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Analysis of the Station Passenger Capacity: The Case Study of Kocaeli Tram Line

Şevval ÖZER [1], Sinem BOZATLI KARTAL [2,*], Yavuz ABUT [3]

[1] *Transportation Planning Branch Directorate, Kocaeli Metropolitan Municipality, Kocaeli, 41040, Türkiye,* ***ORCID:*** *0009-0007-8326-7286*
[2] *Department of Transportation Engineering, Yalova University, Yalova, 77200, Türkiye,* ***ORCID:*** *0000-0002-8285-6050*
[3] *Department of Transportation Engineering, Yalova University, Yalova, 77200, Türkiye,* ***ORCID:*** *0000-0003-4249-7791*

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Abstract

Public transportation systems play a crucial role in facilitating mobility in bustling urban areas and alleviating traffic congestion. Among various urban rail system types, trams have emerged as environmentally friendly, low carbon emission, and high-capacity transportation vehicles. Effective use of tram lines necessitates accurate capacity planning. This study aimed to assess whether the station passenger capacity of the tram serving Kocaeli is adequate for peak hour travel demands. This study initially provides information on tram system criteria, capacity types, and components. Subsequently, details about the line, vehicle specifications, dwell times, peak hours, train and passenger numbers, and their correlation with stations are discussed. Various calculation techniques are explored to estimate station passenger capacity, with analytical methods based on 2022 data employed in this study. The analysis reveals that the tram line operates close to its station passenger capacity, particularly during peak hours, and may exceed capacity on special occasions. It is anticipated that the station capacity of this line, which serves the city center route, may struggle to accommodate passenger demand soon. Consequently, suggestions for enhancing line and station capacity are proposed to ensure that passengers have a comfortable waiting experience.

1. Introduction

In today's urban infrastructure, selecting public transportation systems that meet people's demands for more comfortable and faster travel is crucial. The demand for rail systems in urban public transportation is steadily increasing, driven by considerations of comfort and speed. Rail systems play a vital role in addressing the transportation needs of large cities because of their high capacity, speed, safety, and comfort features [1]. However, the rise in population density in cities brings forth a host of challenges, including environmental pollution, uneven development, demographic shifts due to migration, and inadequate municipal services. Moreover, the surge in population density and private vehicle numbers intensifies issues such as traffic congestion, air pollution, noise pollution, and excessive energy consumption. Therefore, the development of public transportation systems is paramount as a solution to mitigate traffic congestion in large cities. Rail systems offer significant benefits in addressing various urban transportation challenges.

Urban rail system vehicles are categorized based on various criteria tailored to their intended use. These criteria encompass passenger capacity, operating speed, the number of wagons linked to the locomotive, rail specifications, signal control systems, intersections with roadways, station lengths, and distances between stations. These factors play pivotal roles in the classification of urban rail systems and guide decisions regarding their deployment and operation. The preferred rail system vehicles in urban transportation include trams, light rail systems, metros, suburban passenger trains, funicular systems, and monorails [2]. Among these, the tram stands out as a distinctive mode of transportation, combining features from both road and rail transportation [3]. Trams, as electric rail transportation systems, typically accommodate 80-300 passengers across one or multiple vehicles. They operate on partially separated roads or mixed traffic with roadways, controlled by a driver who adjusts according to road and traffic conditions. Trams derive electrical energy from overhead wires [4]. With an average speed ranging from 20 to 30 km per hour, tram

* Corresponding Author: sibel.bozatli@yalova.edu.tr

stations are typically spaced approximately 300–500 m apart [5]. Such public transportation systems do not require traditional air supply systems (+ 750 V) and are therefore referred to as ‘‘catenary-free systems’’ (i.e., APS system, tramwave system, Primove system) [6]. In the literature, various types of studies have been conducted regarding tramway lines [6], [7], [8], [9] [10], [11], [12]. Pyrgidis and Chatziparaskeva (2012) examined the signal priority of the tram network in Athens [11].

The tramway transportation system is a highly specialized mode of transportation in terms of mobility, combining various features of both road and rail transport. [13], [14] [15], [16]. Therefore, calculating the capacity of tram line systems is a very complex problem [17].

