



Shuttle bus service routing: a systematic literature review Servis otobüsü rotalama: sistematik bir literatür incelemesi

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Received/Geliş Tarihi: 27.02.2021
Accepted/Kabul Tarihi: 04.05.2021

Revision/Düzeltilme Tarihi: 29.04.2021

doi: 10.5505/pajes.2021.26243
Review Article/Derleme Makalesi

Abstract

This paper aims to provide a comprehensive literature mapping for shuttle bus routing in different functional application areas. For this purpose, articles which were published in the last 20 years were systematically reviewed. Selected papers related to the topic were classified by their publication year, type of publication, solution approach, application area, usage of mathematical model and objective function. The existing articles were reviewed based on their functional application areas of employee/personnel, patient/hospital, students, elderly/disabled, and airport shuttles. The results of our analysis indicate that there has been an increasing movement in the usage of shuttle bus routing models through the recent years. This study therefore identifies this increasing attention to the topic as well as recent trends, and highlights research opportunities and literature gaps for future research.

Keywords: Systematic literature mapping, Literature review, Shuttle service routing, Bus routing, Vehicle routing problem.

Öz

Bu makale servis otobüsü rotalama modellerinin farklı uygulama alanlarında yapılmış olan çalışmalara ilişkin kapsamlı bir literatür haritalaması sağlamayı amaçlamaktadır. Bu amaçla son 20 yılda yayımlanan makaleler sistematik olarak gözden geçirilmiştir. Konu ile ilgili seçilen makaleler, yayın türü, yayın yılı, çözüm yöntemi, uygulama alanı, matematiksel model kullanımı ve amaç fonksiyonlarına göre sınıflandırılmıştır. Literatürde yer alan çalışmalar çalışan/personel, hasta/hastane, öğrenci, yaşlı/engelli ve havaalanı servisleri şeklinde ayrılmış olan fonksiyonel uygulama alanlarında ayrıntılı olarak incelenmiştir. İnceleme sonuçlarımız son yıllarda servis otobüsü rotalama konusunda yayımlanan modellerin kullanımında artış eğilimi olduğunu göstermektedir. Dolayısıyla bu çalışma son yıllarda konuya dair artan ilgiyi ve yeni araştırma alanlarını işaret ederek, gelecekte yapılacak çalışmalar için araştırma fırsatlarını ve alandaki literatür boşluklarını vurgulamaktadır.

Anahtar kelimeler: Sistematik literatür haritalama, Literatür incelemesi, Servis rotalama, Otobüs rotalama, Araç rotalama problemi.

1 Introduction

Considering the current global socioeconomic and sociocultural structures, transportation systems constitute an important part of the daily life in modern societies. These transportation systems can be for either goods or people. Considering the people domain, transportation systems appear in many areas such as public or intercity transportation, airport, tourism, student, personnel transport etc. These systems have a significant role on the quality of life, affecting factors such as time, comfort, stress, money. Especially in metropolitan cities, it is often said that transportation is the lifeblood.

People prefer to use their private cars to go to work as well as public transport. Although the use of private cars is thought to be more comfortable, it has many disadvantages in urban life such as waste of time, stress due to traffic congestion, increased transportation cost, depreciation cost and fuel consumption. Kent [1] clearly stated in their article that driving a car caused negative effects on people in terms of psychological, social and health aspects, as well as causing ecological damage. Similarly, Baumbach et al. [2] analyzed five different scenarios involving increasing air pollution in Lagos, Nigeria, which is caused by high traffic congestion and restrictions on private cars. Künzli et al. [3] stated that almost half of the deaths from air pollution resulted from motor vehicle traffic, with more than 25,000 new cases of chronic bronchitis in adults and more than 290,000 cases of bronchitis in children. From this point of view, the

shuttle bus systems come into prominence as a more sustainable alternative form of people transportation.

To the best of our knowledge, although shuttle bus systems are important for urban transport and there is an abundant scientific research in the field of the planning and routing of these systems, there are no systematic literature reviews or mapping studies comparing their usage areas in the relevant literature. The only relevant surveys by Park and Kim [4] and Ellegood et al. [5] focused solely on the School Bus Routing Problem (SBRP). The authors described SBRP in five sub-problems and analyzed existing studies in terms of these sub-problems. The classification scheme categorizing the literature based on key problem characteristics were quite similar in both of these surveys. Features such as the number of schools, students and stops, fleet type, whether the service had a mixed load, objective functions and constraints of the mathematical model, region of study, and the type of environment of the school's location were categorized. Mathematical models and different solution methods were explained in both surveys, and especially metaheuristic approaches were examined. While Park and Kim [4] identified the most applied metaheuristic solution methods, Ellegood et al. [5] divided the methods into two categories, as Evolutionary Metaheuristics and Trajectory Based Metaheuristics, and presented a more detailed analysis.

In this study, we analyze and review not only the SBRP, but the more general shuttle bus routing problems over the last 20 years, under five different titles categorized according to

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functional application areas. All problem types and solution methods in these five categories were examined in detail. Namely, we reviewed the existing articles in the functional application areas of employee/personnel, patient/hospital, students, elderly/disabled, and airport shuttles. The results of our survey are presented through a systematic mapping using visual graphics and tables. Hence our study provides a more thorough and state-of-the-art review for shuttle bus routing than the existing review studies. The comprehensive nature of our review also reveals itself in the identification of the solution methods in the existing studies. Not only metaheuristic algorithms but also other methods were identified according to their usage fields.

Considering the above-mentioned contributions, this study intends to shed light into the practically important area of shuttle bus routing by identifying past and current trends and providing insights for future research opportunities. In this respect, it can be very useful for both academicians and practitioners. Namely, the contributions of this study are as follows:

- Classifying the shuttle bus routing studies in the field,
- Providing a systematic overview of the existing solution techniques in the field, and
- Outlining key areas where future research can improve the use of shuttle bus systems.

