AN INNOVATIVE APPROACH TO OPTIMIZATION OF PERSONNEL SERVICE SYSTEM IN DEVELOPING COUNTRIES

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ABSTRACT

Personnel services provide comfortable and accessible transportation for the employees of a workspace. However, the financial load of this system is significantly high for both private sector and government budget. The money spent is for only a group of pasengers and causes missed opportunities, such as improved public transportation systems. This situation causes an equity issue. This research presents an innovative systematic approach for the optimization of the personnel shuttle service of Bogazici University and aims further improvement by integrating the public transportation systems with personnel shuttles. By using clustering and heuristic optimization algorithms, passengers are assigned to the most suitable shuttles and the routes of the shuttles services are organized accordingly. The resulting system significantly decreased the number of required shuttles and the distance traveled per shuttle in the system, which reduces the financial load on the university budget and the overall impact on the traffic network in the city. The saved budget of the university can be used for other needed areas of the university for the benefit of all the students and the staff. The ease of implementation of this system may provide improved traffic conditions in the long term, as other private and public workplaces start to implement this system for their personnel services as well. With this system becoming more common, the public transportation is also promoted, motivating the government budget to be spent for this system, which benefits all passengers. The impact on the equity with this system is expected to decrease significantly.

Keywords: Personnel shuttles, Public transportation system integration, Heuristic optimization

INTRODUCTION AND BACKGROUND

Providing reliable transportation systems for the citizens of a city is crucial in many aspects. Public transportation has a key role for achieving this objective. Developed countries such as Germany, Japan, Austria, Switzerland are offering quick and efficient public transportation for their citizens in their cities. Successful public transportation systems offer mobility and accessibility to its users. Captive users, who have just one motorized mode of transportation for intra-urban trips and mostly have lower income (*1*) are more dependent on the public transportation system. This situation makes this system an important element for compensating the gap between citizens with different levels of income. On a more macroscale, when the benefits of the transit systems are considered, the reduced levels of traffic congestion due to public transportation systems can provide economical and environmental benefits. However, in some cities, the public transportation systems cannot meet the high levels of demand which makes them very crowded and decreases their level of comfort and efficiency. For this reason, governments and private sector firms provide an alternative mode of transportation for their employees in some countries. This alternative is called the personnel shuttle service, offered to the working citizens.

Personnel services provide transportation services for the employees of a given workspace for free of charge. Employees using this service has the benefit of not using their own car for traveling to work and getting free of charge and comfortable transportation service. The personnel services are beneficial to the traffic by providing a decrease in the number of vehicles in the traffic. In this perspective, it can be said that the personnel services act as a type of public transportation. In a research conducted in Seattle, it was observed that if the personnel service vehicles use the bus stops to collect their passengers, the bus schedules are not affected negatively (*2*). In some cities innovative systems that fuses personnel shuttles with the public transportation systems are tested and researched. A last mile service route is offered for the passengers that want to reach the railway systems for the city of Utah. By doing so passengers use these shuttles instead of using their own private vehicles (*3*). In a different research, by utilizing meta-heuristic methods, routes are generated for shuttle services traveling to metro stations which minimizes the cost for both the shuttle service users and providers (*4*). The coordination between the personnel service and public transportation systems is crucial for the improved efficiency of a city. However, there are some drawbacks of these personnel shuttles due to the fact that they are not very sustainable systems and they can cause a negative impact on the equity among all passengers.

As the population of a city increases, the amount of working citizens also increase. The governments and private sector companies need to increase their budget constantly for their employees in keeping this system operating. Without any kind of planning or properly functioning system, the shuttle system is destined to be unsustainable due to the constant increase of budget for operating this system. The money spent by the government can instead be used for improving the public transportation infrastructure, which in the long term benefits all the citizens in a much more efficient way. This missed opportunity causes an equity issue.

The role of public transportation is especially important during peak hours. More specifically, at the business districts these shuttles are causing more load to the traffic network, more so during peak hours. The fact that these vehicles are only being used during the morning and the evening peak hours and leaving these vehicles parked during the rest of the day, decreases the efficiency of this system immensely. While they are not being used, they occupy precious parking space around the city. Business districts become crowded intensively as the end of the work hours gets closer, causing serious traffic problems. For a system that is only being used for specific times of the day, the companies and the governments are paying a tremendous amount of money for it.

The personnel services are currently providing a significant amount of transportation service for the working citizens. However, it is also obvious that the current state of this system, without any kind of systematic planning, causes issues and in the future these issues may worsen. The impact due to these large vehicles can influence the traffic on a much severe scale as the number of these shuttles increase, which will also increase the required financial budget spent for this system. The aggravated state of the traffic condition will cause longer travel times for all vehicles in traffic. The increased travel times will also cause the perceived level of comfort of the personnel shuttles by its users to be decreased. Because of this, shuttle users may choose to purchase private vehicles for transportation purposes, which will cause the number of vehicles in traffic to increase and; therefore, making the traffic congestions in the city even worse. The benefits for only a group of passengers will decrease and the travel conditions for the rest of the passengers will continue to worsen even further. As these issues becomes more severe, the negative impact on the equity due to the personnel shuttle system will continue to increase. The current state of this system is unsustainable and therefore needs immediate improvements. In this study, a new approach is proposed to make the personnel shuttle system less damaging to the equity and traffic conditions. With the data and knowledge available from the Boğaziçi University from previous studies, this new method is applied to the personnel shuttle service of the university. Hence, it was aimed to obtain the following:

- Creating a systematic method for optimizing the current personnel shuttle service by decreasing the number of shuttles in the system. This results in the financial burden of this system on the university budget to be lessened;
- Proposing a new system, namely subwaypooling, which will divert the current passengers of the personnel shuttles to the public transportation system and therefore promoting the public transit modes of transportation.

By decreasing the financial load of the personnel shuttles and increasing the public transportation demand, the government can be encouraged to spend the surplus budget for improving the conditions of the public transport system. The improved public transportation systems will benefit all passengers in the long term and improve the equity among all passengers.