Studies by Parkinson & Fisher (1996), Vuchic (2007), Abril (2008), Landex (2009) and Kittelson & Associates et al. (2013) serve as good sources for public transportation systems and capacities [13], [15], [18], [19], [20]. Vuchic, in his book Urban Transit Systems and Technology, published in 2007, provides a basic classification of transportation modes and their physical components, as well as definitions of the latest public transportation technologies. It covers complementary topics such as travel time, vehicle propulsion, and system integration. In the study by Leurent (2011), a framework is presented for analyzing a public transportation system divided into four subsystems; passenger, vehicle, station, and route. In this framework, the concept of capacity is determined and qualitatively described [21]. Vitosoglu et al. (2014) focused on five major cities in Türkiye (Ankara, Bursa, Adana, Kayseri, and Samsun) and used the Method of Comparative Benchmarking to determine how efficiently light rail public transportation systems operate in these cities. They also discussed how the performance of systems that fall below the average can be improved by following the working policies of efficient systems. Zhang (2022) analyzed the characteristics of urban railway public transportation passenger flow based on spatial data in dynamic analysis. This study uses spatial data along with social and economic development data to analyze the passenger flow characteristics of urban rail transportation from an operational and planning perspective. Research data obtained from passenger data measurement studies are used to obtain the characteristics of passenger traffic from urban railways, including time and spatial distribution, and passengers waiting on the platform. There are different analytical and graphical methods and equations for analyzing the capacity of public transportation systems. Toprakal (2009) described the capacity analysis of rail systems and applied it to the Istanbul– Aksaray Airport line [22]. Bozatlı (2022) focused on the capacity of railway lines and analyzed the capacity of the Malatya-Narlı line using the UIC Code 406 (UIC, 2013) compression method [23]. Öztürk (2011) addressed the capacity of high-speed railways. He focused on the effects of operational quality, train tracking method, freight train ratio, and train speed on daily line capacity [24].

The research on station passenger capacity largely focuses on integrated approaches combining analytical and simulation methods to optimize capacity usage and analyze complex interactions within railway nodes. For example, the study by Kianinejadoshah and Ricci (2022) compares various methods to assess railway capacity, highlighting their suitability for different tasks and the stability of their results in a mixed-traffic network in Trieste, Italy [25]. On the other hand, Pu et al. (2022) utilize an integrated simulation platform, Nexus, to study the interactive effects of pedestrian and train movements at Toronto’s Union Station, demonstrating a 9% drop in train performance due to increased pedestrian dwell times [26]. Similarly, Gao et al. (2022) developed a simulation-based method to evaluate the passenger-carrying capacity of urban rail transit transfer stations. This study analyzed bottleneck areas and overall transfer efficiency to assess fluctuations in passenger flow. Using simulation software, indicators such as platform capacity, building escalator passing capacity, and station transfer efficiency were calculated [27].

The calculation of tram line capacity uses a method similar to that used for bus lines. These methods take into account factors such as dwell time, station efficiency, and the time buses spend at stops. For example, the Transit Capacity and Quality of Service Manual provides comprehensive information on this topic and states that similar parameters are used in capacity calculations for both bus and tram lines [20].

Kocaeli is a regional center where important industrial establishments are concentrated, leading to rapid urban growth. This growth increases mobility rates in the city, and with the development of industry and services, it drives up travel demand and vehicle ownership. İzmit, one of the most populous districts of Kocaeli, experiences significant traffic congestion on main corridors due to its structure, which forms the entire urban center of the province. To alleviate this congestion, the addition of a rail system as a new alternative for public transportation to the city center has been considered. The following planning and construction, with the commissioning of the Akçaray tram line in 2017, preferences for public transportation began to shift. As a result of the increase in passenger numbers from the first day of operation of the rail system line, UlaşımPark Inc. has conducted many studies to increase the capacity of the line.

