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Public Sustainable Transportation Planning with Service Level Efficiency: Hamburg Case Study

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Purpose: Public transportation in large cities has significant impacts on the environmental, social, and economical perspectives. However, the proper assignment of resources in public transportation creates paradoxical challenges since by increasing service level efficiency, the environmental criteria will be violated. This paper has studied the literature and discussed the considerable gap for the fulfillment of the mutual service level satisfaction and environmental emission considerations.

Methodology: The paper has applied the well-known assignment problem technique and multi-objective planning to propose a novel framework for public transportation resource assignment fulfilling the aforementioned perspectives mutually. The model is capable of analyzing the tradeoffs for increasing public service satisfactions and meanwhile to control the environmental emissions. Using the multi-objective analytical capabilities, the proposed model improves the overall citizens' satisfaction and also manage the operational costs related to the produced emission by transportation resources.

Findings: The real data of Hamburg public transportation has been used to verify the capabilities of the proposed model. The findings first validate the model formulation and also gives insights for effective strategic planning for public resource assignment. The analysis emphasizes on establishing control mechanism for passenger's arrival rate as it affects both waiting times in bus stops and also the transportation vehicle weights which drastically affect the environmental factors.

Originality: This paper has studied the related literature and discussed the gap for the mutual fulfillment of passenger's service level satisfaction using public transportation and also controlling environmental emissions of public transportation.

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1 Introduction

Public network transportation is an indispensable component of every city's infrastructure that affects the daily lives of many citizens (Cao and Wang 2017). Efficient public transportation is an important factor for helping the society to reach long term and daily goals (Joewono and Kubota 2006). Hamburg, as a Hanseatic city, settles a large number of inhabitants inside itself which encounters a significant volume of movements every day (Strunk et al. 2017). Additionally, many logistics enterprises are working in Hamburg, where they need to convey their goods from ports to destinations and vice versa. So, in order to control the flow of passengers, a smooth and efficient transportation system should be considered.

According to the European Commission studies, 40 % of CO2 emissions come directly from urban mobility while up to 70 % of other pollutants also has originality from transportation (Nanaki et al. 2017). This triggers a common challenge to most major cities in Europe, where to intensify movement and increase service level, the congestion, pollution, and environmental criteria should be controlled. Thus, for finding the right responses to this challenge, it is recommended to apply Sustainability Assessment (SA) as a critical tool to analyze the environmental aspects by common SA's criteria (Ribeiro et al. 2020). The importance of sustainability in public transport has got more attention since international laws and domestic regulations are impacting transportation for sustainability concerns. The focus of sustainability is to establish principles on reliably sufficing the requirements of public transportation according to the three pillars: economic, environmental, and social (also known informally as profits, planet, and people). So, SA as an appraisal method can be applied to support long-term and short-term decisions for transportation planning fulfilling three aforementioned pillars.

In terms of environmental criteria, SA encourages governments to consider main prospects that influence the wellbeing of the environment, such as to reduce greenhouse gases and emissions, preserve the ecosystem, and hinder the progress of global warming. In public transportation, the consumption of fuels that produce various air pollutants is the primary concern that effects environmental criteria (Nanaki et al. 2016). These pollutants mostly incorporate of Carbon dioxide, Nitrogen oxides, Methane, and particulates. So, an efficient transport planning system with sustainably considerations must seek to diminish the harmful gases. Simultaneously, from the social and economic perspectives, sustainable transportation must consider the preferences of its citizens with proper transportation service level.

Public transport can be analyzed from two perspectives; in the view of users, the cost of transportation, service level and reliability are among the most favored factors (Mishalani et al. 2006). While from the other perspective, the target is to represent public transport as a viable alternative to self-driving, which both satisfies the logistics requirements of passengers and also will be more successful to fulfill the urban environmental traffic regulations. So, it is a significant challenge that needs a proper solution to fulfill the both citizens' service level and also SA considerations mutually.

The research roadmap is structured as follows. In section 2, the paper has conducted a literature review for sustainability in public transportation and service level efficiency. In section 3, the problem is formulated to both satisfy the service level consideration through minimizing the waiting time of passengers at stations as well as minimizing the environmental emission of buses. Section 4 discusss the problem based on a case study which considers the Hamburg city center and then by an analytical approach, the major factors affecting the sustainability in public transportation alongside high passenger satisfaction is discussed.