The rest of the paper is organized in three sections. In the next section, four sub-sections as "Research Questions", "Searching Process", "Inclusion and Exclusion Criteria", and "Classification Procedure" are presented in detail, and we provide the outline of our methodology. The "Results" section expresses the findings and responses to the identified research questions. These findings are explained in detail, supported by tables and figures. The last section includes discussion and comments on the findings and the limitations of our study, as well as future research directions.

2 Methodology

Single reference reviews create bias and hinder getting credible results. For presenting a fair evaluation in research, an unbiased and auditable methodology must be used. Hence, the systematic mapping methodology by Cooper [6] is employed in our study. In this methodology, all related activities are discussed instead of just the ultimate findings. Data is collected through systematic mapping and a linkage is created between the gathered data. The methodology is described by the following steps:

- Determination of the research questions,
- Design the searching process,
- Defining the inclusion and exclusion criteria,
- Defining the classification procedure.

In the following subsections, the followed steps are presented in detail, and information on how they are applied in this study are provided.

2.1 Research questions

Some key research questions were specified for guiding our systematic search. These questions were classified so that they could guide the research methodology and serve as a road map for the researchers. Our research questions are presented in Table 1.

Table 1. Research questions for the literature review.

#	Research Questions
RQ1	What kinds of publications have dealt with the routing of shuttle services?
RQ2	What is the number of publications by year?
RQ3	What are the usage areas of shuttle services?
RQ4	Which approaches have been applied for shuttle services?
RQ5	What kind of solution methods are used in the area of shuttle services?
RQ6	Is a mathematical model used in the published articles?
RQ7	What are the most frequent objective functions?

2.2 Search process

Keywords related to the research field are the main drivers of research. "Shuttle bus", "Shuttle service", "Bus routing problem", "Vehicle routing problem" were defined as a router for search in the topic of shuttle service, as well as "systematic literature mapping" to identify previous efforts. The search process was performed on "Google Scholar" with these keywords between the years of 2000-2020. The three-pass approach introduced by Keshav [7] was applied for avoiding the time wasted in the literature survey. At the end of the search process, a total of 93 studies were identified and examined. While some of these studies were accepted as primary studies, some of them were discarded. The following section provides information on how the articles were chosen or eliminated.

2.3 Inclusion and exclusion criteria

Looking at the last 20 years in the field of shuttle bus routing, a total of 89 operations-research and optimization-based articles (among the encountered 93 articles) were examined. A number of exclusion criteria were set in order to include only the significant studies. Our exclusion criteria were specified as follows:

- If an article is written in a different language than English or Turkish, it is excluded.
- As well as technical papers, university sources and thesis collected under the category of publication type were excluded.

2.4 Classification procedure

After the search process was completed and the inclusion/exclusion criteria were applied, as a first step of classification, an ID number was given to all accepted articles. Then, a table was prepared for classification of the obtained information from the studies. Through this table, the main headings for the classification criteria were determined. As can be seen from Table 2, a total of 7 classification criteria was taken into consideration and an ID number was given to each.

Initially, four different publication types were determined under the categories of journal, conference proceedings, book chapters and others. Except for the comparison and review papers, one general observation for the articles in the scope of this study is that a solution methodology was employed in all. In particular, 37 distinct solution methods were identified in the reviewed papers. For these approaches, both usage in the literature and the abbreviations consisting of the initials of the method have been assigned as identity.

Table 2. Classification criteria.

Classification Criteria	Type of Variables	ID #
Type	Journal	1
	Conference Proceeding	2
	Book Chapter	3
	Other	4
Approach	Exact Method	1
	Matheuristic	2
	Metaheuristic	3
	Simple Heuristic	4
	Hybrid	5
	Other	6
Solution Method	Commercial Solvers	CS
	Constraint Programming	CP
	Genetic Algorithm	GA
	Tabu Search Algorithm	TS
	Clark&Wright Savings Algorithm	CW
	Maximin	MMIN
	K-means	K-M
	Fuzzy C-means	FC-M
	Competitive Learning	CL
	Ant Colony Algorithm (ACO)	ACO
	Evolutionary Algorithm	EA
	Greedy Algorithm	GRASP
	Simulated Annealing	SA
	Local Search	LS
	Hill-climbing Algorithm	HCA
	Variable Neighborhood Search	VNS
	Large Neighborhood Search	LNS
	Nearest Neighborhood Search	NNS
	2-opt Algorithm	2-OPT
	Destroy and Repair Algorithm	DAR
	Insertion Algorithm	INS
	Sweep Algorithm	SWA
	The label-setting algorithm	LSA
	Branch & Cut Algorithm	B&C
	Column-Generation-Based Algorithm	CGBA
	Location Based Heuristic Algorithm	LBHA
	Branch & Bound Algorithm	B&B
	Harmony Search Algorithm	HSA
	Partical Swarm Optimization	PSO
	Two-Phase Algorithm	2PH
	Memetic Algorithm	MEA
	Conflict Ordering Search	COS
Branch-and-price-and-cut algorithm	B&P&C	
Hyperpath-based Algorithm	HPBA	
A set-partitioning-based algorithm	SPBA	
Monte Carlo Method	MC	
Minimum Cost Matching-Based Insertion	MCM	
Mathematical Model	No	0
	Yes	1
Problem Class Proof	No	0
	Yes	1

Table 2. Continued.