In this study, current information related to the line was collected, and an attempt was made to estimate the station's passenger capacity using an analytical solution method. For this purpose, the maximum boarding-alighting counts from 15-minute peak volumes were determined based on the count conducted at the Yenicuma station, identified as a bottleneck for the line, for travels heading toward Plajyolu. The aim was to determine whether the station capacity was sufficient.

In the study, there is an explanation of the calculation of station capacity for public transportation lines and the parameters affecting it. It also discusses the Akçaray tram line where the application was conducted, presents the collected data and its analysis, and provides the overall conclusions and recommendations of the study.

2. Analysis of the Capacity of Public Transportation Lines

The capacity of a system refers to the maximum operating capacity under the current conditions. For public transportation systems, two different capacities are important. These are the vehicle capacity, expressed as the number of seats per vehicle, and the public transportation line capacity, expressed as the number of spaces per hour [1]. While analytical and optimization methods can be used to estimate theoretical capacity, simulation can also be used to determine practical capacity, which includes delays, capacity balancing, and reliability. Different methods can be used for capacity analysis. For complex networks and operating plans, capacity analyses requiring a high level of accuracy can utilize detailed simulation models and methods [20].

Line capacity is the maximum number of seats or passengers that public transportation vehicles passing through a point on the line can carry in one hour [19]. Ensuring ideal control of line capacity is possible by combining dwell times at stations with the train sets and signaling systems used. However, this method provides calculation results that are closer to reality but are both more complex and time-consuming. Depending on the units and operating factors used, several different public transportation capacities can be defined. In classic mixed traffic operations, single trams can be treated similarly to busses and capacity is determined by vehicle lengths and waiting time variability. This is similar to the capacity determined from the procedures for bus transit capacity [20].

A set of n vehicles (where n>1) moving in coordination forms a public transportation series. Public transportation service can also be provided with individual vehicles (where n=1). Examples of a one-vehicle series are bus and tram systems. The number of trains passing a given point on the line during an hour is called the *service frequency (f)* or frequency, which is also the inverse of the *headway (h)*, the time interval between two consecutive trains [19]:

$$f = \frac{3600}{h} (train/hour) \quad (1)$$

According to this definition, the line capacity is represented at the maximum frequency *Max (f)*. This frequency is obtained by the shortest headway that can be provided at all points and stations along the public transport line. Generally, two different headways can be defined on lines: way headway *(h_w)*, which applies to sections of the line without stations, and station headway *(h_s)*, which represents the time interval between consecutive sequences at stations. The maximum frequency on the line can be determined by selecting the longest minimum headway [19]:

$$Maks\ (f) = \frac{3600}{Min\ (h)} = \frac{3600}{Maks\ (Min\ hw, Min\ hs)} (train/hour) \quad (2)$$

Since *Min h_s > Min h_w* for most public transport lines, the station headway determines the line capacity. However, in some special cases, e.g., in the case of multi-track or sidetracked stations, the way headway can be decisive. Therefore, both way headway and station headway and, capacities should be analyzed [19].

The vehicle capacity of the line is the maximum number of vehicles that can pass through a given point:

$$c = Maks(f) \times n\ (vehicle/hour) \quad (3)$$

When transportation is by a single vehicle, *c = Max(f)*. The maximum line capacity offered represents the maximum number of passengers that the line can carry and is expressed as the number of passenger places per hour. Therefore, it is often referred to as "line capacity". Line capacity is determined by multiplying the vehicle capacity of line *(c)* by the passenger capacity of the vehicle *(Cv)* [19].

$$C = c \times C_v = Maks(f) \times n \times C_v \left(\frac{spaces}{hour}\right) \quad (4)$$

The line capacity can also be considered as a function of the minimum headway:

$$C = \frac{3600n\ Cv}{Min(h)} (space/hour) \quad (5)$$

As a result, two different definitions of capacity can be made for public transport lines; the way capacity *(Cw)*, which is a function of the headway *(Min h)*, and the station capacity *(Cs)*, which is a function of the station headway *(Min hs)*. The smaller of the two represents the line capacity [19]:

$$C = Min\ (C_w, C_s)(space/hour) \quad (6)$$

Both minimum headways depend on various factors and are often not constant. The minimum headway time is influenced by the performance of the vehicle and the mode of travel; however, the degree of control of the route often has a greater effect. Minimum station headway depends on passenger boarding-alighting processes and control measures. In public transportation systems, station capacity often determines the capacity of the line. Through station capacity analyses, the space requirements on platforms are determined and stations are arranged accordingly. Design considerations should include capacity analyses, vehicle time intervals for passenger loading, and safety requirements in emergencies [28]. The critical steps in determining the relationship between the required capacity on a line and the capacity provided are as follows [19]:

- Identifying the highest passenger demand occurring in any interstation interval, known as the maximum load section, which represents the critical volume that the line must carry.
- Determining the maximum capacity that a line can physically deliver, both in vehicles per hour and spaces per hour, which is influenced by the station on the line that requires the longest dwell time.
- Understanding that station progression is primarily a function of dwell time, which in turn depends on passenger volume (number of passengers boarding-alighting) and station operations.
- Acknowledging that the two critical elements for the capacity supply and demand of a line, the load section and the critical station, are independent; thus, the critical station can be located far away from the load section.

In the scope of this study, the station capacity of the tram line was assessed. To measure the station capacity, a passenger boarding and alighting count was conducted at the station, which is one of the methods for determining public transportation line capacity. Based on this count and the information obtained from the relevant institution regarding the tram line, the station capacity was evaluated. The capacity of tram systems is determined similarly to bus systems because both consist of a single vehicle.

2.1. The station capacity

In a specific safety regime, the minimum headway between consecutive series increases when the series stops at a fixed location. Therefore, the station capacity is generally considered to be smaller than the line capacity. The exception to this situation is when stations can accept multiple series simultaneously (i.e., the station accommodating several stopping places operated simultaneously). As a result, station capacity often determines the capacity of the public transportation line in most cases. In other words, the station with the longest minimum headway along the line determines the line's capacity (for both vehicle/hour and space/hour capacities). The minimum headway at a station usually is a function of the dwell time, which depends on the volume of boarding-alighting passengers and the station's operational practices. The minimum headway between consecutive series at a station consists of two groups of components: a) the time interval in series movements (i.e., acceleration of the leading series and deceleration of the following series). These intervals depend on the dynamic characteristics of the series, operating regime, and safety conditions, and b) dwell time; this time consists of the opening of doors, boarding-alighting, and preparation time for departure (warning, door closing, and signaling the driver to depart).

Figure 1 illustrates the minimum headway between the arrival and departure of consecutive series at a station. The shaded area in the figure related to the series trajectories is termed the "dwell shadow." The dwell shadow of a series is the length equal to the stopping distance ahead of the series for a specific braking acceleration. This length, traveling with the series, forms a kind of "shadow area." Other factors remaining constant, the shadow area increases rapidly. Typically, the distance between the front end of the decelerating series and the rear end of the following series is examined. However, in some cases, the distance between the shadow line of the leading series' rear end and the shadow line of the following series' front end is used to determine the level of operational safety [19].

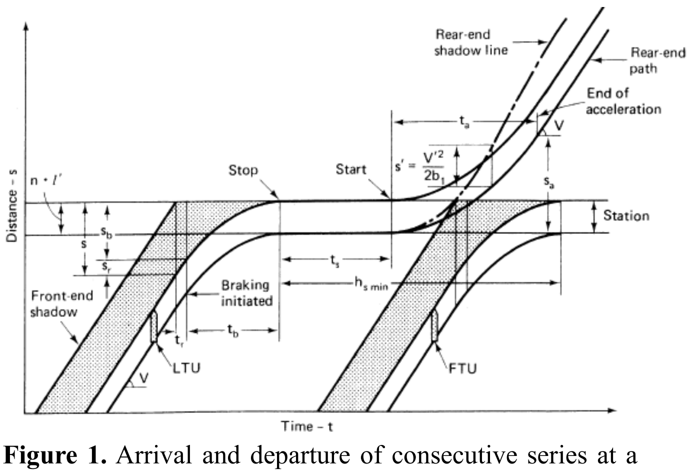

Figure 1. Arrival and departure of consecutive series at a station and the minimum headway between them [19]