2 Literature Review

The public transportation resource assignment is well-known in literature, see Guihaire and Hau (2008) for a comprehensive list of references. Binder et al. (2017) proposed an algorithm for capacitated passenger public transportation in the morning rush hours for Canton Vaud, Switzerland. Their results showed that the ordering of the passengers does not have a significant impact on aggregate performance indicators. Though, on the contrary, the variability at the individual passenger level is substantial. Rafael et al. (2018) applied mix-objective programming to simultaneously maximize the profit and also to minimize the running cost for the regional bus scheduling problem in Tanzania. Cao and Wang (2017) proposed an optimization method for assigning passengers on customized buses. The waiting time and penalty of delay are improved while at the same time traffic congestion was reduced.

One of the vital aspects of public transportation is passenger satisfaction, which is critical for analyzing the customers' service level. In recent years, service level efficiency has been one of the research topics that has been considered in multiple large cities' public transportation service level studies. Fellesson and Friman (2008) compared the level of service in public transportation between eight European countries by organizing a comprehensive survey searching for the respondents' opinions about public transport services. They assessed the internal reliability of the identified factors with Cronbach's coefficient alpha. They indicated important conclusions, including the heavy reliance on technology and infrastructure that is inherent in public transport operations, and the critical role of safety/security, system (supply and reliability), comfort, and staff behavior for traveler satisfaction. Friman and Fellesson (2009) analyzed the relationship between the objective performance measures of public transport services and the satisfaction perceived by travelers. Le-Klähn et al. (2014) studied the service level satisfaction of public transport by visitors in the city of Munich, Germany. They gathered data from a survey with a random sample resulted in four different service dimensions, including traveling comfort, service quality, accessibility, and additional features. They investigated the characteristics of service dimensions with previous studies and proposed some attributes for better service enhancement.

The literature considers the sustainability in public transportation as one of the urban comfort factors. The sustainability is discussed based on three dimensions which the focus is usually on environmental issues. Specially, the emission of different harmful gases to the air is important in environmental issues. For instance, Rebeiro et al. (2019) provided a multi-criteria analysis to evaluate the SA criteria of a bus transportation system in a Portuguese mid-sized municipality. They appended the institutional criteria to other SA pillars in order to calculate the impact of planning and management for public and private agents in the bus system. Three main sources for acquiring data used in their study was: fieldwork, questionnaires, and estimated values. They assessed the SA criteria with ranking and scoring through considering the average evaluation of the values for all urban centers. Errampalli et al. (2020) proposed a methodology for two modes of transportation, including buses and metro in South Delhi, to determine the level of integration by SA criteria consideration. This methodology was applied for evaluating the incorporation of modes and also studied the impacts of public transportation on service level with the multi-criteria analysis. Li and Head (2009) studied the bus scheduling problem by applying a time-space network for evaluating environmental emissions. They followed two primary objectives in their paper, first, minimizing the number of required buses for weekdays and second, minimizing the operating costs.

Qin et al. (2016) studied the impact of using electric transit buses instead of diesel buses on transportation costs and their effects on the environment in Tallahassee, Florida. Using simulation, they attempted to find an optimal charging strategy for fast-charging buses. Feng and Timmermans (2014) focused on tradeoffs between mobility and equity maximization under environmental capacity constraints. They formulated three types of hypothetical policies, including network improvement, population increase, and urban sprawl via using data for Dalian in China.

The waiting time of passengers at the bus stations is a critical component of a passenger's service level efficiency. According to previous studies, the mean waiting time was expressed as half of the transportation headway while passengers were arriving randomly (Osuna and Newell, 1972; Welding, 1957). Hsu (2010) formulated the waiting time based on the characteristics of both connecting service and its feeder service. With the simulation technique, he compared the effects of connecting service variables with the corresponding variables of the feeder service. Mishalani et al. (2006) used regression analysis to estimate the relationship between observed waiting times and actual waiting times at bus stations. Ingvardson et al. (2018) proposed a framework to estimate passenger waiting time in the great area of Copenhagen while passengers come to stations based on two separate groups (as traditional models, one group coming randomly, and the other one coming according to scheduled times). They used a combination distribution consisting of a uniform and a Beta distribution for each group to obtain the waiting time. Vehicle Routing Problem (VRP) is an integer programming that seeking to find an optimal set of routes for vehicles. VRP applications have been used in public transportation problems to assign buses to the routes optimally (Assari et al. 2018, Aghamohammadzadeh et al. 2019). Kim et al. (2011) applied VRP to optimize bus schedules to serve all the given trips. For general cases, they proposed an assignment problem based on a heuristic approach. According to the related literature (Delaram and Valilai 2017, 2018), the mutual service level satisfaction of passengers, and environmental emissions in public transportation are considered as a motivational gap for this research.