Classification Criteria	Type of Variables	ID #
Application Area	Employee/Personnel	1
	Patient/Hospital	2
	Students	3
	Elderly/Disabled	4
	Airport Shuttle	5
Objective Function	Min. # of bus stop	1
	Min. # of bus	2
	Min. total travel distance	3
	Min. # of travelling time	4
	Min. the total travelling cost	5
	Min. the rental cost	6
	Min. the distance to the students'/employees' destinations	7
	The balance of routes among drivers	8
	Min. the lateness on the delivery time	9
	Max. the number of served requests	10
	Max. the remaining coverage for emergency calls	11
	Min. the average occupancy rate of used vehicles	12
	Max. the travel time reliability	13
	Max. the total profit	14

As it can be seen from the table, some items under the criteria such as Type and Approach were specified as "Other". This means that the employed method is not seen frequently among the searched articles. In the Type category, university sources, thesis and technical papers are involved under "Other". In addition, methods such as simulation, data mining and machine learning, which are not widely used in the reviewed studies, are defined as "Other" under the Approach category.

The field of shuttle bus routing can be considered under the type of vehicle routing (VRP) or location-routing-problems (LRP). Generally, the researchers dealing with this kind of problems employ a mathematical model like mixed integer linear programming (MILP) or nonlinear mixed integer programming (NLMIP). Due to this observation, the existence of a developed mathematical model was chosen as a classification criterion and evaluated with a yes/no answer. Obtaining exact solutions to routing problems solely through a mathematical model is rather difficult, as these problems generally fall under the NP-hard class. In the Problem Class Proof criteria, if the article assumed the value of 1, the authors have provided the NP-hardness proof for the studied problem. A value of 0 on the other hand indicates that the problem was mentioned as NP-hard, however this result was not accompanied in the article with a proof.

Another important criterion is the Application Area. This classification was made in order to understand in which areas the studies are used more widely. It also helps for observing in which areas there are deficiencies, and to determine whether they can be adapted to different fields.

The last criterion that guides our study is the Objective Function. The quantity to be optimized of a mathematical model is defined in the objective function. When the objective functions in the reviewed articles were examined, they were classified under 14 different titles according to what they aim. This field could be an important guide in understanding the different purposes among the studies.

3 Results

In this section, we present the results of our survey with regard to the research questions.

3.1 RQ1: What kinds of publications have dealt with the routing of shuttle services?

In the scope of this study, conference proceedings and journal articles were investigated. The last 20 years were taken for consideration and 75 articles were examined in total. The distribution of these studies according to publication type are shown in Figure 1. Approximately 80% of the articles (58 out of 75) were journal articles, while the remaining 17 were published as conference papers.

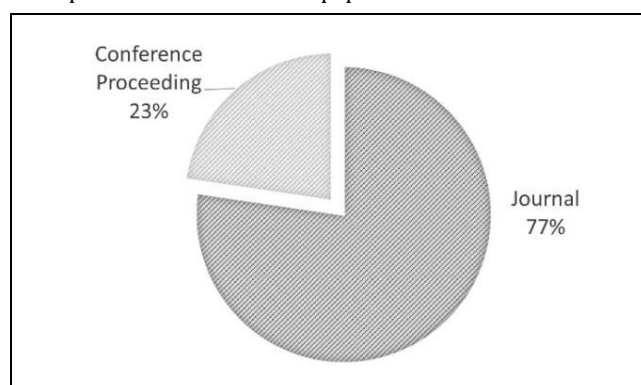


Figure 1. Publication types.

The articles were also categorized according to type based on the journal domains. While 48 articles were published in journals in the "Operations Research" domain, 17 were published in "Computer Science" and 10 were published in "Operations Management" journals. The distribution percentages are depicted in Figure 2. Moreover, the distribution of the articles in terms of the journals they were published in can be seen in Table 3.

Table 3. Journal indices.

Journal Name	Frequency	WOS Index			
		SSCI	SCI	SCI-E	ESCI
4OR-A Quarterly Journal of Operations Research	1			√	
Advanced Engineering Informatics	1			√	
Brain-Broad Research in Artificial Intelligence and Neuroscience	1				√
Computers & Industrial Engineering	1			√	
Computers & Operations Research	3			√	
Electronic Notes in Discrete Mathematics	1				
Engineering Applications of Artificial Intelligence	1			√	
Engineering Optimization	1			√	
European Journal of Operational Research	5			√	
International Arab Journal of Information Technology	1			√	
International Journal of Computer Applications	1			√	
International Journal of e-Education, e-Business, e-Management, and e-Learning	1				
International Journal of Operations Research	1				
International Journal of Production Resource	1			√	
International Journal of Software Engineering & Applications	1			√	
I.J. Intelligent Systems and Applications	1				
Journal of Advanced Transportation	1			√	
Journal of Emerging Trends in Computing and Informations Sciences	1				
Journal of Scheduling	1			√	
Journal of the Operational Research Society	4	√		√	
Mathematical Problems in Engineering	1			√	
Mugla Journal of Science and Technology	1				
Mühendislik Bilimleri ve Tasarım Dergisi	1				
Natural Computing	1			√	
Networks	2			√	
Omega	2				
Operations Research	1	√		√	
Operations Research for Health Care	1				√
OR Spectrum	1			√	
Plos One	1			√	
Procedia-Social and Behavioral Sciences	1				
Promet-Traffic & Transportation	1			√	
Quantitative Approaches in Logistics and Supply Chain Management	1				
Research in Logistics& Production	1				
Revista Escuela de Ingenieria de Antioquia	1				
Socioeconomic Planning Science	1	√		√	
Swarm and Evolutionary Computation	1			√	
Transportation Research Part B: Methodological	3	√		√	
Transportation Research Part C: Emerging Technologies	1			√	
Transportation Science	5	√		√	
Uluslararası Mühendislik Araştırma ve Geliştirme Dergisi	1				

The journals with the largest number of publications are the European Journal of Operational Research and Transportation Science, each with 5 articles. These journals are followed by the Journal of the Operational Research Society with 4 papers, Transportation Research Part B: Methodological, and

Computers & Operations Research with 3 papers, and Networks with 2 papers, respectively. The remaining 23 journals have one selected paper per journal of the 41 selected papers, 21 were published in journals ranked in SCI-E, 5 papers

both in SSCI and SCI-E, 2 papers in E-SCI, and 13 papers in other area indices.

