming location model as transit network design problem so that the number of bus stops are minimised with simultaneous minimisation through balancing of total access distance, and weighted combination of bus stops [8].

As mentioned earlier bus-based public transportation systems have a vital importance for urban traffic system. The efficiency of public bus systems can be enhanced by optimising bus stop locations in the network and on the paths resulting in more economical and social advantages to the community. Spatial locations of bus stops with this respect is an essential task for urban transportation planners. The optimisation is to be performed in a way that public demand is satisfied, walking distances to the stops are acceptably provided and minimal number of stops are determined for the most possible service coverage [9].

As a result of having the status of metropolitan city, the public transportation system activities started to be planned and carried out from the single centre within the Sakarya Metropolitan Municipality. The continuous growth in the number of population and vehicles throughout the city increased traffic intensity and decreased the quality of transportation. In addition, because Sakarya is geographically located on the transitional routes of Istanbul, Ankara, Bursa, Kocaeli and other large cities along with the socio-economic other facilities that city provides, the population tends to increase constantly.

Looking at the number of motor vehicles registered in traffic and the population for the last 5 years, it is seen that both are increasing. Figure 1

compares the increase both in the number of vehicles registered and the population for that period in Sakarya.

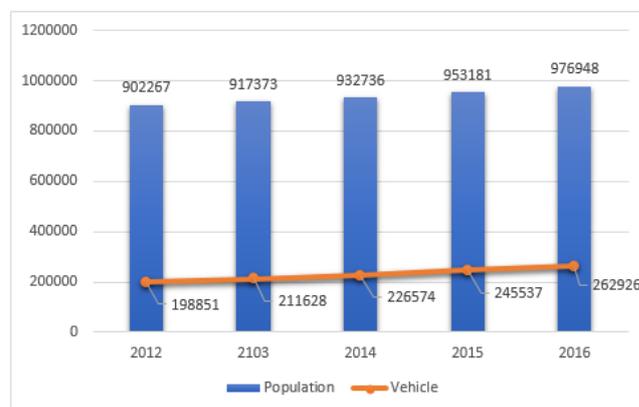


Figure 1. The change in population and number of vehicles for the last 5 years in Sakarya.

In this study, the present state of the public transportation system provided by Sakarya Metropolitan Municipality through buses and the population served by the system were examined using geographic information system software (ArcGIS) and the results of the spatial analysis of the present structure and the proposed model were compared.

2. STUDY AREA, MATERIALS AND METHODS

2.1. Study Area

The study area was determined as Adapazarı, Arifiye, Erenler and Serdivan districts, which were provided by Sakarya Metropolitan Municipality bus services. The geographical locations of these study areas and Sakarya are shown on the map in Figure 2. These four districts, determined as the study area, are the areas where the most intense population of Sakarya is inhabited.

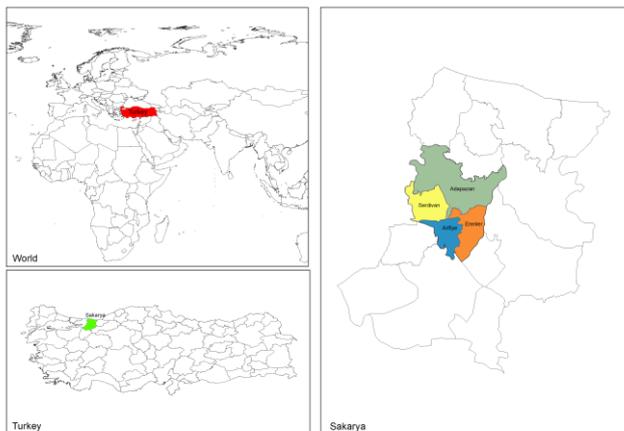


Figure 2. Geographical location of study area.

2.2. Materials

The Geographic Information System (GIS) software used in this study is ArcGIS software developed by the Environmental System for Research and Innovation (ESRI) and commercially used worldwide. The software is obtained with a trial license provided at the company's official site.

The spatial data as of the end of 2016 related to 29 different routes and 860 bus stations operated by SBB were brought together by taking Sakarya Intelligent Transportation System (SAKUS) into consideration available at <http://sakus.sakarya.bel.tr>.

The population data related to the districts and neighbourhoods used in this study were obtained from Address Based Population Registration System (ADNKS) prepared by the branch of the General Directorate of Census and Citizenship Affairs of Turkish Statistical Institute (TUIK) for the year 2016. In addition, the number of motor vehicles for the last five years for the city of Sakarya has been obtained from motor vehicle reports prepared by TUIK and the General Directorate of Security (EGM).