3 Problem Formulation

In this section, the main goal is to model and minimize both the waiting time of passengers at stations and environmental emissions of transportation vehicles by a Multi-Objective Optimization Problem (MOOP). The developed MOOP model tries to fulfill the SA criteria in the public transport system based on its three pillars. This motivation is important since transportation system have a significant impact on the environment, economy, and social equity as the main pillars of SA. The target is to support the transportation system for affordable, customer satisficing, and friendly working peace to the environment. So, by optimizing waiting time alongside reducing environmental emissions, SA criteria can be satisfied. For this reason, the assignment problem technique is applied for the public transport system, while based on Vehicle Routing Problem (VRP)problem, stations are assumed as fixed location nodes and buses are optimally assigned to the routes as acres. Therefore, the MOOP has two objective functions that would be mutually optimized.

3.1 Evaluating Waiting Time

The paper assumes passengers are arriving to stations based on a Poisson Process. Consider passengers arrive at station j with Poisson Process rate λ_j and let h_j be the headway in station j. If the first passenger comes at station j exact at the moment when the bus has moved from the station and misses the bus, he/she has to wait for h_j until the next bus arrives.

Continuously, if the other passengers come in an identical separate time until the bus arrives, then all arrival times of passengers would be $\left(0,\ \frac{h_j}{\lambda_j},\ \frac{2h_j}{\lambda_j},\ \frac{3h_j}{\lambda_j}, \dots ,\ \frac{(\lambda_j-1)h_j}{\lambda_j}\right)$, and subsequently, the waiting times for passengers are $\left(h_j,\ h_j-\frac{h_j}{\lambda_j},\ h_j-\frac{2h_j}{\lambda_j},\ h_j-\frac{3h_j}{\lambda_j}, \dots ,\ h_j-\frac{(\lambda_j-1)h_j}{\lambda_j}\right)$. So, the average waiting time at station$j$, $\overline{W_j}$, can be obtained as equation (1):

$$\overline{W_j}=\frac{h_j+(h_j-\frac{h_j}{\lambda_j})+(h_j-\frac{2h_j}{\lambda_j})+(h_j-\frac{3h_j}{\lambda_j})+\cdots+(h_j-\frac{(\lambda_j-1)h_j}{\lambda_j})}{\lambda_j}=\frac{\lambda_j h_j-\frac{h_j}{\lambda_j}(1+2+\cdots+(\lambda_j-1))}{\lambda_j}= h_j-\frac{\lambda_j(\lambda_j-1)}{2h_j} \qquad (1)$$

3.2 Evaluating Environmental Emissions

Air pollutants are responsible for several adverse ecological effects. Various air pollutants such as greenhouse gases, Carbon dioxide, Methane, and particulates are origins of global warming and also suspected of having a critical impact on regional climates. Environmental perspectives in transportation, particularly in the VRP, may lead the system to achieve less polluting vehicles, use the optimal volume of vehicles, and change the mode of transport. According to Carlos Molina (2014), climate change impacts transport are mainly produced by emissions of the greenhouse gases, including carbon dioxide (CO2), nitrogen oxides (NO+NO2), and methane (CH4). Moreover, tier 2 methodology (EMEP/EEA, 2010) is used for categorizing vehicle fuel combustion and fuel policy legislation to control environmental emissions.

3.3 Mathematical Modeling

According to the Vehicle Routing Problem (VRP), the following parameters are defined:

$$G(V,A):\begin{cases} V=(v_0,v_1,\dots,v_n),\ v_0: depot,\ V'=V\backslash\{v_0\}: Stations \\ A=\{(v_i,v_j)|v_i,v_j\in V, i\neq j\}\end{cases},$$

$K=(k_1,k_2,\dots,k_m)$: Vehicles which are assigned individually to each route,
d_{ij}: Distance between station i and$j$,
t_{ij}: Travel time between different stations,
T^k: Maximum allowing travel time for vehicle k,
S_i^k: Service time at station i.
Decision Variables:

$$x_{ijt}^k:\begin{cases}1,\ If\ vehicle\ k\ travel\ from\ station\ i\ to\ j\ at\ period\ t\\ 0,\ Otherwise\end{cases},$$

y_{jt}^k: Arrival time of vehicle k at station j in period t,
xy_{ijt}^k: Dummy variable for linearization,
By y_{jt}^k definition, the headway at station j could be obtained as

$$h_j=\sum_K y_{jt}^k-\sum_K y_{j(t-1)}^k \tag{2}$$

Constraints:

$$\sum_{j=1}^n x_{0jt}^k=1 \qquad \forall t,k \tag{3}$$

$$\sum_{j=1,j\neq i}^n x_{ijt}^k-\sum_{j=1,j\neq i}^n x_{jit}^k=0 \qquad \forall i,t,k \tag{4}$$

$$\sum_{k=1}^m\sum_{i=1}^n x_{ijt}^k=1 \qquad \forall j,t \tag{5}$$

$$\sum_{i=1,i\neq j}^n\sum_{k=1}^m x_{ijt}^k\left(y_{it}^k-y_{jt}^k\right)=0 \tag{6}$$

$$\begin{cases} y_{jt}^{k} \geq x_{0jt}^{k} . t_{0j} & \forall k, t \\ y_{jt}^{k} = \sum_{i=1}^{n} xy_{ijt}^{k} + x_{ijt}^{k} * s_{i}^{k} + x_{ijt}^{k} * t_{ij} & \forall j, t, k \\ xy_{ijt}^{k} \leq M . x_{ijt}^{k} & \forall i, j, t, k \\ M\left(1 - x_{ijt}^{k}\right) + xy_{ijt}^{k} \geq y_{it}^{k} & \forall i, j, t, k \\ xy_{ijt}^{k} \leq y_{it}^{k} & \forall i, j, t, k \end{cases} \tag{7}$$

$$\begin{cases} y_{it}^{k} + s_{j}^{k} + t_{ij} \leq y_{jt}^{k} + T^{k}\left(1 - x_{ijt}^{k}\right) \\ t_{0j} \leq y_{jt}^{k} + T^{k}\left(1 - x_{0jt}^{k}\right) \end{cases} \tag{8}$$

$$\sum_{i=1}^{n} \sum_{j=1}^{n} x_{ijt}^{k}(t_{ij} + s_{j}^{k}) \leq T^{k} \quad \forall t, k \tag{9}$$

$$\begin{cases} xy_{ijt}^{k} \geq 0 & \forall i, j, t, k \\ y_{ijt}^{k} \geq 0 & \forall i, j, t, k \\ x_{ijt}^{k} = (0,1) & \forall i, j, t, k \end{cases} \tag{10}$$

Buses aim to serve passengers throughout routes in an optimal manner. Hence, constrain (3) means for constructing a tour in each period; one bus type k should exit the depot. For creating continuity of each route, constrain (4) is employed, and with constrain (5), each station in each period belongs precisely to one route. Constrain (6) is expressed for sub-tour elimination. Constrain (7) calculate the bus arrival time and since it is not linear, the dummy variable, xy_{ijt}^{k}, is defined. Besides, constrain (8), determined the starting service times. Constrain (9) specifies the maximum allowable time for transportation for each vehicle. Finally, constrain (10) shows non-negativity constrain for assumed values.

Thus, according to equations (1) and (2), the objective function for the minimizing waiting time based on all stations is as follows:

$$\min(\overline{W_j}) = \min \sum_{j=1}^{n} (h_j - \frac{\lambda_j(\lambda_j - 1)}{2.h_j}) = \min \sum_{j=1}^{n} (\sum_K y_{jt}^k - \sum_K y_{j(t-1)}^k - \frac{\lambda_j(\lambda_j - 1)}{2(\sum_K y_{jt}^k - \sum_K y_{j(t-1)}^k)}) \qquad (11)$$

The objective function of fuel consumption of buses is obtained based on three factors: the vehicle type, the distance traveled, and the load carrier (Carlos Molina, 2014). The main gas produced by buses is CO2, so the objective function considers the amount of CO2 released in air based on the mentioned factors.

$$\min(F) = min \sum_i \sum_j \sum_k \sum_t ef^{CO_2 r}. d_{ij}. x_{ijt}^K (fe^K + feu^K. L_{ij}^K) \qquad (12)$$

The parameters used in equation (12) for objective function are as following:

$ef^{CO_2 r}$: The amount of CO_2 emitted per unit of fuel consumed as an emission factor

fe^K: The amount of fuel consumed while the vehicle is empty

feu^K: The amount of fuel consumed based on the additional load in the vehicle

L_{ij}^K: The load carried by the vehicle between the considered stations

4 Case Study

Hamburg public transportation is structured into five rings centered on the Alster Lakes named from ring A to ring E. Most of the city is covered with rings A and B (called Großbereich). By using rings, C, D and E, passengers can travel up to 60 km far from the city. Moreover, some regional trains are also included in the fare (Gesamtbereich). An extensive range of bus services complements the rail network with metro buses that called frequent services, express buses, sprinter buses, and regional buses. These are connecting to stations and surrounding towns. (For more information see, Hamburg.com website). The paper considers the city center of Hamburg for model evaluation. The graphical view of studied zone is presented in figure 1.