Personnel Service System of Boğaziçi University

Bogazici University offers private shuttle services to its personnel which are free of charge. 61 different routes are available for 1166 personnel registered to this system. The services travel 3460 km per day. The personnel show their id card when they get on the shuttle both in the morning and the evening.

The system is funded by the budget from the government. However, due to the increased number of employees and shuttles, in 2015 the university administration had to additionaly allocate its own budget to fund this system instead of using it for other needed places in the university. Therefore, the university has conducted a study to analyze the current state of this system. In this study, the system was monitored for 2 weeks in order to observe the condition and a survey has been conducted with the personnel of the university. Monitoring of the card system showed that 25.3% of the registered users did not use the shuttles during this period.

In the survey, some demographic properties of the personnel, such as the distribution of age, level of income and gender, are collected. Majority of the level of monthly income of the personnel is below 1100$ (FY 2015 dollars).

Of the 537 personnel participated to this survey 309 of them (57.54%) does not own a private vehicle and 349 of the personnel (64.99%) is living close to the campus. The preferred mode of transportation for reaching to or departing from the campuses was asked to the participants. The majority of the participants (50.47%) declared that they prefer personnel shuttle services. 26.26%, 15.08% and 8.19% of the participants use private vehicles, public transportation and walking respectively. The reason why personnel are not using their private vehicles was inspected. The most probable reasons are asked to the survey participants. The traffic congestion and the price of gas (31.03%) was the most selected answer.

The results of the monitoring period of the card system indicates the need to inspect the reason why the personnel are not using this system. The top three answers to this question are as follows:

- 35.59% of the participants declared that the alternative preferred mode of transportation is faster;
- 23.87% of the participants declared that the shuttle routes are not suitable (too long) for the users;
- 20.27% of the participants declared that the timetable of the shuttle (picking up too early) is not suitable.

In a study, it was determined that as the level of income decreases the demand for public transportation increases (*5*). By looking at the level of income of the personnel, it can be assumed that in the case of cancelling the personnel shuttles, the users most probably will choose public transportation as their preferred mode of transportation.

The planning of this system is currently made without any systematic method. The routes and passenger assignments are determined using only the experience of the officers. The results of the survey and monitoring of the card system shows that the current system is not very efficient. That is why a new method for the personnel service is required. The number of shuttles needs to be decreased while maintaining the level of comfort of this system for lessening the financial burden of this system on the university's budget. Still, optimization of this system may not make this system sustainable. Therefore, a new system is also proposed which integrates the public transportation system as well for transporting the passengers to the campuses and to their homes, promoting the public transportation ridership during this process.

THEORY

For the construction of this new system the following algorithms are utilized for clustering and classifying the passengers, drawing routes for passengers going to the shuttles and the shuttles going to their assigned campuses:

- K-Medoids Algorithm;
- Hierarchical Clustering Algorithm;
- Support Vector Regression (SVR);
- 3-Opt Algorithm;
- Tabu Search Algorithm.

K-Medoids Algorithm

K-medoids clustering algorithm has the objective to distribute a set of N data points into K many clusters. The process begins with a random selection of distinct data points as cluster centers. Afterwards, each of the remaining data points are assigned to the closest cluster center subsequently:

$$c(n) = \arg\min D(x_n, x_k), n \in \{1,..., N\}, k \in \{1,..., K\}, \quad (1)$$

where c(n) is the assigned cluster of the data point *n*, and x_n and x_k are the coordinate vectors of data point *n* and cluster center *k* respectively. During the assignment process a distance matrix is required. The required computation amount for this part is proportional to *K* x *N*.

For the next step, the objective is to minimize the total dissimilarity cost which is defined as follows:

$$\min_{c_i \{i_k\}_1^K} \sum_{k=1}^{K} \sum_{c(n)=k} D(x_n, x_k), \quad (2)$$

where i_k is the index for the k^{th} cluster center in the data set. This objective is accomplished by the exchange of the center of each *k* cluster with other data points in the cluster which minimizes the given objective. This process has the computational complexity of O $(K(N - K)^2)$. The two-step process is iterated multiple times until the medoid assignments are stable between 2 consecutive iterations. Due to the randomization of this process, the overall algorithm is repeated multiple times to observe the best results. The intensive computation of this algorithm is counterbalanced by the increased efficiency by utilizing the relative rank of the cluster members as an intrinsic part of the search algorithm (*6*).

Hierarchical Clustering Algorithm

The idea behind hierarchical clustering algorithm is to build a binary tree of the data that combines similar groups of points, where at the beginning of this process each data instance is treated as a singular cluster. By visualizing this constructed tree, the results are much easier to interpret.

For initiating the process, each observation is initially treated as a separate cluster with a population of one. Then the following two steps are repeated until all clusters are merged together:

1. Select and identify two clusters that are closest to each other;
2. Merge the most similar clusters.

At the end of this process, a dendogram is generated, which indicates the hierarchical relationship between each clusters. This process is more specifically called agglomerative hierarchical clustering. The opposite way of this process is to consider all data points as one big cluster and successively dividing this cluster. This way of this algorithm is called divisive hierarchical clustering and it is rarely applied in practice.