Approximated boundaries and road central lines of the districts and neighbourhoods were attained from the Computer Centre and Software and GIS branches of the General Directorate of Water and Sewerage Administration (SASKI). In addition, the 1/25000 development plan prepared by SBB was also used to distribute population data to the residential areas.

2.3. Methods

The boundaries representing the districts and neighbourhoods, population data of districts/neighbourhoods, public transportation routes and locations of the stations, the central lines of the roads were all combined spatial data and non-spatial data in the geographic database using ArcGIS software.

It was considered that using Service Area Analysis instead of Buffer Area Analysis would lead to better results for the spatial population analysis in the study. Figure 3 illustrates the comparison of Buffer Area and Service Area Analysis with this respect.

The Buffer Analysis for the bus stop in the figure seems to cover more space, therefore more populations. However, given the fact that people will not be able to reach the bus stops directly in the bird's-eye view, this analysis does not provide preferred reliable results. For this reason, it is aimed to carry out a better analysis through Service Area Analysis by assuming that people will use existing roads to reach the bus stops.

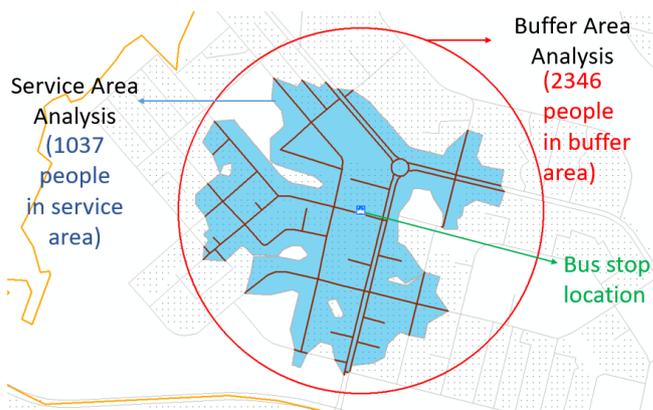


Figure 3. Comparison of Buffer and Service Area Analysis.

3. CURRENT SITUATION ANALYSIS AND PROPOSED MODEL

3.1. Current Situation

There are 29 bus routes and 860 bus stops in the study area as of the end of 2016. The total surface area of these districts corresponds to about 13% of the city of Sakarya (4817 km²), while the total population is about 54% of the population of Sakarya (976948 population at the end of 2016). Figure 4 shows the changes in population over the last 5 years for the districts selected as the study area of this research.

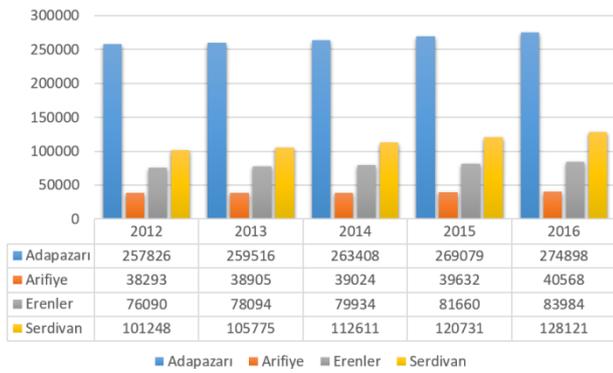


Figure 4. Population change in the study area for the last 5 years

When the last 5 years population data of the study area are examined, it is observed that the population is increasing every successive year in all the districts. The resulting population growth triggers urbanization and in parallel increases the demand of people's daily mobility.

According to report prepared by TUIK and Security General Directorate (EGM), there are a total of 262296 registered motor vehicles in Sakarya at the end of December, 2016. Figure 5 illustrates the distribution of the motor vehicles available in the city for this year.

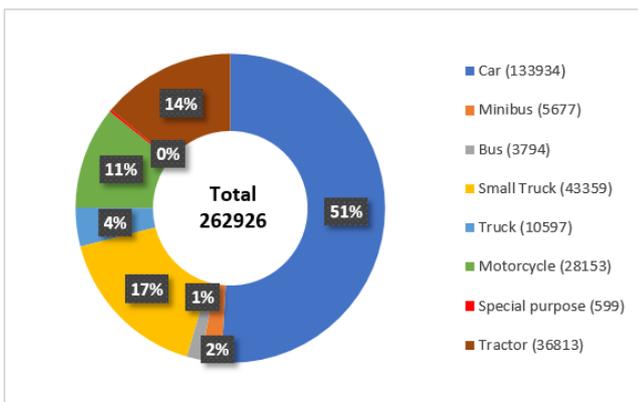


Figure 5. Vehicle distribution in Sakarya for 2016.