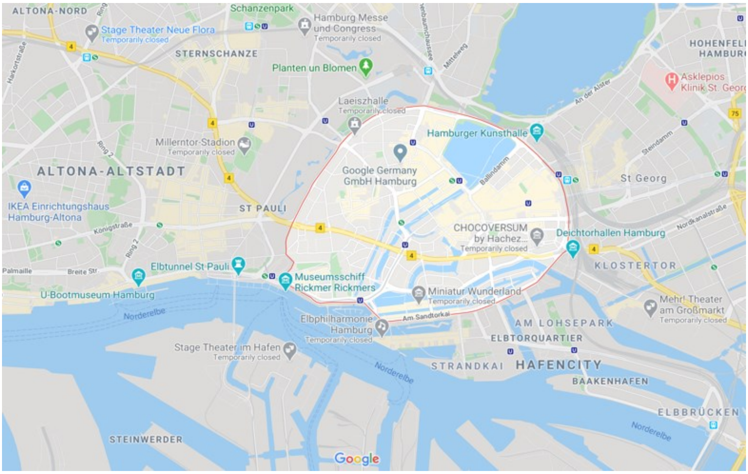

Figure 1: Hamburg city center map obtained from Google© (Date 03/2020)

All bus stations for the city center of Hamburg (Ring A) are illustrated in table 1. These bus stations are crowded with high demand since a large number of people use them every day. Due to the location of the central railway station, called Hamburg Hauptbahnhof, a large number of people commute to the city center, and they need to access to the reliable and efficient public transportation. It is assumed that all stations are fixed as nodes and the model should find the optimum routes which incorporate all stations effectively for minimizing the waiting time of the passengers at stations and also simultaneously yielding the minimum environmental emissions such as CO2. figure 2 shows the Hamburg city center stations and the graph which demonstrates the nodes as stations and acres as the possible route between each two nodes.

Table 1: Bus stations in the Hamburg city center

1	HBF/ Spitalerstraße	9	Handwerkskammer	17	U Rödingsmarkt 2	25	Michaeliskirche
2	Hauptbhf./ Steintorwall	10	Johannes-Brahms-Platz 1	18	Axel Springer Square 1	26	Bei St Annen
3	U Steinstraße (Deichtorplatz)	11	U Stephansplatz	19	Axel Springer Square 2	27	Auf dem Sande (Speicherstadt)
4	Singapurstraße	12	Kunsthalle	20	Johannes-Brahms-Platz 2	28	Meßberg
5	Am Sandtorkai	13	HBF/Mönckebergstraße	21	U Steinstraße	29	US Jungfernstieg
6	Am Kaiserkai	14	Gerhard Hauptmann Square	22	Jakobikirchof	30	U Gänsemarkt
7	Baumwall	15	Rathausemarkt	23	Rathausemarkt (Petrikirche)	31	Valentinskamp
8	Museum für Hamburgische	16	U Rödingsmarkt 1	24	Brandstwiete	32	Dragonerstall

Figure 2: Bus stations in Hamburg city center and related connecting graph

According to figure 2, the time and distance of transportation between two direct stations can be determined based on the available real data obtained from google© map. This problem also considers a depot similar to the Vehicle Routing Problem master model, where buses start and finish their travel routs. It is assumed that the depot location is located near to the Hamburg central train station (Hamburg Hbf).

4.1 Numerical Results

In this subsection, the GAMS© optimization software is used according to the information of table1, table 2, and figure 1. As mentioned earlier, the paper has considered 32 stations in the Hamburg city center and also one central depot for launching buses from near Hamburg Hbf. Three buses are assumed to be active in the problem area. The rate of passengers' arrival is Poisson process in each station, where obviously in high demand stations, this rate considered rationally higher than others. In addition, the mean time of service in each station is assumed in according to the density of passengers in that station. Table 2 shows the values of these parameters for Poisson processes is expressed by the mean number of persons arriving to stations and mean time of providing services in minutes for each station, respectively.

Table 2: The passengers arrival rate and service time mean of buses in each station

1	30, 6	9	10, 4	17	10, 2	25	15, 3
2	25, 5	10	15, 4	18	8, 2	26	15, 3
3	20, 5	11	15, 4	19	10, 3	27	15, 3
4	15, 4	12	30, 5	20	15, 3	28	10, 3
5	15, 4	13	25, 4	21	15, 3	29	10, 3
6	15, 3	14	25, 3	22	15, 3	30	10, 3
7	15, 3	15	30, 6	23	20, 4	31	5, 2
8	15, 4	16	15, 3	24	20, 5	32	3, 1

Each bus can drive in a limited time frame which is defined as the maximum allowed time about 960 minutes.