Support Vector Regression (SVR)

SVR is one form of the support vector machines (SVMs) and it is also the most common. Assume that the training data $\{(x_1, y_1), \dots, (x_N, y_N)\} \subset$ x χ where χ stands for the space of the input patterns.The goal is to determine a function $f(x)$ that has less error than ε where ε has been determined at the beginning of the process. For linearly seperable cases the following formula is valid:

$$f(x) = \langle w, x \rangle + b \;\; with\, w \in \chi, b \in \Re \,, \qquad (3)$$

where <, > stands for the dot product in χ. w in (3) stands as the inverse of margin, which indicates the separation distance between the different classes. Maximization of this margin is equivalent to minimize w, which can be written as a convex optimization problem:

$$\begin{aligned} &miinimize && \frac{1}{2}\|w\|^2 \\ &subject\ to && \begin{cases} y_i - \langle w, x_i \rangle - b \le \varepsilon \,, \\ \langle w, x_i \rangle + b - y_i \le \varepsilon \end{cases} \end{aligned} \qquad (4)$$

Formula (4) can be perfectly valid during linearly seperable cases. However, majority of the real time situations are not linearly seperable and thus, some errors must be allowed. Vapnik (1995) introduced slack variables ξ_i, ξ_i* for dealing with infeasible constraints of the optimization problem. The formula (2) transforms into the following form:

$$\begin{aligned} &miinimize && \frac{1}{2}\|w\|^2 + C\sum_{i=1}^{l} \xi_i + \xi_i^* \\ &subject\ to && \begin{cases} y_i - \langle w, x_i \rangle - b \le \varepsilon + \xi_i \,, \\ \langle w, x_i \rangle + b - y_i \le \varepsilon + \xi_i^* \\ \xi_i, \xi_i^* \ge 0 \end{cases} \end{aligned} \qquad (5)$$

where $C > 0$ is the constant that determines the tolerance for the permitted errors.

3-Opt Algorithm

This algorithm is a local search algorithm used for various network optimization problems (*7*). The aim is to minimize the length of the tour by changing the visiting order of locations. A link is defined between a location X and a location Y. The algorithm is as follows:

1. Arrange the locations in a random order and call it the initial route;
2. The total length of the initial route is calculated by considering the distances between the locations and it is called D_0;
3. 3 different links between any 2 consequtive locations of the route are selected and virtually interexchanged. The new route distance is again calculated and called D_1;
4. If $D_1 < D_0$ interexchange made in step 3 is now permanent, else reset the tour route to the state constructed in step 1;
5. Return to step 3 and repeat process while shorter length tours are found;
6. Stop procedure when the pre-determined stopping condition is satisfied.

The crucial point of this process is that, although the algorithm provides near-optimum solutions, getting stuck in a local minimum is a potential problem for this process. This indicates that the 3-opt algorithm can get stuck near some undesirable local minima. By widening the search zone for an optimum solution or by accepting worse solutions for escaping the local minima, the search algorithm can escape from its local minima entrapment.

Tabu Search Algorithm

The aim of this algorithm is to widen the scope of the search algorithm that is looking for an optimum solution, by avoiding the previously constructed improved solutions for a predetermined length of time. This algorithm was created in order to decrease the local search method's probability of the tendency to become stuck in sub-optimal solution zones. The fundamental rule of not accepting worse solution is softened by this algorithm and the search scope is widened by discouraging the search algorithm to repeat similar solutions. The previously constructed solutions are kept in a memory structure called tabu list. The solutions in this list are kept in memory for a short term in order to avoid repetition and getting stuck in one search space. The memory types are divided into three categories (*8*):

1. Short-term: consisting of recently visited solutions and cannot be revisited until the solution on the tabu list expires based on a pre-determined time;
2. Intermediate-term: rules that turns the search towards more promising areas of the search space;
3. Long-term: rules that cause the search algorithm to dive into new regions.

The algorithm is completed when the pre-determined stopping condition of the search algorithm is satisfied.

METHODOLOGY

Initially, the addresses of the personnel using the personnel shuttles were obtained from the university administration. For visualization, the addresses were plotted on a map using ARCGIS software. The registered personnel are then classified based on which side of the city that they are residing in (Europe or Anatolia) and their destination, which is one of the campuses of Bogazici University.

By using the constructed method, an improved system with decreased number of shuttle, is aimed to be obtained. For further improvement a second system is also proposed, which aims to take advantage of rail and bus rapid transit (BRT) public transportation systems. That system will be called "Subwaypooling".

Shuttle Optimization

This method is applied to the South campus personnel residing in the European and Anatolian part of Istanbul separately due to the fact that the majority of the personnel's destination is to South Campus; thus the effort is put into the optimization of South Campus shuttles. The overall process is shown in the flowchart below as a summary (Figure 1).