The distances between bus stops should be the optimised one so that people can reach them on foot for an efficient and preferable system design a sign of worthy performance in urban public transportation. In this sense, the problem of determining the location of the bus stops affecting the system performance of the bus related public transportation is accompanied by the distances of bus stops.

Distances between bus stops directly affect the duration of the passengers' access to the stops and the travel times experienced in the vehicle. In the presence of more frequent and large number of stops, the walking distances and times decrease. In the opposite case, however, the access distance to

the stops leads to increase but in vehicle travel times decrease. The problem of identifying bus stop distances should be, hence, considered as a problem to balance the expectations and demands of passengers and operators. While the passengers' anticipation is minimizing the sum of accessibility and in-vehicle travel time, operators aim to minimise operating costs and maximise revenues, reliable services and customer satisfaction.

The availability of walking distances to some extend of which public transportation system users do not get away from the system is closely related to the fact that both operators and passengers travelling within the vehicle do not have very long in-vehicle journey times [1].

The parts of cities whether being residential area, commercial, and/or a central business district (CBD) region etc. will form the goals of mobility affecting the determination of bus stop spacing. Alternatively, major trip generators may be used to locate the stops [10]. According to the results of research conducted by the Transit Cooperative Research Program (TCRP), the standard intervals for bus stops valid in the international literature are given in Table 1. The values represent a composite of prevailing practices.

Table 1. Bus stop spacing in literature

Environment	Spacing Range (m)	Typical Spacing (m)
Central Core Areas	92-305m	183m
Urban Areas	152-366m	229m
Suburban Areas	183-762m	305m
Rural Areas	198-805m	381m

In the above table, it can be seen that the distance between bus stops is 152-366m in the areas defined as the city centre and 229m in the general practice.

When the distances of 860 stops belonging to 29 routes in the study area are examined, it is observed that the stops do not have a homogeneous distribution in some places. In Figure 6, there are distribution maps of 29 routes and 860 stops for the current situation in the study area.

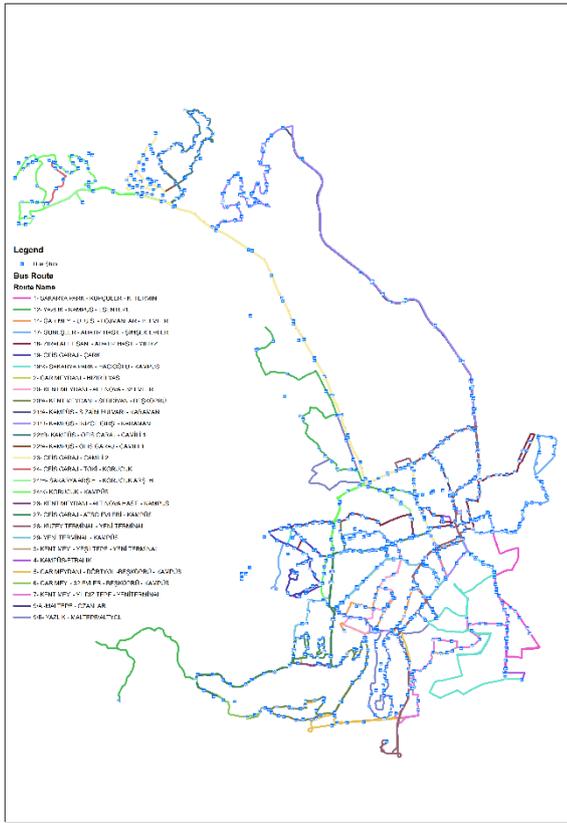


Figure 6. Distribution map of present bus routes and stops.
Figure 7 and 8 show the density map of 860 bus stops and 29 routes, respectively.

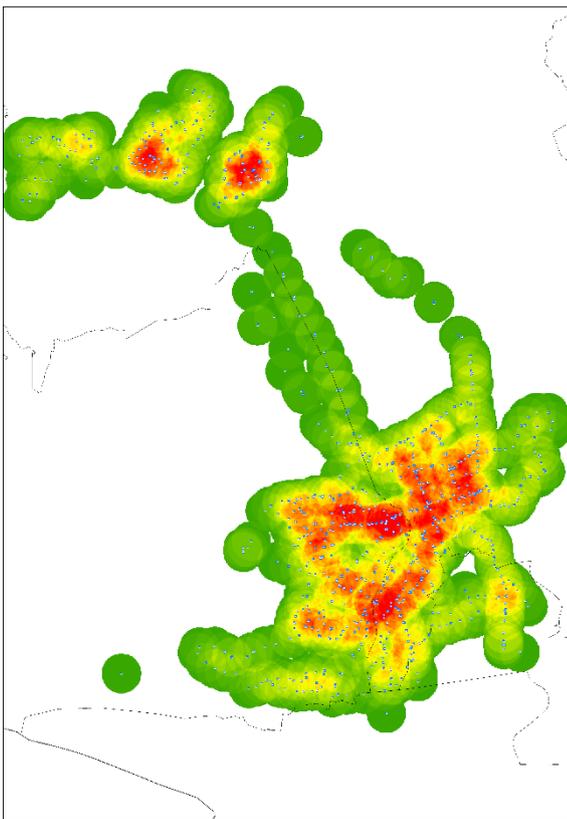


Figure 7. Density map of bus stops.