The time interval between the start of the leading series' movement and the stopping of the following series at the station consists of several components, as depicted in Figure 1. The accepted lengths for these components depend on the critical conditions for which the control system is designed. The critical event occurs when the acceleration of the leading series is unexpectedly interrupted for an unknown reason, and the series stops during its departure from the station. When the leading series suddenly stops *(b1 = ∞),* the critical curve in the diagram represents the trajectory of the rear end of this series. If the series decelerates with a finite acceleration (for example, b_e or b_n), the critical curve becomes the shadow line of the rear end determined by the relevant acceleration value. Station capacities for the five regimes are plotted in Figure 2. Here, the same vehicle and operating characteristics are used when drawing the station capacity curves.

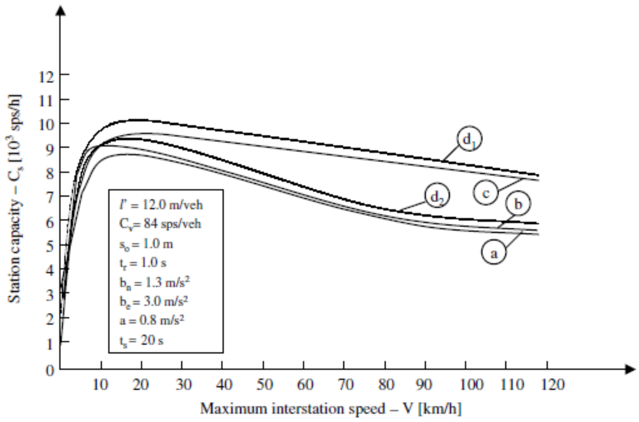

Figure 2. Station capacity curves; different safety regimes for the same vehicle [19]

The diagram illustrates that the effect of b_2 on capacity is significant at high speeds; the two regimes with $b_2 = b_e$ exhibit higher capacity than the three regimes with $b_2 = b_n$. Conversely, the effect of b_1 is negligible. Figure 3 displays the station capacities for various types of public transportation in their respective safety regimes.

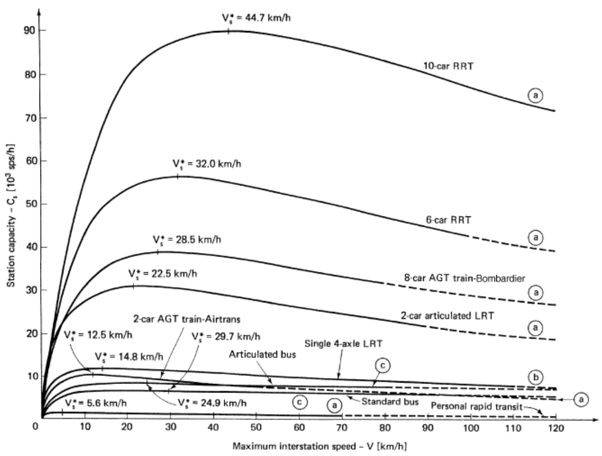

Figure 3. Station capacities of different modes and their typical safety regimes [19]

When examining Figures 2 and 3, several observations can be made regarding station capacities:

- Both way and station capacities are functions of operating speed, but station capacity is slightly less sensitive to speed than way capacity.
- Way capacities are approximately four times larger than station capacities for all speeds and safety regimes.

To accurately calculate station passenger capacity, it is essential to thoroughly examine specific factors and parameters. Station capacity represents the maximum operational capacity of a public transportation system, and various parameters must be considered for precise calculations. Vehicle capacity plays a significant role in determining station capacity. The larger the capacity of the vehicles in a convoy, the higher the passenger handling capacity of the station. Therefore, when high capacity is required, larger convoys should be operated. Station dwell time refers to the duration that vehicles stop at a station, influenced by several factors. Reducing dwell time by even one second can directly decrease headway, thus increasing station capacity. Dwell time depends on boarding and alighting times, the number of doors, door design, and platform height. This section provides a detailed examination of the factors affecting station dwell time and their impact on station capacity.