For calculating the environmental emissions, the amount of CO2 emitted per unit of fuel consumed is considered 2.7 liters. About the amount of fuel consumed while the vehicle is empty per 1 kilometer is 0.3 liters, and based on each additional load in the bus per 1 kilometer is 0.05. The average load carried between two stations is assumed 600 kilograms.

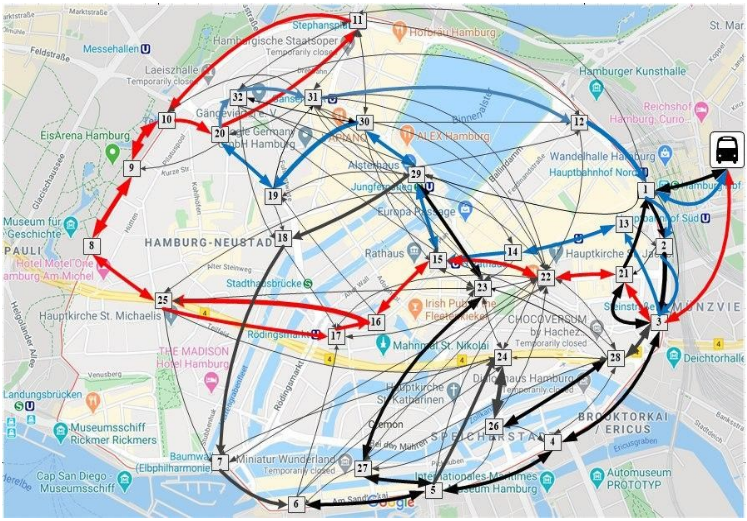

Figure 3: Graph of optimum assigned routes for three buses

The developed model is solved in GAMS© software package, and the optimum routing of buses is obtained and illustrated in figure 3. The waiting time objective function is calculated by considering the Poisson processes for the arrival rate of passengers, which is described in table 2. The comprehensive calculations of waiting times in each station are shown in table 3 based on the resulted routings. In table 3, $\bar{W}_j$ represents the optimum average waiting times (min) in each station that is calculated according to Formula (11). C_j stands for the total cost of waiting times in each station, and it is calculated based on the minimum wage rate for each hour. By assuming the minimum wage as 10 Euro per hour, the value of waiting times can be obtained by $\frac{\bar{W}_j \times 10}{60}$.

Moreover, dividing the total waiting time by λ gives the average waiting time per person in each station that is expressed with W_{pp} in table 3. Similarly, the value of waiting time for each person can be calculated by $\frac{W_{pp} \times 10}{60}$.

Based on calculations of table 3, the total cost of waiting times will be $\frac{2105.75 \times 10}{60} \approx 351$ Euro.

Table 3: Detailed calculation for waiting times

j	1	2	3	4	5	6	7	8
λ_j	30	25	20	25	15	15	15	15
$\overline{W}_j$	146	75.2	213.4	41.75	91.6	45.8	45.8	85.4
C_j	24.3	12.5	35.5	6.9	15.2	7.6	7.6	14.2
W_{pp}	4.8	3	10.6	1.6	6.1	3	3	5.6
C_{pp}	0.8	0.5	1.8	0.3	1	0.5	0.5	0.9

Cont.

j	9	10	11	12	13	14	15	16
λ_j	10	15	15	30	25	25	30	15
$\overline{W}_j$	88	85.4	78	17	21.3	21.3	70.3	85.4
C_j	14.6	14.2	13	2.8	3.5	3.5	11.7	14.2
W_{pp}	8.8	5.6	5.2	0.6	0.8	0.8	2.3	5.7
C_{pp}	1.5	0.9	0.9	0.1	0.1	0.1	0.4	0.9

j	17	18	19	20	21	22	23	24
λ_j	10	8	10	15	15	15	20	20
$\overline{W}_j$	44	46.8	29.5	70.3	136.6	85.4	44	44
C_j	7.3	7.8	4.9	11.7	22.8	14.2	7.3	7.3
W_{pp}	4.4	5.8	2.9	4.7	9.1	5.7	2.2	2.2
C_{pp}	0.7	0.9	0.5	0.8	1.5	0.9	0.4	0.4

Cont.