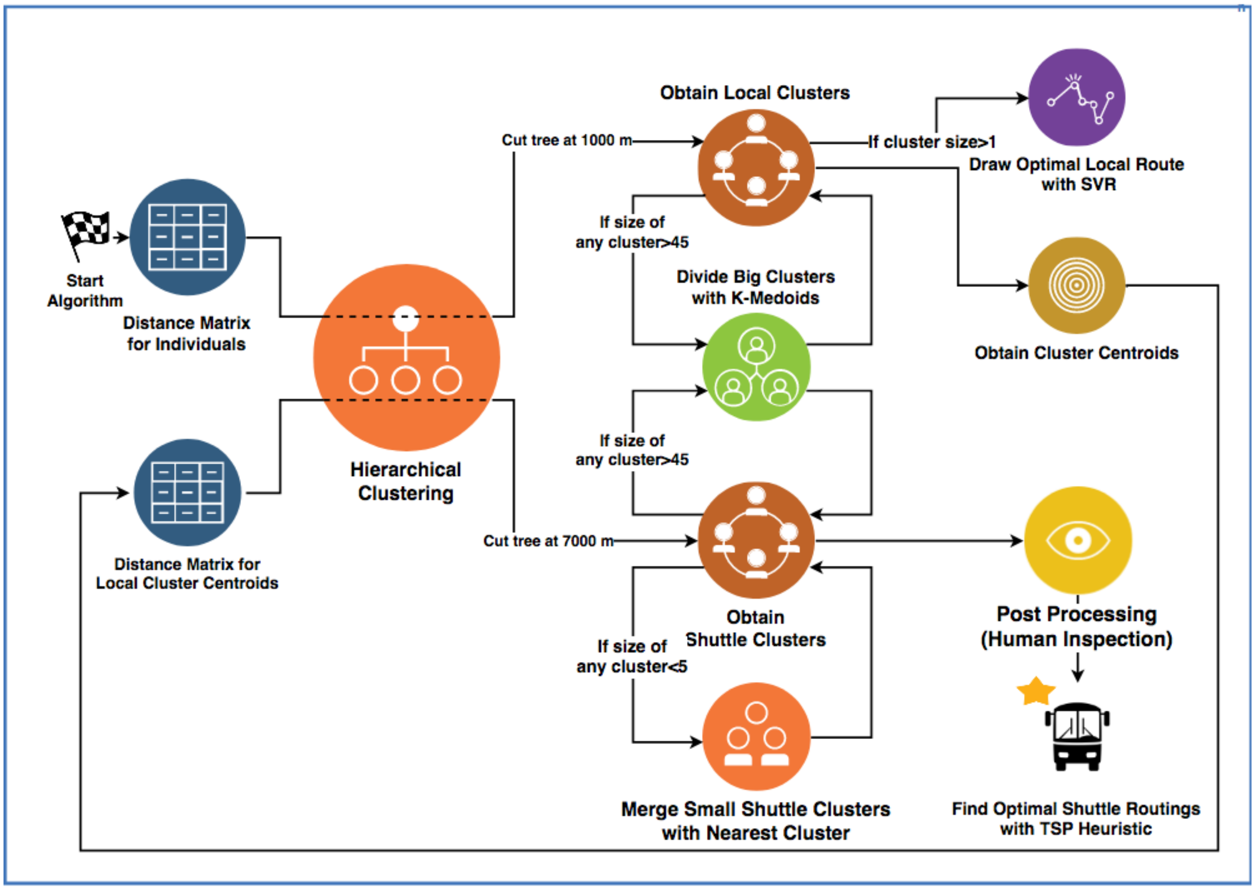

FIGURE 1 Flow-chart for shuttle optimization process.

Distance matrix is calculated for individuals using the manhattan distance. Manhattan distance, also called as city block distance, is chosen since it is the most realistic distance metric for the city environment in both walking and driving scenarios. Manhattan distance is calculated using the following formula:

$$d(x, y) = \sum_{i=1}^{m} |x_i - y_i| \quad (6)$$

The constructed inter-individual distance matrix is used to make a hierarchical clustering with complete linkage to achieve compact local clusters.

Local clusters are the cluster of individuals to be picked up at a common point by the shuttle or to the main road that shuttle passes, individuals are required to walk to this point or to the main road on their own. The maximum walking distance is taken as 1000 meters, thus the hierarchical clustering tree is cut at 1000-meter height and local clusters are obtained. After the local clusters are obtained, they are checked to see if the size of any of the local clusters exceeds the shuttle capacity which is 45 passengers. If any of the local clusters exceed this limit they are divided using k-medoids into evenly sized and closely clustered sub-clusters.

For each local cluster that has more than a single person, an idealized route that passes between the individuals is required for the shuttle. An ideal route should be drawn such that the maximum walking distance of any passenger to the route of the shuttle, should be as small as possible. SVR is used for drawing the ideal route for its ability to fit in various shapes given the correct epsilon parameter and kernel. A cross validation is applied to the data points in the cluster for various epsilon parameters, various kernels (polynomial, radial basis function and sigmoid) and error term is defined as maximum absolute error rather than a mean squared error since the maximum walking distance is the main concern. Radial basis function (RBF) found to be the best suiting kernel. The RBF kernel for two samples, x and x' which is represented as feature vectors in some input space is defined as follows (*9*):

$$K(x,x') = \exp\left(-\frac{\|x-x'\|^2}{2\sigma^2}\right) \quad (7)$$

Centroid of the local clusters are obtained and each local cluster is treated as a single point. Another distance matrix is formed for this cluster-center points using manhattan distance since the distance between clusters will be travelled by the shuttle in a city environment. The cluster center locations are clustered by hierarchical clustering with complete linkage. Since a shuttle's users should not be too spread out, causing long personnel collecting times on top of actual travel time, this linkage method was preferred. Shuttle's user collecting route length should be smaller than a previously designated distance, 7 kilometers in our case thus the hierarchical clustering tree is cut at 7000 meters. This new clustering is named as "shuttle clusters" since it indicates which local cluster is assigned to which shuttle. A major assumption while assigning shuttles is that a shuttle picks-up people in a close neighbourhood and does not pick up others on the way to the campus.

In some cases, local clusters had very few number of people and are very far apart to other local clusters for merging. Therefore, a shuttle is assigned to these far apart clusters with the algorithm. However, assigning a shuttle for less than 5 people is deemed to be economically infeasible and damaging for both the traffic and the environment. For these reasons, small shuttle clusters are merged with the closest shuttle cluster center recursively until there are no small clusters left.

If the maximum capacity limit of a shuttle, which is 45 passengers, is exceeded, these shuttle clusters are divided into smaller groups. K-medoids clustering was again utilized for this operation due to the same reasons specified before.

The road conditions of a city may not always be up to date and cause shuttle assignments to be useless. City divisions and other aspects that are difficult or impossible to analytically define require a human intervention during the post-processing phase.

After the post-processing of the shuttle assignments, for each shuttle, an optimal route that passes through the local clusters assigned to that shuttle is investigated. This can be formulated as a traveling salesman problem with an additional dummy starting node, which is the university campus. The distance from each node to dummy and vice versa is taken as 0. A heuristic method is used for the problem since Traveling Salesman Problem (TSP) is and Non Deterministic Polynomial (NP)-Hard problem.

3-Opt algorithm reinforced with Tabu search algorithm is selected as the search algorithm in order to generate a wide scope of solutions and avoid getting stuck at some local minima for this minimization problem.

Subwaypooling System

This innovative approach for personnel shuttles, combines the previously constructed method with the public transportation system of the city. If the city's public transportation has sufficient capacity for satisfying the demand levels especially during the beginning and end of work hours this system can improve the efficiency of the personnel shuttles even further, as well as promote public transportation indirectly. In the long term, it may motive the passengers to use more public transportation instead of personnel shuttles. The overall process is shown in the flowchart below as a summary (Figure 2).