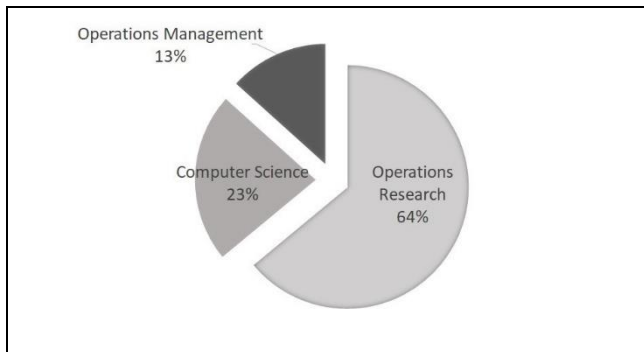


Figure 2. Categories of articles.

3.2 RQ2: What is the number of publications by year?

Distribution of papers through five-year sub-periods is illustrated in Figure 3.

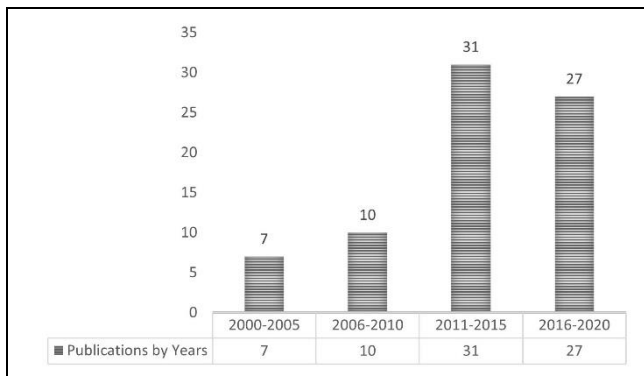


Figure 3. Publications by year.

It seems that there has been a significant increase in the number of articles published during the last 10 years. While 58 (78%) articles were published in the last decade, only 17 (21%) of the total number of articles were 2000 and 2010. This increase shows that there is a trend for studies on shuttle bus in recent years and the problem is gaining popularity. This may be an expected result due to increasing global urbanization and environmental concerns. The researchers and practitioners both recognize the importance of possible cost and ecological savings through shuttle usage as opposed to private transportation. Therefore, we can safely claim that this trend of increased attention to the field is expected to extend into the future.

3.3 RQ3: What are the usage areas of shuttle services?

As opposed to previous review studies, we identify the practical application areas of the studied problems and categorize the domains under which these studies are conducted. For this purpose, Figure 4 expresses the distribution of the reviewed publications for each identified context or application area. It can be seen that nearly half of the studies are applied in the field of students. This may be the reason as to why the previous review efforts only focused on school bus routing problems. The larger number of publications mainly involved students, patient/hospital and employee/personnel, whereas elderly/disabled and airport shuttles attracted less attention analytically during the last 20 years.

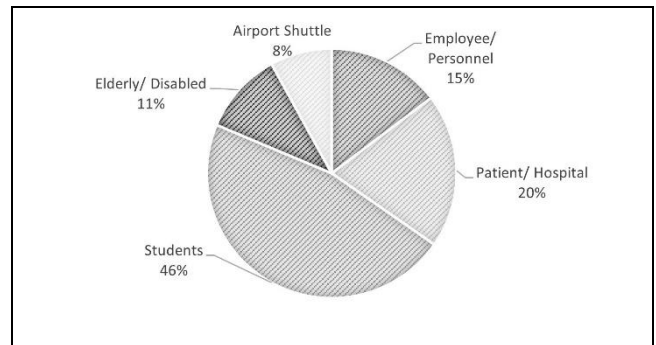


Figure 4. Distribution among different application areas.

However, there is still a considerable and growing number of studies in the less-studied functional areas of the shuttle bus routing problem. The distribution of these areas throughout the five-year periods can be seen in Figure 5.

Although many studies have been carried out in almost every field within a period of 20 years, it can be observed that the studies involving airport shuttle services are rather new; they came into existence only during the last decade. This can be an indication for growing focus in the less studied but yet important variants of the problem.

3.4 RQ4: Which approaches have been applied for shuttle services?

As the problem falls under the NP-hard problem class, many authors have chosen to tackle the problems by using heuristic, metaheuristic or matheuristic approaches. Figure 6 illustrates the distribution of different solution approaches. While 37 of the publications (around 40%) tended towards problem-specific heuristics, 36 (39%) employed metaheuristic approaches. The dominance of usage of these two methodologies reveals the complexity of the problem's structure.

The most frequent approach among the remaining studies is the exact method, with a frequency of 8 (around 21% among all articles). Next, hybrid approaches including more than one heuristic/metaheuristic appear in 6 articles with a 6% share. Matheuristics appear in only 1 article. This can be due to the fact that this category is relatively newer. Also, matheuristics involve the exact solution of some inherent mathematical model, which can be quite hard for this problem category. The "other" category was used for methods that are less common among the examined studies in this field such as simulation and data mining, including 6 papers (5%).