When these density maps are examined, it can be seen that while the routes are mainly concentrated in the city centre where the main bus stops are located, the stops are intensified at places where

there is an increase in population like university, central areas, etc. In addition, it is observed that the density of bus stops increases in the areas towards the north of the study area where the population resides to a large extent, and the density of the routes intensifies in the vicinity of the university located in the west part of the study area.

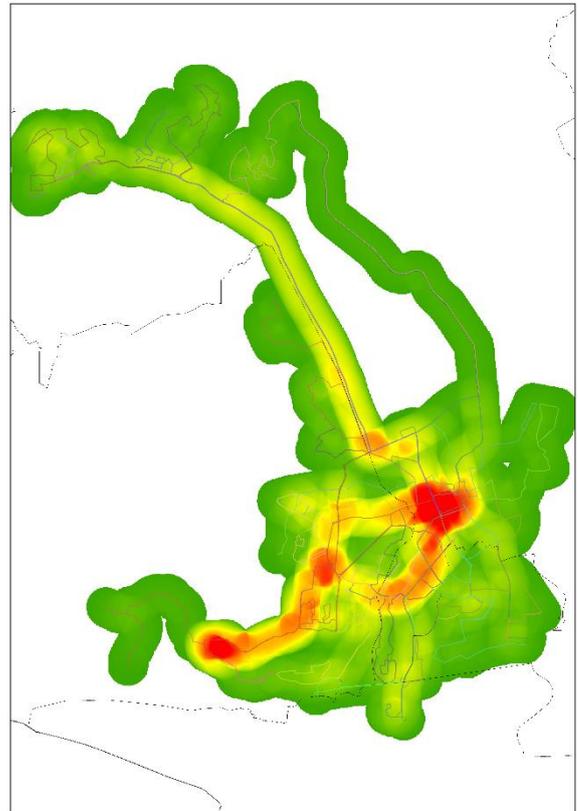


Figure 8. Density map of bus routes.

Figure 9 shows the population density and distribution areas obtained by transferring population data of the year 2016 from the database of TUIK into the neighbourhood boundaries in prepared geographical database. Population densities of the neighbourhoods increase as the green colour areas shift towards the red ones. In addition, the dark areas in the figure show the residential areas in the development plans.

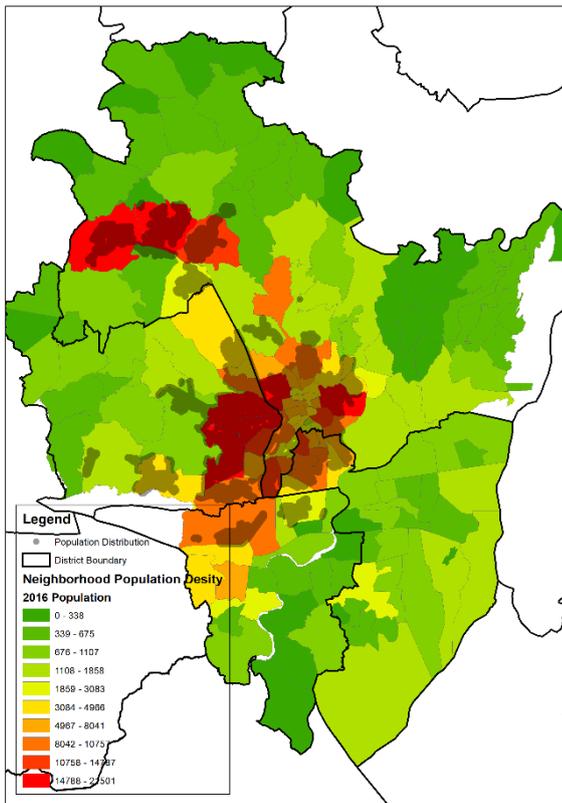


Figure 9. Density and distribution of population in neighbourhoods.

3.2. The Analysis of Current Situation

The population and borders of the districts and neighbourhoods, the locations of public transportation routes and stops, the central lines representing the roads for the study have all been combined in the geographic database using ArcGIS software. In Figure 10, there is a visual image of the layer structure from the spatial data (district boundary, bus route, road central line, etc.).