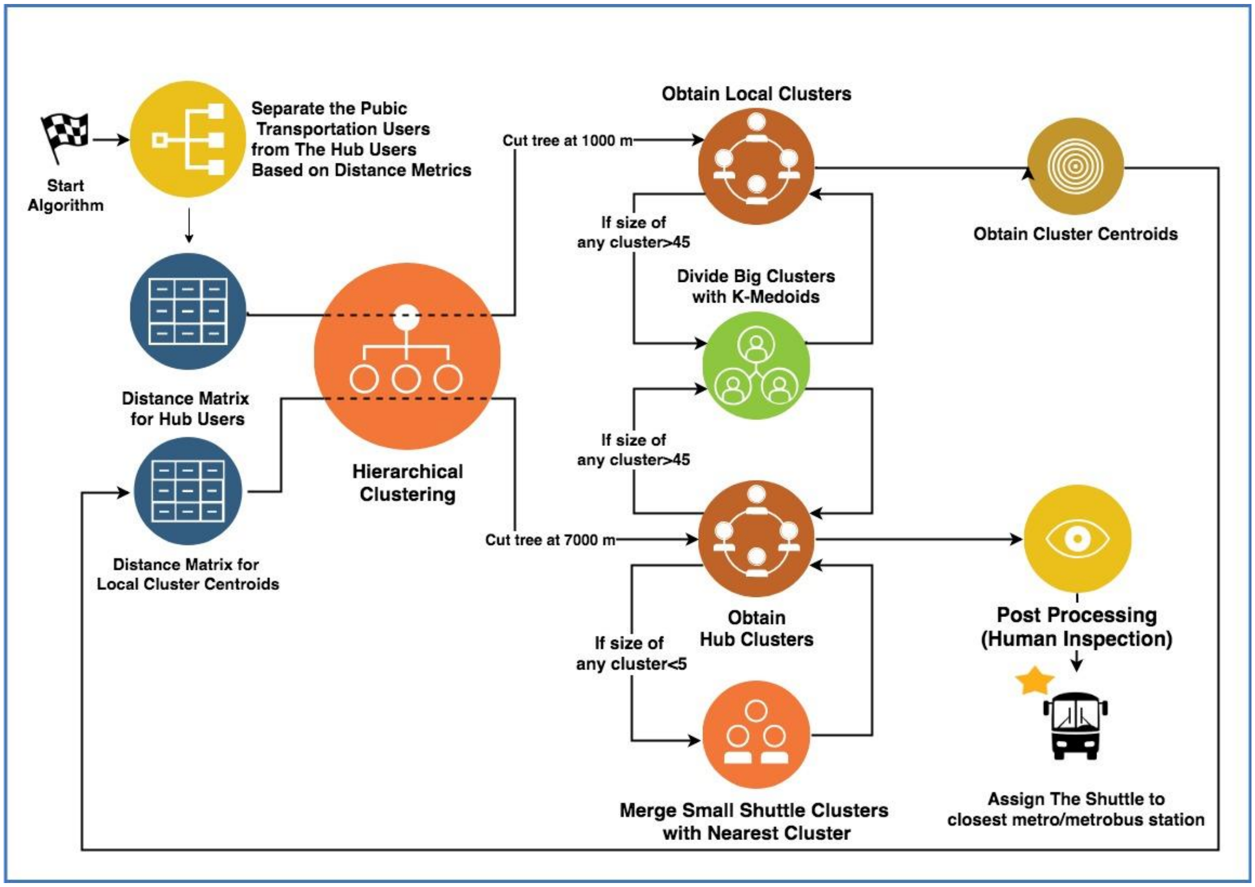

FIGURE 2 Flow-chart for subwaypooling system process.

Initially the public transportation systems of the city of Istanbul is inspected. It was observed that M2, M4, M5, M6, T1, F2, F3 subway lines and metrobus system have access to the campus in a reasonable time. In addition, data of bus lines and stations are gathered and bus station interchange matrix and bus station distance matrix are calculated from the IETT data. Bus station interchange matrix shows how many interchanges are needed for going from one station to another in the shortest travel case. Bus distance matrix shows how many stations should be passed to go from one station to another in the shortest travel case. A major assumption used in here was that stations on the average are not too far apart from each other and total distance from a station to another is minimized by minimizing the stations visited in between. The personnel are divided into categories named as follows:

- Direct Public Transportation Access, which means passengers that have access to the subway/BRT stations and can reach to campus directly by themselves;
- Transfer Public Transportation Access, which indicates passengers that do not have direct access to the subway/BRT stations but can reach to those stations by traveling with bus for at most 2 stations;
- Hub/Vanpool based on their closeness to subway system, which is consisting of the passengers that are picked up by shuttles from their homes and transported to either a suitable subway/BRT station or to campus directly, based on the final decision made in the manual checking process.

The categorization is done in the following way:

1. Is the person in walking distance to a metrobus station or a station of a selected metro-line (M2, M4, M5, M6, T1, F2, F3) (from now on, metrobus station or a station of a selected metro-line will be abbreviated as metro/bus station)?

1.1. If the answer is yes, then assign passenger to Direct Public Transportation Access category.

1.2. If the answer is no, then: check if the passenger is in walking distance to any bus station?

1.2.1. If the answer is yes, then determine the bus stations in vicinity of that person.

1.2.2. If the answer is no, then: check if the passenger can access to a metro/bus station in less than 2 stations and 1 transportation mean? (Calculated from Bus Station Distance Matrix and Bus Station Interchange Matrix, respectively.)

1.2.2.1. If the answer is yes, then assign passenger to Transfer Public Transportation Access category.

1.2.2.2. If the answer is yes, then assign passenger to Hub/Vanpool category.

Individuals in Direct Public Transportation Access and Transfer Public Transportation Access categories are expected to use the public transportation network to arrive at the campus the remaining individuals in Hub/Vanpool category will be taken via shuttle bus. The remaining methodology deals with individuals in this group.