3.5 RQ5: What kind of solution methods are used in the area of shuttle services?

During the last 20 years, the studies in the field have utilized 37 different solution methods as can be seen in Table 2 with the most implemented being Commercial Solvers (CS), Genetic Algorithm (GA), Variable Neighborhood Search (VNS), Tabu Search (TS), Insertion Algorithm (INS) and Local Search (LS).

A total of 26 authors chose to use CS. Among these, Yalçındağ [8], Schittekat et al. [9], Uzumer and Tamer [10], Bektaş and Elmastaş [11], Arik et al. [12], Van Den Berg and Van Essen [13] aimed for the solution of the mathematical model using only CS without any other solution method. The rest solved their mathematical models in a CS, accepted this result as an initial solution and tried other methods to improve their results.

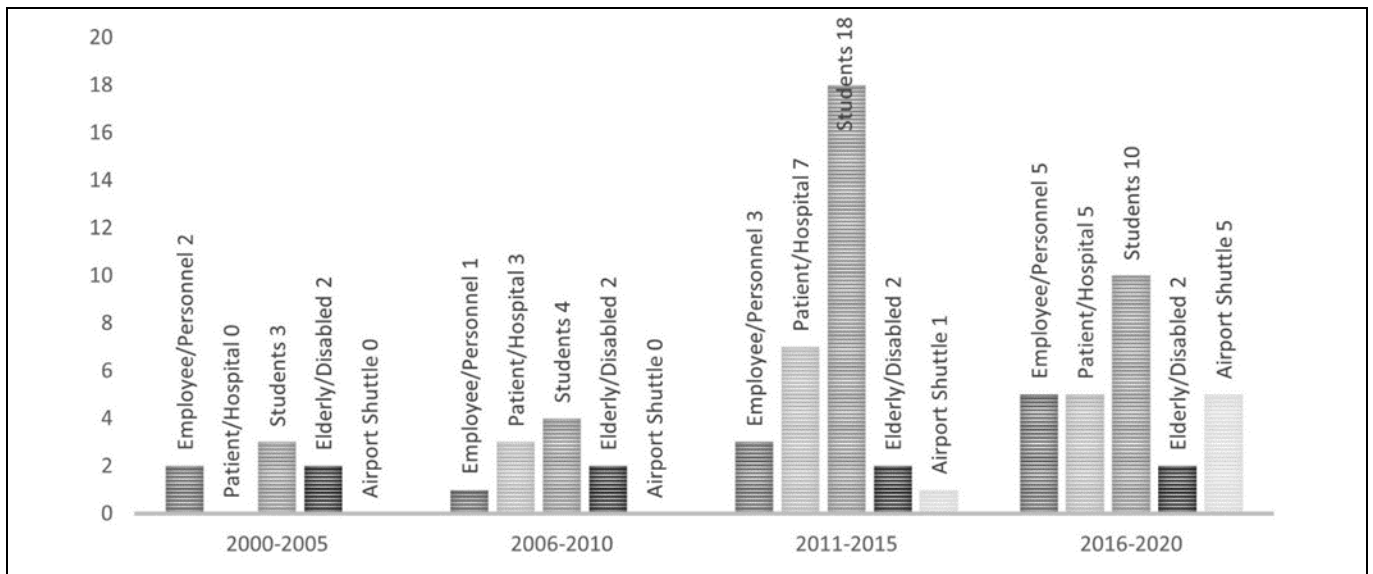


Figure 5. Distribution of the application areas by years.

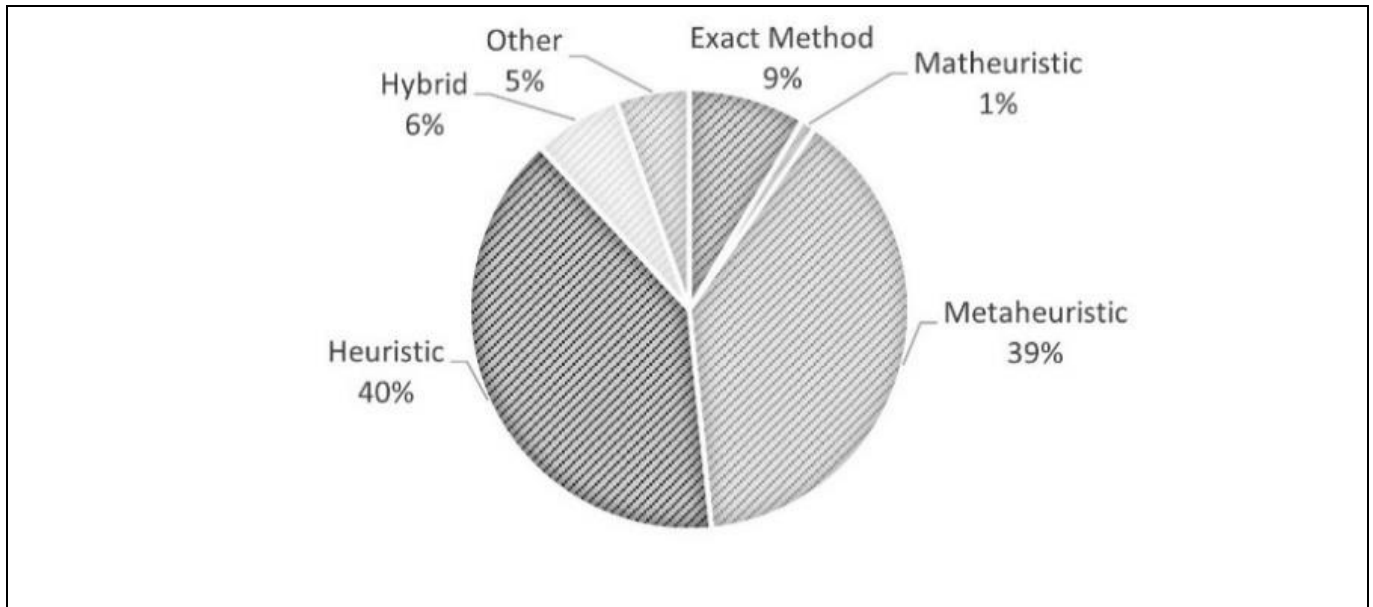


Figure 6. Approaches used in solving shuttle bus routing problems.