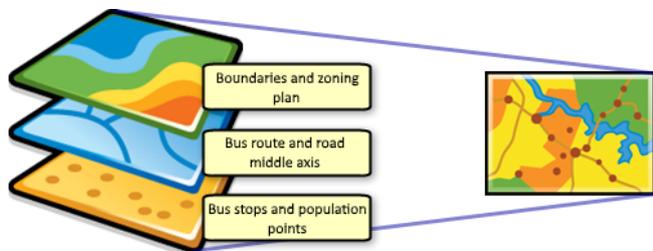


Figure 10. Example of ArcGIS map layers.

Firstly, related points in a separate detail class within the areas covering all neighbourhoods were created at a distance of 10mx10m between them by adding population data belonging to the districts/neighbourhoods the administrative regions to the relevant district/neighbourhood tables. Then, the extraction of the residential areas not represented by these points was performed using the 1/25000 scaled zoning plan data and satellite/aerial photograph images.

After this extraction process, the neighbourhood population values represented by each point are calculated by selecting the points remaining in each neighbourhood. In this way, the population value for each point in the relevant regions is expressed by the following equation.

P: Population value for the point

NP: Neighbourhood population

PP: Number of points within the boundaries of the neighbourhood

$$P = \frac{NP}{PP} \tag{1}$$

Missing and erroneous drawings of road central lines are arranged by using various aerial/satellite photographs as bases and the drawings of 29 public transportation routes were reproduced in such a way as to coincide with these lines. A network dataset was created on the spatial database in which the data is stored in a way that the resulting road network can be used for network analysis. Using the created network dataset and ArcGIS software, transportation areas of 300m, 400m, 500m, 600m and 700m walking distances to existing 860 bus stops were obtained. The 10mx10m spaced points within these areas were spatially determined and the approximated population values of the bus stops serving at the respective access distances in each district/neighbourhood were calculated and tabulated separately. Table 2 demonstrates the population, route and number of stops in the study area.

Table 2. Population, bus routes and bus stops in districts

	District Population in 2016	Number of Bus Routes	Number of Bus Stops
Adapazarı	274898	29	474
Arifiye	40568	5	2
Erenler	83984	14	62
Serdivan	128121	22	264

Table 3 shows the population-based analysis obtained by these calculations. When these analyses are examined, it can be seen that the highest and lowest population values are in Adapazarı and Arifiye districts, respectively. It can also be concluded that the number of population increases gradually from 300m to 700m.

Table 3. Population analysis in districts

	Analysis in 300m	Analysis in 400m	Analysis in 500m	Analysis in 600m	Analysis in 700m
Adap.	153530	196425	214781	225388	231867
Arif.	0	0	0	21	102
Eren.	29635	38297	46504	52615	56460
Serd.	77231	90142	97826	101908	104202

3.3. Bus Stop Optimization and Proposed Alternative Model Analysis

At the first stage of bus stop optimization process, 909 new positions with an average distance of 300m on the road central lines through 29 public transport routes have been determined to be an alternative to existing stops. In the second phase, access areas of 300m, 400m, 500m, 600m and 700m walking distances to these 909 new bus stops were obtained using the Service Area tool in the Network Analyst which is a pre-built network dataset in ArcGIS software. Thus, the above-mentioned process steps applied for the bus stop topology (860 stops) representing the current situation are repeated for new topology. The obtained district based population, route and the number of alternative stops are presented in Table 4.

Table 4. Population, bus routes and bus stops in districts

District	District Population in 2016	Number of Bus Routes	Number of Bus Stops
Adapazarı	274898	29	513
Arifiye	40568	5	9
Erenler	83984	14	96
Serdivan	128121	22	294

Table 5 shows the district-based population analysis obtained from these calculations using alternative stops.

Table 5. Population analysis in district

	Analysis in 300m	Analysis in 400m	Analysis in 500m.	Analysis in 600m	Analysis in 700m
Adap.	181172	211044	226058	233475	236731
Arif.	0	0	20	923	1067
Eren.	47458	56256	60443	61533	61886
Serd.	83126	96037	103180	106542	108740

The current bus stop positions and distributions of the alternative positions are shown in Fig 11.