Shuttle assignments are done in the same fashion as the “Shuttle Optimization” part except the merging and final route planning and a few minor changes. Merging is not applied since the shuttles will travel a shorter length than before and shuttle users will travel through public transport after using a shuttle thus shuttle route should not be long for anyone for fairness. After the assignments and post-processing are done the shuttles are directed to the closest metro/bus station to their cluster centroid rather than the campus. People inside the shuttle continue their journey to the campus from the public transportation station. It was also decided that shuttle’s user collecting route length should be smaller than a previously designated distance, which is 5000 meters for this case.

This new clustering is named as hub clusters since it indicates which local cluster is assigned to which shuttle. For each hub, the closest metro/bus station to the hub centroid is investigated and shuttle route is assigned to end at the closest metro/bus station. People inside the shuttle will continue their journey from the public transportation station. With this method it is aimed that the travel times will decrease even further and public transportation will be promoted.

RESULTS

After applying the new shuttle optimization method for passengers from both Europe and Anatolia sides (Figure 3) of the city, the clusters of passengers were visualized.

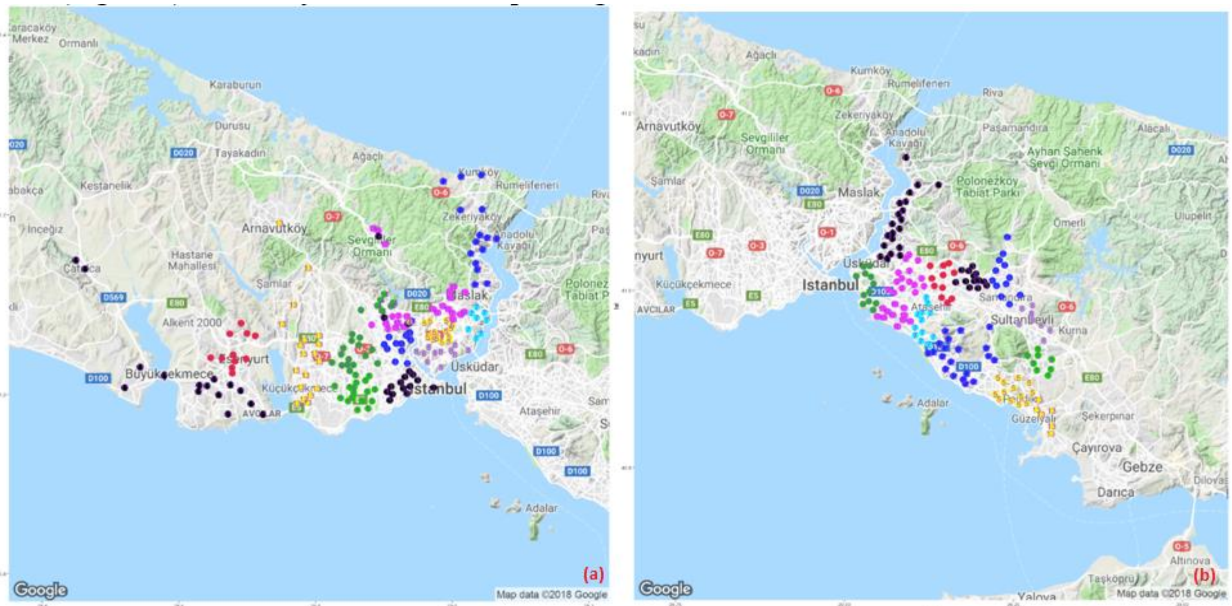

FIGURE 3 Passengers with their shuttle labels after the merging for European (a) and Anatolian (b) side of the city.

After the process is completed, the shuttle routes were generated and were manually checked for avoiding avenues with too many traffic signals and excessive traffic congestion during the peak hours. Examples for the final routes are given for both European and Anatolian side (Figure 4).

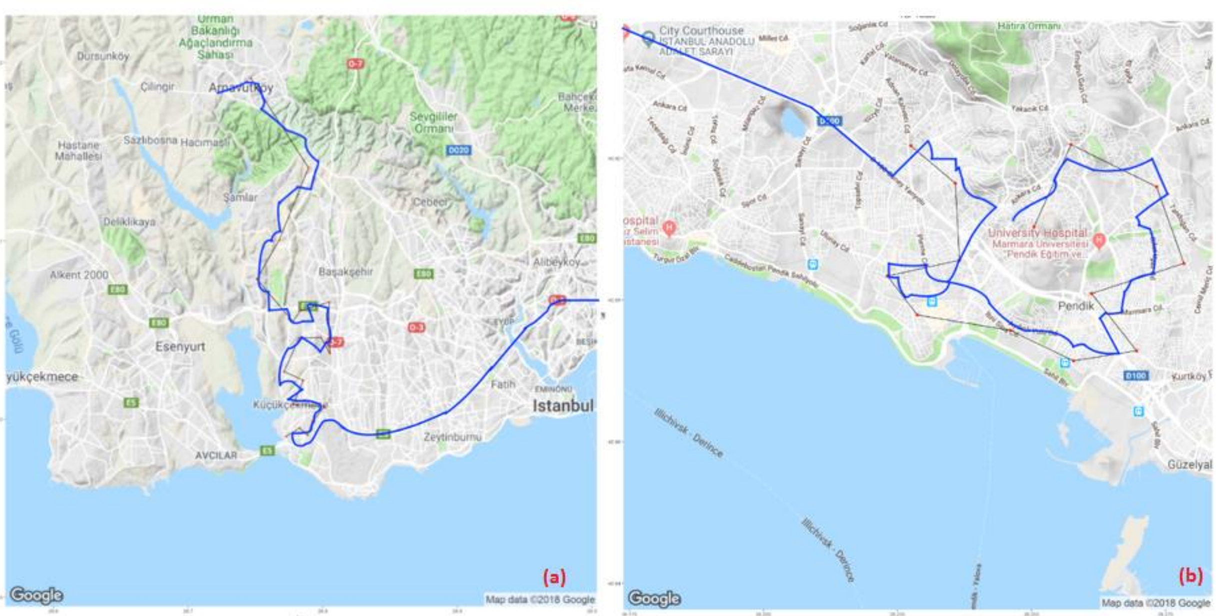

FIGURE 4 An example for the shuttle route for European side of the city picking up the passengers in cluster 13 (a) the shuttle route for Anatolian side of the city picking up the passengers in cluster 5 (b).