Although some authors have reached a solution using only one method, most of them used more than one solution method instead of a single one. While there is generally no other solution method in the articles using GA, only 4 publications used a different solution method together with genetic algorithm. Ünsal and Yiğit [14] developed a method for the optimization of SBRP by using artificial intelligence and clustering techniques together. It was aimed to determine the most suitable route for each shuttle vehicle using GA. Minocha and Tripathi [15] used a hybrid metaheuristic by combining GA and LS. Bao et al. [16] implemented the hill-climbing algorithm (HCA) with a strong local search ability in the field of airport shuttles. The initial solution was obtained with HCA and was then integrated into GA for improvement.

Beaudry et al. [17] and Aldaihani and Dessouky [18] used both TS and INS methods. They proposed a two-phase heuristic for

the problem. In these papers, the insertion method was used in first phase for generation of a feasible solution, and it was improved in the second phase through TS. Spada et al. [19] created an insertion heuristic. After they obtained an initial solution, the authors improved it with LS, TS, and SA. On the other hand, Shafahi et al. [20] used Minimum Cost Matching-Based Insertion and improved a hybrid solution using TS and SA.

Lim et al. [21] proposed a LS metaheuristic that uses a VNS method. In addition, the INS method has been modified and employed to obtain the solution in their study. Detti et al. [22] used VNS and TS for a multi-repository dial-a-ride problem (DARP) with heterogeneous drivers as well as vehicles, while Molenbruch et al. [23] and Souza Lima et al. [24] used a versatile LS that was developed and integrated into the VNS to solve the problem. Schittekat et al. [25] developed an MIP

model for the SBRP. Then, they used the variable neighborhood descend (VND) method, which is a kind of VNS, and a greedy algorithm for solving large instances of the SBRP. Kergosien et al. [26] used TS algorithms with VNS which is built by a swap operator in the field of patient/hospital. Euchl and Mraih [27]

developed a hybrid method by applying Ant Colony Optimization (ACO) and VNS. In addition to these common methods in the field of shuttle bus routing, there are also certain different methods used by many authors, which are shown in the Table 4.

Table 4. Solution methods.

Solution Methods	Papers
Commercial Solvers	[8]-[13], [22], [28]-[46]
Constraint Programming	[46]
Genetic Algorithm	[14]-[16], [47]-[56]
Tabu Search Algorithm	[17]-[20], [22], [39], [42], [57]-[60]
Clark&Wright Savings Algorithm	[33], [61], [62]
Maximin	[63]
K-means	[14], [63]-[65]
Fuzzy C-means	[63], [65]
Competitive Learning	[63]
Ant Colony Algorithm (ACO)	[27], [35], [63], [66], [67]
Evolutionary Algorithm	[28], [58], [68]
Greedy Algorithm	[25], [34], [57], [69]-[71]
Simulated Annealing	[19], [20], [31], [36], [41], [43]
Local Search	[15], [19], [21], [23], [24], [30], [31], [69]
Hill-climbing Algorithm	[16]
Variable Neighborhood Search	[21]-[27], [30], [42], [72]
Large Neighborhood Search	[43],[46], [73], [74]
Nearest Neighborhood Search	[75]
2-opt Algorithm	[62], [75]
Destroy and Repair Algorithm	[30], [73]
Insertion Algorithm	[17]-[19], [21], [29], [33], [44], [68], [75]-[77]
Sweep Algorithm	[75]
The label-setting algorithm	[36], [78]
Branch & Cut Algorithm	[37]
Column-Generation-Based Algorithm	[32], [40], [44], [59], [60], [78]
Location Based Heuristic Algorithm	[79]
Branch & Bound Algorithm	[38], [80]
Harmony Search Algorithm	[45]
Partical Swarm Optimization	[65]
Two-Phase Algorithm	[17], [44], [64], [66], [78]
Memetic Algorithm	[68]
Conflict Ordering Search	[46]
Branch-and-price-and-cut algorithm	[78]
Hyperpath-based Algorithm	[81]
A set-partitioning-based algorithm	[81]
Monte Carlo Method	[82]
Minimum cost matching-based insertion	[20]

In addition to the most common solution methods described above, in Figure 7, the distribution of the solution methods among the application areas are illustrated. Considering the usage areas, it is obviously clear that GRSAP and ACO have not been used, except in the field of students and employee/personnel routing. VNS and TS algorithms are mostly used in the Patient/Hospital area. It is seen that GA, which is also one of the mostly preferred methods in the student bus area, is mostly used in the articles involving airport shuttles. Finally, although commercial solver usage is the most preferred method in student, patient/hospital, and employee/personnel areas, it is not used much in elderly/disabled and airport shuttle areas.

3.6 RQ6: Is a mathematical model used in the published articles?

While the school bus routing problem (SBRP) model is commonly employed in the student and the

employee/personnel contexts, it is observed that the dial-a-ride problem (DARP) is mostly used in the application areas of elderly/disabled and patient/hospital. The employed mathematical models are mostly in the form of mixed integer linear programming (MILP) and nonlinear mixed integer programming (NLMIP).

In the reviewed literature, while 49 articles (around 65%) included a mathematical model, 26 articles used various solution techniques without explicitly presenting a mathematical model of the problem, corresponding to a percentage of 35%. The distribution is shown in Figure 8. Even when the mathematical models were included, the problem complexity was stated in many studies, and the authors reverted to approximate solution methods rather than exact ones. Problem class proofs were included in 33 publications.