The purpose of these sections is to comprehensively address all necessary parameters and influencing factors for accurately calculating station passenger capacity. This comprehensive approach ensures that capacity planning for public transportation systems is conducted more reliably and effectively.

2.2. Effect of vehicle capacity

Since the station capacity is a linear function of the public transportation series capacity, the largest-sized series should be operated when high capacity is required. Under certain conditions, an n-vehicle series provides almost n times the capacity of a single vehicle.

2.3. Effect of station dwell time

Reducing the station dwell time by each second directly decreases the headway, thereby increasing the station capacity. In general, shortening the headway by reducing the station dwell time is much easier and cheaper than improving the dynamic performance of vehicles. Numerous factors affect station dwell time, and some of these can be modified to increase capacity.

For vehicles where boarding and alighting are done through different doors (e.g., buses), the station dwell time is expressed as follows:

$$ts = to + max(\lambda.p_b, \mu.p_a)(seconds/train) \quad (7)$$

Here, to is a fixed time lost during the arrival and departure of the vehicle, λ and μ are the time a passenger spends boarding-alighting the vehicle, and p_b and p_a are the numbers of passengers boarding-alighting from the busiest door, respectively.

For vehicles that allow passenger boarding and alighting through the same door (e.g., most rail vehicles), the expression for dwell time is as follows:

$$ts = to + \lambda.p_b + \mu.p_a \ (seconds/train) \quad (8)$$

The interaction between alighting and boarding passengers, known as friction, increases the rates of λ and μ in operations where passengers use the same door for both actions. The dwell time *(t_0)* primarily depends on alighting and boarding operations, such as communication between the conductor and the driver for door operations and passenger movement within the series. Passenger exchange rates (λ and μ) play a significant role in determining the dwell time at crowded stations. These rates are influenced by various factors, including the number of door channels in each series fair collection methods, platform and vehicle floor heights, door design, clearance areas, and passenger flow direction. Rail public transportation systems with 16 to 80 door channels, where platforms and floors are at the same level and fare payment are not made upon boarding, typically exhibit the fastest passenger exchange rates. In such operations, a duration of approximately 1 second per passenger is common. However, because of high passenger volumes at stations, dwell time for series in rail systems generally ranges from 10 to 20 seconds.

3. The Akçaray Tram Line

The Akçaray tram line operates in İzmit, the central district of Kocaeli, and is the first and currently the sole tram line in the region. Managed by UlaşımPark Inc., the line designated as T1 was designed in two stages. The inaugural stage was launched in 2017, encompassing a route of 7.2 km with 11 stations between the Coach Station and Sekapark. With the inclusion of the Kuruçeşme station in May 2023, the length of the Akçaray tram line extended to 10.1 km with 16 stations. (Figure 4) [29]. Table 1 shows the distances between stations. These distances are an important factor affecting travel times and capacity planning.

Table 1. Distances between stations

Stations	Distances between stations (km)
Coach Station - Yahya Kaptan	1.189
Yahya Kaptan - Yenişehir	0.660
Yenişehir - Mehmet Alipaşa	0.836
Mehmet Alipaşa - Doğu Kışla	0.553
Doğu Kışla - Milli İrade	1.142
Milli İrade - Fair	0.651
Fair - Yeni Cuma	0.387
Yeni Cuma - Fevziye	0.553
Fevziye - Train Station	0.619
Train Station - Seka	0.667
Seka - Seka State Hospital	0.754
Seka State Hospital - Congress Center	0.439
Congress Center - Education Campus	0.343
Education Campus - Plajyolu	0.585

Figure 4. The Akçaray tram line (T1) [29]

The technical details of the Akçaray tram system are provided in Figure 5 and Table 2.