For the passengers at European side 18 shuttles were used. Maximum and average walking distance of individuals are 509.9 meters and 69.36 meters, respectively. For the passengers at Anatolian side 14 shuttles were used and maximum and average walking distance of individuals are 564.9 meters and 59.51 meters, respectively. In total, 32 shuttles are being used for the optimized system which was 61 shuttles before this new system. The short walking distances and a decrese of this size indicates that the new system shows promise. Also checking the road conditions by hand as a final check, to avoid roads with congestion especially during peak hours and too many traffic lights, is expected to provide improved travel times. Also, manual control as a last step can provide more useful routes for the passengers, which was one of the biggest complaints of the passengers.

After the shuttle optimization method showed promising results, for further improvement and increased sustainability of the system, the shuttle system is integrated with public transport systems. This system has increased level of complexity compared to the previous method, which only required manual final checks. For this system to be fair and effective, more ground rules were required. These are as follows:

- The passengers in the HUB category are picked up from their homes directly instead of making them walk for a certain distance;
- For shuttles with very few passengers (3 or 4 passengers at max), these shuttles will be merged with other suitable shuttles and these shuttles will either go to the campus directly or to the most adequate public transportation station;
- Passengers that can arrive to the campus with subway directly or with one transfer, will not be picked up by any shuttles;
- The shuttles that are coming from very distant locations will go to the campus directly due to the fact that the travel time with public transportation may significantly increase their previous travel time. This decision will be made during the final manual check with great care for avoiding the exploitation of this rule.

The categorized personnel based on how they will reach to the campus, are plotted with the previously mentioned public transportation lines. The passengers that are assigned to their categories are shown in the figures with assigned colors for both European and Anatolian (Figure 5) side of the city.

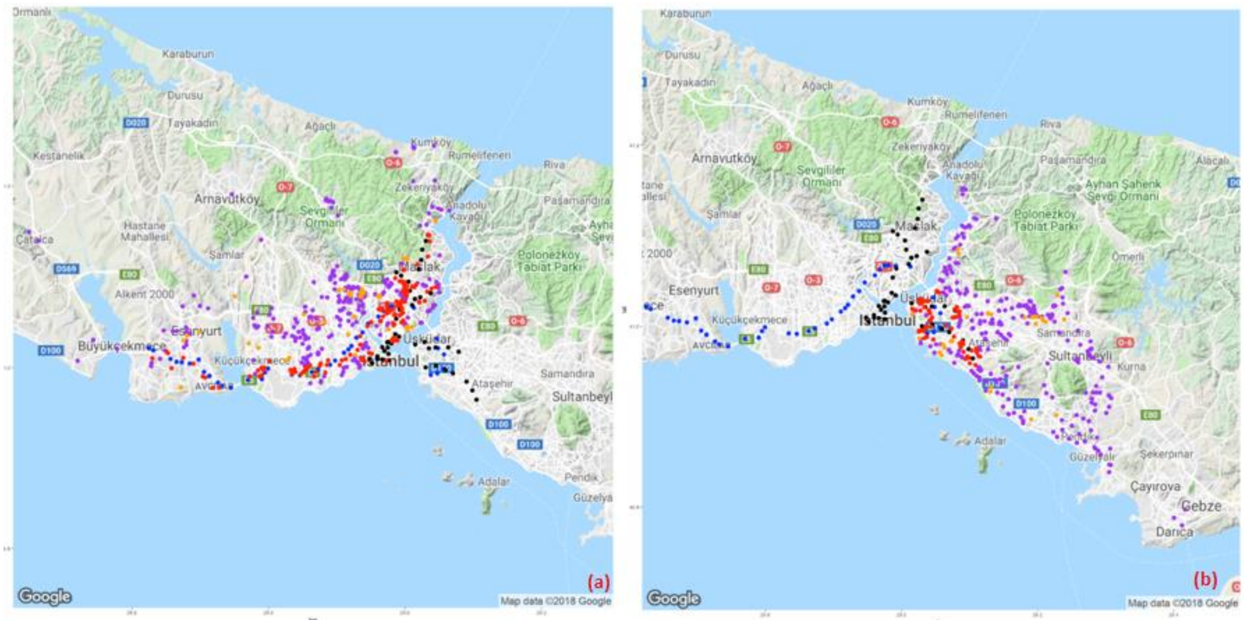

FIGURE 5 The passengers at European (a) and Anatolian (b) side assigned to their categories (Purple: Hub, Red: Direct public transport, orange: transfer public transport) and the BRT (blue) and metro stations (black).

After classifying the passengers, the previously mentioned algorithm is again utilized and the manual check is conducted with the consideration of the rules presented before. The shuttles with the passengers that are assigned to them will go to the public transport stations in both the European and Anatolian side. The assigned public transit stations are given in the figure (Figure 6).