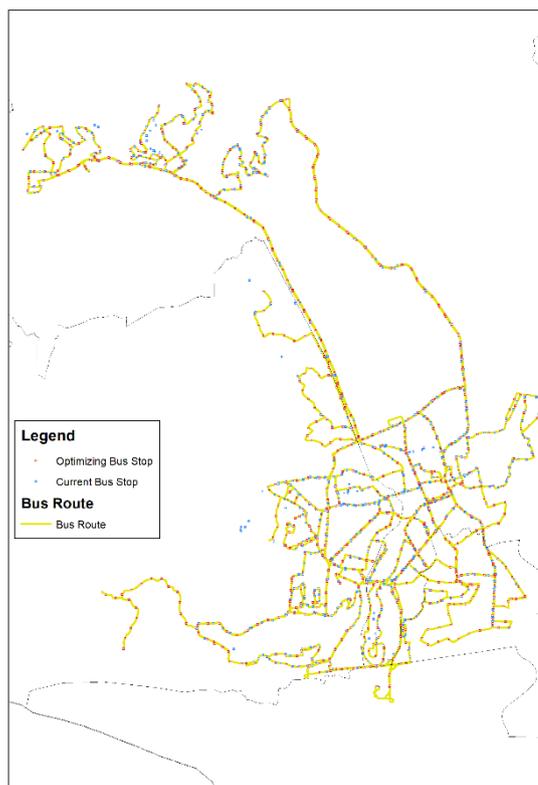


Figure 11. Comparison of the optimised and current bus stops.

The accessibility analysis of the population being 300m, 400m, 500m, 600m and 700m away from the current and model bus stops through the central line of the roads are illustrated in Fig. 12 and Fig. 13, respectively. The analysis was carried out in the form of determination of areas that could be reached by network analysis using the existing central lines located nearest to any stop, instead of the circular coverage area created by a buffer analysis at a distance determined by a bus stop. The population increases as it is moved from the light blue areas (300m area) towards the areas covered by the red (700m field) colour. If Figure 12 and Figure 13 are investigated, it can be observed that although access areas are increased and enriched in general and in non-residential industrial areas of Erenler District, the served population has not changed at the desired level with respect to this improved coverage area by the bus stops.

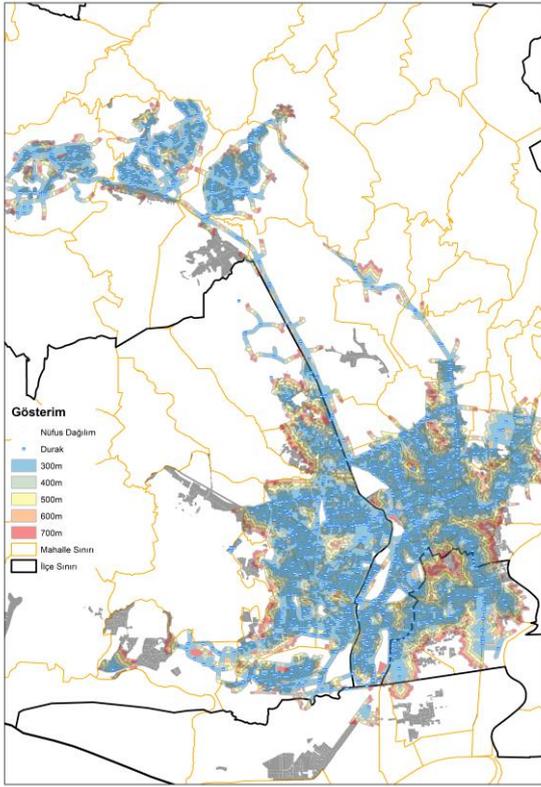


Figure 12. Population analysis of bus stop access areas for present situation.

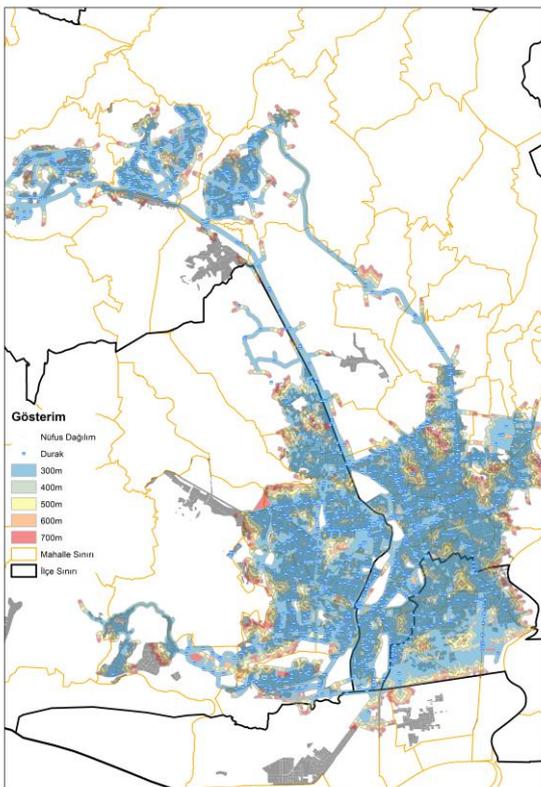


Figure 13. Population analysis of bus stop access areas for proposed model.