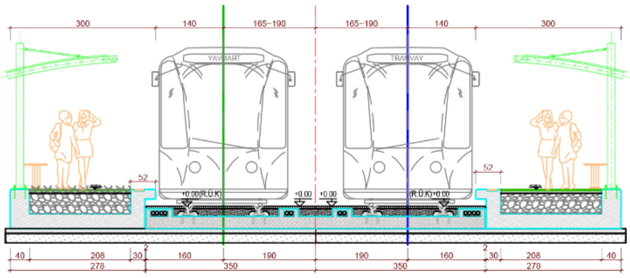

Figure 5. The cross section of Akçaray tram line

Table 2. Technical specifications of the Akçaray tram [29]

Vehicle Length	33 m
Vehicle Width	2,650 m
Vehicle Height	3,300 m
Number of Doors	8 double + 4 singles
Passenger Capacity	290
Average Operating Speed	18 km/h
Maximum Acceleration	1.2 m/s^2
Maximum Brake Deceleration	2.8 m/s^2
Track Gauge	1435 mm
Platform Length	45 m
Energy System	Catenary

The Akçaray tram line was established to cater to the transportation needs of densely populated areas in İzmit, particularly the central district of Kocaeli, providing mass transit for short trips concentrated around the city center. Moreover, it facilitates transportation along the coastline, Yahya Kaptan residential area, and connects the bus station with the city center. Notably, stations at the Education Campus and Seka State Hospital experience heavy passenger traffic on weekdays. Since its inauguration in June 2017, the tram line has consistently exceeded passenger expectations, with an average of 19,050 passengers per day in its inaugural year.

Subsequently, in 2018 and 2019, the annual number of passengers steadily rose to 12,700,198. However, because of the global pandemic, the passenger count for 2020 dropped to 7,427,877. The average for the three years was calculated to be 22,509. As of October 28, 2021, the tram line achieved its highest record of 53,613 passengers (Ulaşım Dairesi Başkanlığı, 2022). The design capacity of the tram line, operating actively for 18 hours a day, is set at 10,000 passengers per hour per direction. Although there are 18 trams on the line, a maximum of 14 trams are used. All station and platform designs are tailored to accommodate vehicle heights.

Presently, tram vehicles operate at 5-min intervals during peak hours to meet high demand. The one-way travel duration is 30 min, with an average commercial speed of 18 km/h. A total of 292 trips are made per day based on the current demand. There are 68 entry– exit turnstiles at the 15 serving stations, with eleven stations featuring independent passenger entry and exit to and from the platforms. In addition, four stations (Coach Station, Yahya Kaptan, Yenişehir, and Fevziye) are designed with central platforms, facilitating joint use for both inbound and outbound travel. The increase in passenger and travel counts per year for the tram line is detailed in Table 3. Upon examining Table 3, it becomes evident that the Akçaray, which started service in 2017 with six trams operating every 10 min, has progressively expanded its capacity by augmenting its fleet and increasing travel frequency in response to escalating travel demand until 2022. By the end of 2022, the line had amplified its passenger count by 3.75 times compared to its inaugural year of operation.

Table 3. Operating and travel counts by years [30]

Year	Tram Number	Operating /Minute	Operating hours/day	Travel /Day
2017	6	10	186	12000
2018	8	7.5	232	20411
2019	10	6	272	27178
2020	14	5	274	41117
2021	14	5	274	36000
2022	14	5	292	45000

4. The Case Study of Kocaeli Tram Line

4.1. The critical station

This section includes specific days from 2022 to analyze station capacity. Based on these data, current counts were thoroughly examined, and the impact of density was evaluated. By scrutinizing the line's hourly average occupancy rate table and boarding-alighting counts at stations, a bottleneck station was identified during the line's peak hours [29].

In the process of determining the critical station (bottleneck station), identifying the station with the highest passenger volume as the bottleneck is a commonly used method in public transportation line capacity calculations. However, this criterion alone is not sufficient. Other important constraints that need to be considered in determining the critical station include the physical capacity of the station, service frequency and train capacity, passenger flow dynamics, connections with other public transportation systems, and infrastructure limitations. Among all the constraints mentioned in this process, passenger flow dynamics, service frequency, and train capacity constraints were also used in the station capacity calculation in the study.

When determining the critical station, passenger counts in both directions of the line and during peak hours are taken into account. The station with the maximum number of passengers is identified as the bottleneck station because the train's waiting time will also be maximum at this station, directly affecting the line's capacity. Other factors affecting the train's waiting time are explained in Section 2. Based on data obtained from the Kocaeli Metropolitan Municipality Department of Transportation, the critical station, initially identified as the bottleneck, was determined. Passenger boarding and alighting counts were conducted at this critical station in the study.