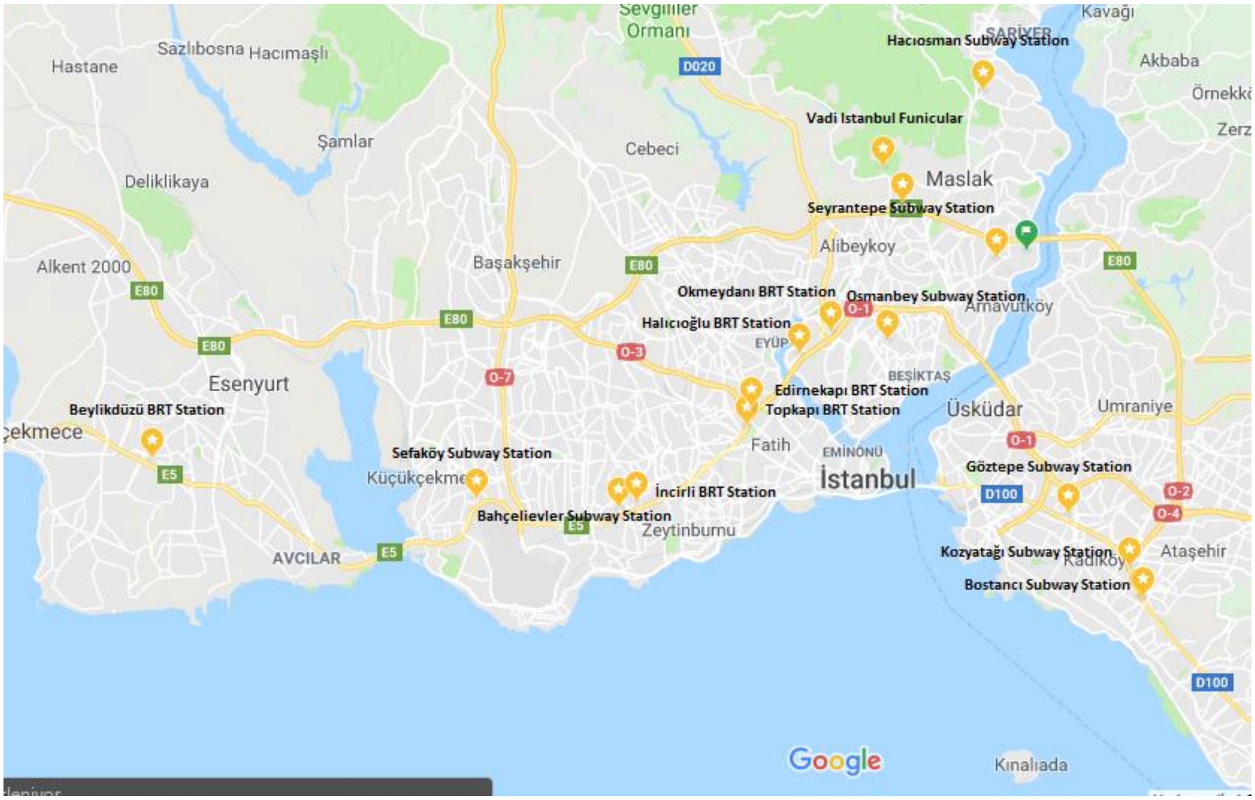

FIGURE 6 The shuttles' assigned public transport station locations.

With the assignments of these shuttles, the number of shuttles is decreased significantly. This gives the opportunity for improved traffic conditions in the city center and especially in the business district zones due to the fact that majority of these stations are not inside zone that can be considered as the city center or the business district.

By applying this new systematic method, the number of shuttles is decreased from 61 shuttles to 32. When subwaypooling system is presented additional benefits were gained by decreasing the number of shuttles even further from 32 to 24. With the subwaypooling system the number of passengers that are transported with this shuttle system also decreased from 1166 to 574 (Table 1).

TABLE 1 Comparison of The Shuttle Systems.

	Current System	**System Obtained with Shuttle Optimization**	**Subwaypooling System**
Number of Shuttles	61	32	24
Number of Passengers Transported with Shuttles	1166	1166	574

The decrease of the number of shuttles can benefit the traffic conditions in the long term. Especially due to the fact that they occupy significant amount of parking space during the day and cause additional traffic load in the city center and business district zones. This additional traffic load effects the public buses in these zones negatively and therefore the passengers using public buses also get effected negatively, creating an equity issue. By decreasing the number of shuttles the negative impact of the personnel shuttles on the equity is decreased. In addition, the number of passengers that are transported via shuttles are decreased by diverting the most number of passengers to the public transportation systems for going to and returning from the campus. By diverting these passengers, the public transportation is, in a way, promoted. Promoting the public transportation may increase the daily usage of this system and can provide improved traffic conditions and environmental benefits with decreased CO_2 emissions. With the excess budget gained from these improvements, the public transportation systems can be improved, making it more accessible and comfortable. The benefits to all groups of passengers will improve the equity conditions.

CONCLUSION

Personnel shuttle system is an important transportation service that provides comfortable travels for its passengers free of charge. This system; however, only transports a group of travelers, which are the employees of a private or a public workplace. In addition, these services are planned with no systematic method and therefore cause additional traffic congestion especially during peak hours and loss of precious parking space for the rest of the day after they complete their tasks in the morning or evening. With the increase of the population and workforce in the city, this system will continue to grow its impact on the traffic conditions, government and private company budgets. These properties of this service show that the system in its current state is unsustainable and the fact that in order to maintain this system a significant amount of finance is required, creates an equity issue. The improvements of other public transportation systems that can benefit all citizens in the long term may be encumbered due to this financial burden. In order to improve the efficiency and decrease the impact of this system to the equity among other passengers, a systematic method is proposed which aims to decrease the number of vehicles in the system and decrease its financial burden on the budgets of the private companies and governments. For further improvements, a new system is also proposed for cities with sufficient capacity that can satisfy the travel demand of passengers especially during peak hours. This new system, which was called *Subwaypooling* does not only improve the personnel shutte services' efficiency, but also it promotes the use of public transportation systems and may provide long term benefits. With the newly proposed system the government can spend its budget more, for improving the conditions of the public transportation systems. With systematic methods and a final manual check before finalization of the routes and passenger assignments, the travel times of the personnel shuttles are expected to be decreased and a more efficient system environment will be possible.

AUTHOR CONTRIBUTION STATEMENT

The authors confirm contribution to the paper as follows: study conception and design: Gokasar; data collection: Gokasar; analysis and interpretation of results: Gokasar, Arisoy, Aytekin; draft manuscript preparation: Gokasar, Arisoy, Aytekin. All authors reviewed the results and approved the final version of the manuscript.

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