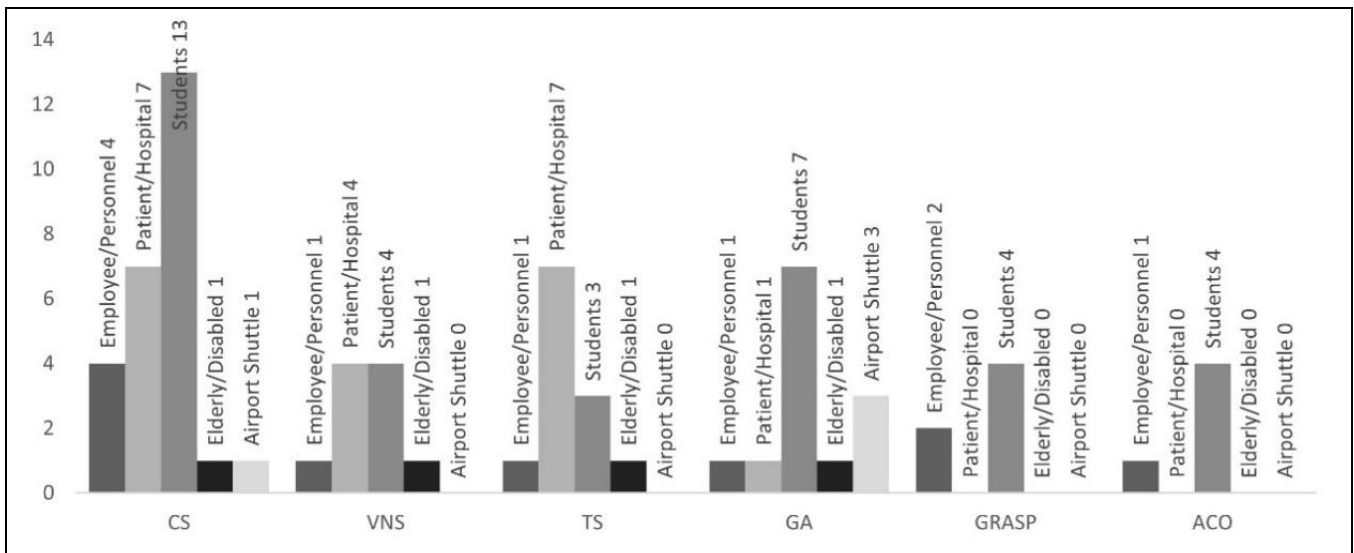


Figure 7. Solution methods by using areas.

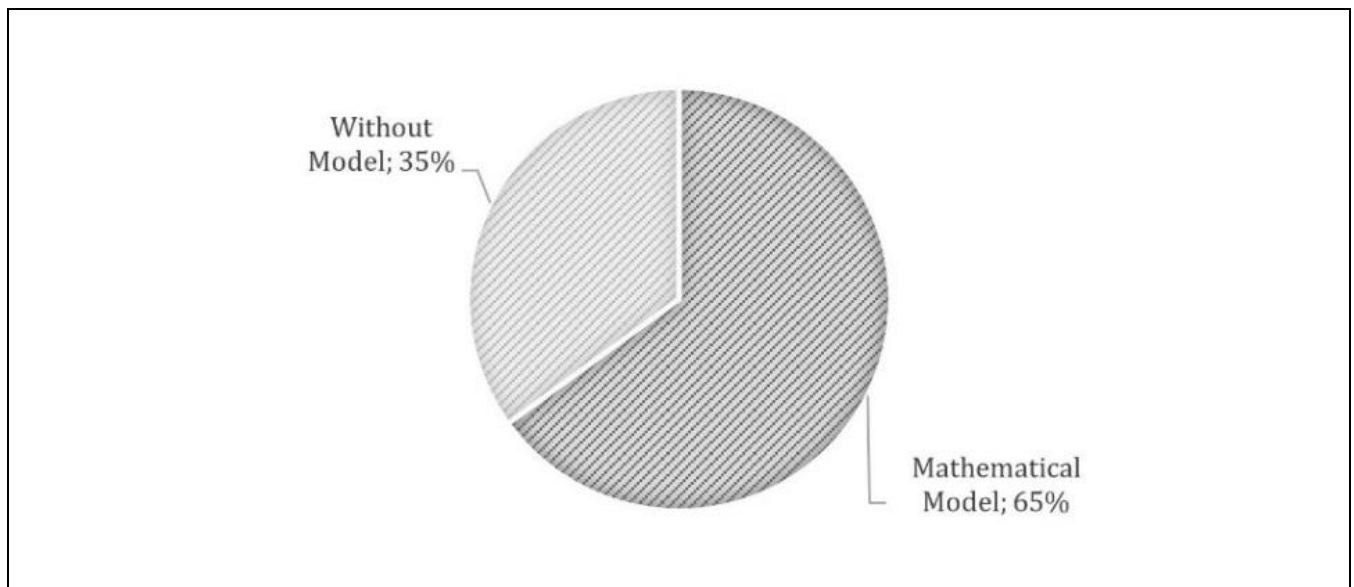


Figure 8. The existence of mathematical models in the studies.

3.7 RQ7: What are the most frequent objective functions?

In the scope of this study, the objective functions are examined and the distribution of papers according to the mostly used objective functions is presented in Table 5. Many studies in the field of student transportation (Chen et al. [28], Diaz-Parra et al. [49], Fügenschuh [37], Kim et al. [35], Minocha and Tripathi [15]) employed the minimization of the number of buses and the total travel distance as an objective function. The most frequent objective functions minimize the total travel distance, cost, time, and the number of buses.