4. CONCLUSION

As a result of the initial examinations regarding the present state; it has been determined that only 802 stops out of 860 are associated with the existing

routes. The remaining 58 stops have no relation with any routes whatsoever and 93% of the stops are connected with at least one route. It has also been observed that distances between stops do not have a specific standard. In this article, the passengers' access areas to the stops and the distances between the stops are designed to be approximately 300 meters in order to propose an optimum model so that the distances to bus stops to access and travel times experienced in public service vehicles are minimised for the system users. In the proposed model, it was concluded that the number of population accessing to the proposed stops is generally increased. In comparison to the analysis made between the suggested and the existing models, it has been determined that the number of stops increased from 860 to 909. Furthermore, the ratio of one bus stop being related to at least one route rose from 93% to 100% for the proposed model.

In the present case; Adapazarı District is the place where the most of the routes is located and Arifiye District has the least route and bus stops. It is also determined that there is not much increase in the model situation in terms of the number of stops in this latter district. It has been observed that the Arifiye District is benefited from the public transportation service only through the Sakarya Metropolitan Municipality Intercity Bus Terminal located within the boundaries of this district. In the case of the suggested model, it seems that despite the fact that there is an increase in the access areas for bus stops in Erenler district, the expected growth in the population of potential service users has not been reached due to the widespread non-residential industrial areas. The number of stops for existing and optimized cases is shown in Table 6 and Table 7 separately for each district in the study area. When the figures in tables are examined; it can be determined that the number of stops without changing the routes in the existing and model cases differentiates. In addition, the number of bus stops increased in all districts in the proposed model. It can also be seen from the tables that the number of stops for both the present and the model cases on any specific district is directly proportional to the number of routes available in that district. The tables express the fact that for both present and proposed cases, while the maximum number of stops is in the district with the largest number of routes, the least number of stops are available in the district with the least number of routes.

Table 6. Number of routes in districts for both cases.

	Number of Routes for Present Case	Number of Routes for Proposed Model	Increase (%)
Adapazarı	29	29	0
Arifiye	5	5	0
Erenler	14	14	0
Serdivan	22	22	0

Table 7. Number of bus stops in districts for both cases.

	Number of Stops for Present Case 1	Number of Stops for Proposed Model	Increase (%)
Adapazarı	474	512	8.02
Arifiye	2	9	450
Erenler	62	94	51.62
Serdivan	264	294	11.36

As a result of comparison of the accessibility analysis to the stops between present situation and proposed model over the road central lines of the population at 300m, 400m, 500m, 600m and 700m distances, it was observed that the population receiving service in the proposed model shows an increase in district basis, but when compared at the neighbourhood level, it was seen that there is both increase and decrease in some neighbourhoods. In some, however, no significant change was identified. This indicates that the distance between stops is very short for some of them, very long for some and is about 300m just as in the case of the model. Since the location of the bus stops is not homogeneous, the population receiving the services on neighbourhood basis shows different tendencies in the form of increasing, decreasing or not changing. The results to be obtained from a more detailed study in comparing the bus stop/population ratios within the boundaries of each neighbourhood separately would be useful in determining how much population was considered when determining the current bus stop locations in the past.

The percentage of the district base population receiving service for both existing and proposed model is shown in Table 8 and Table 9. It was observed that in all districts except Arifiye, there was a significant population increase related to the service procurement for proposed model compare to the current case. Determination of the distance between stops on the suggested model as 300m

through the evaluation of the locations of bus stops in present case has accordingly played a very effective role in increasing the population that can access to the stops. Moreover, if the proposed model is spatially analysed, it is determined that the expected population increase in Erenler has not occurred due to the fact that some of the new bus stop locations created remain in the non-residential industrial area.

Table 8. Change of population receiving bus stop accessibility at 300m, 400m, and 500m range.

	Change in 300m (%)	Change in 400m (%)	Change in 500m (%)
Adapazarı	56...66 (% 17.85)	71...77 (% 8.45)	78...82 (% 5.13)
Arifiye	0...0 (% 0.0)	0...0 (% 0.0)	0...0 (% 0.0)
Erenler	35...57 (% 62.86)	46...67 (% 45.65)	55...72 (% 30.91)
Serdivan	60...65 (% 8.33)	70...75 (% 7.14)	76...81 (% 6.58)

Table 9. Change of population receiving bus stop accessibility at 600m, 700m range.