j	25	26	27	28	29	30	31	32
λ_j	15	15	15	10	10	10	5	3
$\overline{W}_j$	85.4	45.8	45.8	47	78.4	29.5	30.7	30.9
C_j	14.2	7.6	7.6	7.8	13	4.9	5.1	5.1
W_{pp}	5.7	3	3	4.7	7.8	2.9	6.1	10.3
C_{pp}	0.9	0.5	0.5	0.8	1.3	0.5	1	1.7

The second objective function aims to minimize the environmental emissions. For this purpose, the total amount of CO2 (kg) produced in the transportation system is calculated by Formula (12). The parameters are determined in table 4. By considering the total distances for three tours of buses, 2360 kg CO2 is approximately produced that is obtained with multiplying the travel distance by CO2 emissions factor as $10.553 \times [2.7 \times (0.3 + 0.05 \times 600)] + 6.620 \times [2.7 \times (0.3 + 0.05 \times 600)] + 11.670 \times [2.7 \times (0.3 + 0.05 \times 600)]$. Each one-kilogram CO2 emission creates cost of 0.06 Euro according to Duong (2009). Therefore, the total emission cost equals to 141.5 Euro.

Table 4: Detailed calculations for CO2 emissions

K	Total Distance (km)	$ef^{CO_2r}\left(\frac{kg}{lit}\right)$	fe^K(lit/km)	$feu^K\left(\frac{lit}{kg.km}\right)$	$L_{ij}^K(kg)$
1	10.553	2.7	0.3	0.05	600
2	6.620	2.7	0.3	0.05	600
3	11.670	2.7	0.3	0.05	600

These results obtained for the three available buses in service with cost of 141.5 Euro for the amount of CO2 emissions and waiting time of passengers with 351 Euro. One of the crucial factors that have a significant impact on CO2 emission is the weight of the vehicle. This weight includes the weight of the vehicle plus the weight of passengers, so the fluctuation in the number of passengers as a load of the vehicle could affect the emission cost.

Vehicle load reduction will decrease the CO2 emission cost; however, it increases the passenger's waiting time since load reduction means the decrease in the number of passengers.

From the other point of view, by the increase in the arrival rate of passengers at stations, the load for vehicles will be increased and this will affect both waiting time cost of passengers and CO2 emission costs. For example, if the rate of passenger arrival becomes twice, then average waiting time's cost for the current routings will decrease to 280 Euro, which means a 20% cost reduction for passengers waiting times due to more boarding of passengers. On the other hand, passengers' increasing arrival rate leads to enhancing the load of vehicles twice. Calculation of the CO2 emission cost with the new amount of load determines 282 Euro as a CO2 emission cost, which is a 100% cost increment. Therefore, there is a dilemma for policymakers as two objective functions do not behave in the same direction in different possible scenarios. The main focus for strategy making is recommended to be the control of passengers' arrival rate to avoid the crowded buses.

5 Acknowledgment

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6 Conclusions

Public transportation in large cities has significant impacts on the environment, society, and economy perspectives. The proper management of public transportation creates paradoxical challenges for fulfilling the mutual service level for the passengers and the environmental considerations. This paper has studied the related literature and discussed the considerable gap for the fulfillment of mutual service level satisfaction and considerations for environmental emissions. By investigating the literature for assignment problem technique and multi-objective planning, the paper has proposed a model to enable the public transportation resource assignment with the considerations of tradeoffs for increasing public service satisfactions and meanwhile controlling the environmental emissions. The real data of Hamburg public transportation has been used to verify the capabilities of the platform. The designed case study supported the model validity and by the analysis of results, the main factor in the model is recognized to be the weight of buses. So, the model encourages the strategy makers for setting strategies for passengers' arrival rate to avoid the crowded buses.