While some studies tended to employ a one or few objectives, some of them included more than three. Wanigasooriya and Fernando [47], and Caceres et al. [32] used multiple objective functions from the cost and time perspectives, like Li and Fu [36]. Their objection functions attempted to minimize the number of buses, travelling times, and travelling distances. Melachrinoudis et al. [39] and Emanuel and Min [42] studied in the patient/hospital area and also used multi-objective functions, which are the minimization of the total travelling cost, the lateness on the delivery time, and the travelling time used as total inconvenience times of the clients.

Bögl et al. [30] used a bi-objective function that aimed to minimize the total travel times of the buses and the penalty cost applied if the number of transfers exceeded the number of allowed transfers. Souza Lima et al. [24] shared almost the same objective functions with Melachrinoudis et al. [39], but also aimed to balance the route workload between drivers, which was not encountered in other publications. Although Oluwadare et al. [53] did not use a mathematical model, they constructed three different objective functions as the number of bus stops, the number of buses and the minimization of total travel distances.

It has been observed that the above mentioned and most frequent objective functions were employed also within the field of student and employee/personnel. In this sense, the fields sharing the same type of problem structure shared similar objective functions, as well. In addition to the most frequent objective functions mentioned above, other objective functions in the studies are listed in Table 5.

4 Conclusion and future work

This study presents a systematic literature mapping in the area of shuttle bus service routing to understand the current research trends between the years of 2000 and 2020. In the scope of this study, research questions were determined, and a search strategy was designed and applied. All related studies within the target period were systematically reviewed based on the search strategy. A total of 75 research papers were selected as primary articles. The analysis of these papers was made in accordance with the posed research questions, and the results obtained provide some important findings as follows:

- It was determined that SBRP was used in student and employee/staff contexts, whereas DARPs were used in the patient/hospital and elderly/disabled domains,
- During the period of 20 years, the airport shuttle context emerged within the last 6 years, and an increased trend was observed in that area,
- In shuttle bus routing research field, due to problem complexity, heuristic and metaheuristic approaches were preferred by many authors instead of direct mathematical model solutions. The results obtained from the mathematical models were improved with these approaches,
- Most of the studies have focused on student transportation, followed by the patient/hospital application area. The employee/personnel transportation show similar characteristics as the student domain,
- The most frequent solution methodologies in the reviewed papers include genetic algorithm, variable neighborhood search, tabu search and local search methods. Hybrid methods are also common.

The implications presented here would be highly beneficial to researchers who want study in the shuttle bus routing area in terms of solution methodologies and trends. However, there are some potential limitations, and these provide direction for further research. Firstly, only operations research and optimization-based papers were included within the scope of this study. Future research can simulate this mapping on a more comprehensive level by including the articles with different approaches. Further, publications except for English and Turkish languages were excluded. Therefore, another future research topic may be to include papers written other languages to obtain on a broader level review of literature.

Table 5. Objective functions.

Objective functions	Publications
min. # of bus stop	[13], [16], [30], [39], [42]-[44], [46], [53], [70], [73], [74], [78], [82]
min. # of bus	[15], [31]-[33], [36]-[38], [47], [49], [53], [58], [61], [74], [75], [80]
min. total travel distance	[9], [10], [12], [14], [15], [17], [18], [25], [31], [32], [34], [36]-[38], [41], [47], [49], [52], [53], [62]-[65], [67], [71], [74], [77]-[79], [82]
min. # of travelling time	[18], [19], [23], [24], [30], [32], [33], [35], [36], [39], [42], [46], [47], [58], [61], [66], [73], [76]
min. the total travelling cost	[8], [11], [12], [20]-[22], [24], [27], [28], [30], [39], [40], [42], [44], [45], [48], [51], [54], [55], [57], [59], [68], [72], [81]
min. the rental cost	[28], [59]
min. the distance to the students'/employees' destinations	[30], [36], [65], [72], [79]
the balance of routes among drivers	[24]
min. the lateness on the delivery time	[39], [42]
max. the number of served requests	[46], [78], [82]
max. the remaining coverage for emergency calls	[13]
min. the average occupancy rate of used vehicles	[73], [74]
max. the travel time reliability	[16]
max. the total profit	[43]

Generally, it was observed that heuristic and metaheuristic methods were used in the reviewed articles, or a mathematical model was solved with a commercial solver and the result obtained was improved by heuristics or metaheuristics. The objective functions were mostly based on reducing traveling cost, distance, time and the number of buses. For future research, hybrid methods and more effective solutions can be studied with these or additional objective functions. Especially in the field of airport shuttles, our findings suggest signals that a trend has been caught recently. Any future study within this context may prove fertile.

Finally, other future lines of work may include studies in the tourism context. The shuttle buses are frequently used in tourism. These shuttles, which are sometimes referred to as hop-on/hop-off, touristic bus or bus sightseeing in some cities, are very useful and popular among tourists. However, studies in this field are not in the field of route determination, but rather include features such as the tour portfolio selection, analysis of tourists' demand, and service quality. Therefore, it seems that there is an opportunity for researchers for determining the most-efficient routes of such shuttle services with various objectives such as maximizing exposure.

5 Author contribution statements

Within the scope of this study, Gaye PEKER and Deniz TÜRSEL ELİYİ jointly took part in the formation of the idea. Author 1 contributed to this study on literature review, methodology creation, obtaining results, and writing the original draft. Author 2 contributed to content review and editing of the article, and also supervised the whole study.

6 Ethics committee approval and conflict of interest statement

There is no need to obtain permission from the ethics committee for the article prepared. There is no conflict of interest with any person/institution in the article prepared.

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