	Change in 600m (%)	Change in 700m (%)
Adapazarı	82...85 (% 3.66)	84...86 (% 2.38)
Arifiye	0...2 (% 200.0)	0...3 (% 300.0)
Erenler	63...73 (% 15.87)	67...74 (% 10.45)
Serdivan	80...83 (% 3.75)	81...85 (% 4.94)

The results of the proposed model in the study revealed that distances both to reach the bus stops and between the stops themselves in public transportation systems are very important in terms of the demands of the passengers and the population served.

As a result of the analysis it is determined that in the proposed model the population within 300m, 400m, 500m, 600m, 700m coverage areas is higher than the current system according to the criterion of 300m distance between bus stops through the road central lines. This results in a significant increase in the population served if distances between the bus stops are set as standard, 300m, in urban public

transportation system of Sakarya Metropolitan Municipality.

The changes obtained are illustrated in Figure 14, Figure 15, Figure 16, and Figure 17.

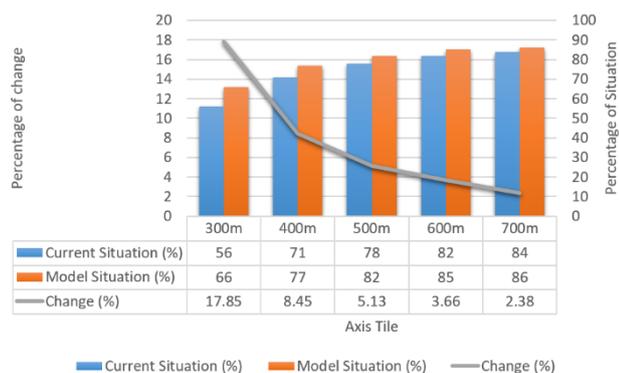


Figure 14. Change of population according to the various distance ranges served by public transportation in Adapazarı for present and proposed case

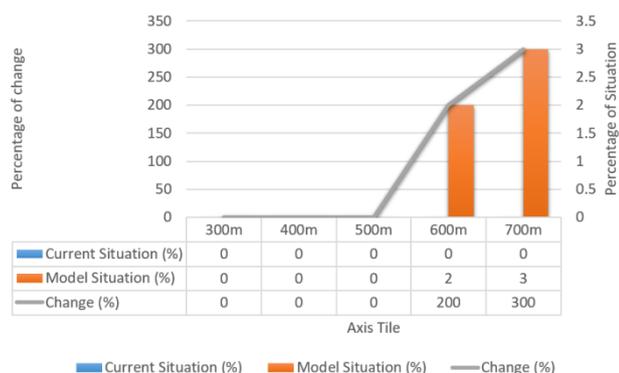


Figure 15. Change of population according to the various distance ranges served by public transportation in Arifiye for present and proposed case

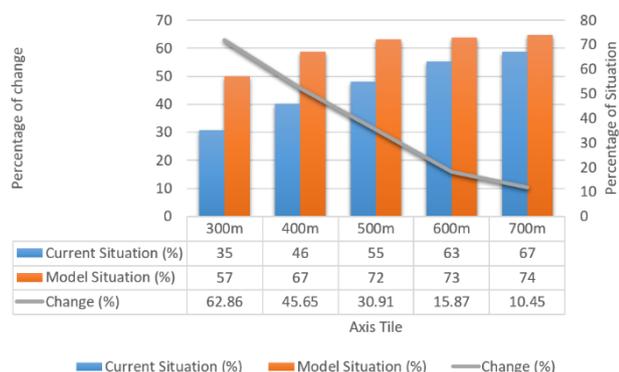


Figure 16. Change of population according to the various distance ranges served by public transportation in Erenler for present and proposed case

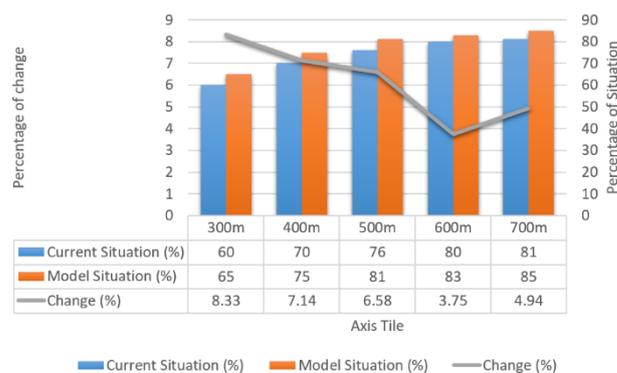


Figure 17. Change of population according to the various distance ranges served by public transportation in Serdivan for present and proposed case

The results clearly point out the importance of bus stop locations in public transportation planning for an effective and efficient operation.

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