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Appendix

Please find the GAMS codes as follows:

```
Set
i 'start nodes' /0*32/
k 'vehicles'   /1*3/
t 'period time' /1*2/ ;
alias (i,j); alias (k,m);
scalar
Tmax 'maximum allowable time (16hour=960 min) for driving'   /20/
Q /1000/;
$call gdxxrw.exe time.xls par=tt rng=sheet1!A1:AH34
parameter tt(i,j) distance of time data set;
$gdxin time.gdx
$load tt
$gdxin$call gdxxrw.exe distanceKm.xls par=d rng=sheet1!A1:AH34
Parameter d(i,j);
$gdxin distance.gdx
$load d
$gdxin
parameters
efCo2   'the amount of Co2 (kg) emitted per unit of oil consumed'   /2.7/
feK     'the amount (Liters) of fuel consumed while vehicle k is empty per 1 km'  /0.3/
feuK    'the amount (Liters) of fuel consumed based on additional load in the vehicle per 1 km'   /0.05/
Lij     'the average load carried between station i and j based on kg'     /600/
l(j)    'the rate of arrival of passengers at stations based on Poisson processes' /0 0,1 30,2 25,3 20,……14 25,15 30,16 15,17 10,18 8,1910,20 15,21 15,22 15,23 20,24 20,25 15,26 15,27 15,28 10,29 10,30 10,31 5,32 3/
```

```
s(j)    'service time (min) at stations'  /0 0,1 6,2 5,3 5,4 4,5 4,6 3,7 3,8 4,9 4,10 4,11
      4,12 5,13 4,….. 3,22 3,23 4,24 5,25 3,26 3,27 3,28 3,29 3,30 3,31 2,32 1/
Variables
        x(i,j,t,k) "vehicle k travells from station i to j in period t"
        y(j,t,k) "arrival time of vehicle k at station j at period t"
        xy(i,j,t,k) "dummy variable for linearization"
Binary Variable x;
free variables
z1,z2,z;
Equation
objwait  'objective for minimizing waiting time'
objco2   'objective for minimizing co2 emitted in Kt'
Total    'Combination of two Objectives'
cons1    'constrain for constructing a tour in each period'
cons2    'constrain for creating continuity in aech period'
cons3    'constrain for relate each station to exactly one route in each period'
cons4    'constrain for eliminating sub-tour'
cons5    'constrain for expressing equality between time of arrival at station i and
      time of departure from station j'
cons6    'arrival time 1'
cons7    'arrival time 2'
cons8    'arrival time 3'
cons20
cons21
cons9    ' arrival time 4'
cons9    'constrain for determining the service times'
cons10   'constrain for determination of service times'
cons11
cons12   'y limit interval'
```

```
cons13   'y limit from lower bound';
*objective functions
objwait .. z1 =e= SUM ((j,t)$(ord(t)>1),abs( sum(k,y(j,t,k)) - sum(m,y(j,t-1,m)) - l(j)*(l(j)
    - 1)/2*(sum(k,y(j,t,k)) - sum(m,y(j,t-1,m)))));
objco2 .. z2 =e= SUM((i, j, t, k),efCo2*d(i, j)*(feK + feuK*Lij)*x(i, j, t, k));
Total..z =e= 0.06*z2 + 10*10*(1/60)*z1 ;
cons1(i,t,k) .. SUM(j,x(i, j, t, k)$(ORD(i)=0)) =l=1;
cons2(i,t,k) .. SUM(j,x(i, j, t, k)$(not sameas(i,j))) - SUM(j,x(j, i, t, k)$(not sameas(i,j)))
    =e=0;
cons3(j,t) .. SUM((i, k),x(i, j, t, k)) =e=1;
cons4(j,t)..sum((i,k)$(ord(i)<>ord(j)),x(i,j,t,k)*(y(i,t,k)-y(j,t,k))) =e=0;
cons5(i,j,t,k)..y(j,t,k)- x(i,j,t,k)$(ord(i)=0)*tt(i,j)$(ord(i)=0) =g=0 ;
cons6(j,t,k)..y(j,t,k)- sum(i,xy(i,j,t,k) + s(i)*x(i,j,t,k) + tt(i,j)*x(i,j,t,k)) =e=0;
cons7(i,j,t,k)..xy(i,j,t,k) - Q*x(i,j,t,k) =l= 0;
cons8(i,j,t,k)..Q*(1-x(i,j,t,k))+ xy(i,j,t,k) - y(i,t,k) =g= 0;
cons20(i,j,t,k).. xy(i,j,t,k) - y(i,t,k) =l=0;
cons21(i,j,t,k) .. xy(i,j,t,k) =g=0;
cons9(i,j,t,k) .. y(i,t,k) + s(j) + tt(i,j) =l= y(j,t,k) + Tmax*(1 - x(i,j,t,k));
cons10(i,j,t,k) .. tt(i,j)$(ORD(i)=0) =l= y(j,t,k) + Tmax*(1 - x(i,j,t,k)$(ORD(i)=0));
cons11(t,k) .. SUM((i,j),x(i,j,t,k)*(tt(i,j) + s(j))) =e= Tmax;
cons12(j,t,k) .. y(j,t,k) =l= 10;
cons13(j,t,k) .. y(j,t,k) =g= 0;
Option minlp = dicopt;
Option domlim = 10;
xy.L(i,j,t,k)=1;
y.L(j,t,k)=1;
Model transport /all/;
solve transport USING MINLP minimizing z;
display x.l, y.l, z1.l, z2.l,z.l;
```