Upon reviewing Tables 4 and 5, it becomes clear that the line operates at high capacity during the morning peak hours from 08:00 to 10:00 and the evening peak hours from 16:00 to 18:00. The morning hours correspond to the rush when individuals commute to school or work, whereas the evening hours reflect the round trip. Consequently, passenger movement is more significant during these morning and evening intervals than in the afternoon. Hence, data within these time intervals were peak hours, with Yenicuma station identified as the busiest (Table 6) [29]. Each line features a bottleneck that constrains capacity, and determining the capacity of this bottleneck dictates the overall line capacity. This insight can aid in accurately planning infrastructure investments.

Table 4. Daily occupancy rate (all directions) [30]

Hours	Occupancy rate (%)	Hours	Occupancy rate (%)
05:00	3	15:00	62
06:00	10	16:00	90
07:00	29	17:00	76
08:00	84	18:00	64
09:00	38	19:00	50
10:00	39	20:00	34
11:00	44	21:00	30
12:00	56	22:00	31
13:00	67	23:00	19
14:00	67	00:00	7

Table 5. Daily boarding counts [29]

Hours	Boarding counts	Hours	Boarding counts
05:00	16	15:00	3635
06:00	229	16:00	5920
07:00	1927	17:00	4577
08:00	4522	18:00	3829
09:00	2072	19:00	2499
10:00	1986	20:00	1453

Table 5. (Cont.) Daily boarding counts [29]

Hours	Boarding counts	Hours	Boarding counts
11:00	2119	21:00	1022
12:00	2767	22:00	741
13:00	3405	23:00	377
14:00	3110	00:00	72

Table 6. Daily passenger count at the station [29]

Station	Daily passenger count at the station
Coach Station	5167
Yahya Kaptan	5166
Yenişehir	4118
Mehmet Ali Paşa	2912
Doğu Kışla	3667
Milli İrade	3781
Fair	2858
Yenicuma	5284
Fevziye	4810
Train Station	1844
Seka	1468
Seka State Hospital	1019
Congress Center	721
Education Campus	1761
Plajyolu	1902

4.2. Passenger mobility

Passenger mobility was assessed in 15-minute increments during the evening peak hours, ranging from 16:00 to 18:00. This assessment was conducted through field counts and evaluation of ticket data obtained on the same day. The rationale for focusing on evening peak hour data lies in Yenicuma station being identified as the busiest interchange during these hours, as evidenced by the two-way hourly passenger demand outlined in the Rail Systems Operational Plan for Kocaeli [31] Yenicuma station, experiencing the highest passenger volume, was identified as the bottleneck for analysis, as per Table 6. Passenger counts during peak hours were conducted in both directions—Coach Station to Plajyolu and Plajyolu to Coach Station—at Yenicuma (refer to Figure 6), with the Coach Station to Plajyolu direction selected due to its higher passenger demand. The peak hour for passenger counts at Yenicuma was determined to be between 17:00 and 18:00, during which passenger counts were conducted.

Figure 6. Passenger counts at the Yenicuma station

As seen in Tables 3 and 4, the number of boarding and disembarkation in fifteen minutes between 17:00 and 18:00, which is determined as the busiest hour, is selected and given in Table 7.

Table 7. Fifteen-minute boarding-alighting counts between 17:00 and18:00

Station	**Direction**	**Hour range**	**Boarding**	**Alighting**	**Fifteen-minute segments**
Yenicuma	Plajyolu	17:00-17:15	71	91	162
Yenicuma	Plajyolu	17:15-17:30	67	97	164
Yenicuma	Plajyolu	17:30-17:45	93	96	**189**
Yenicuma	Plajyolu	17:45-18:00	69	86	155
		Total	627	707	

During the analysis phase, data from the busiest hour interval among the 15-min boarding-alighting counts were used. It was determined that the peak hour interval occurred between 17:30and17:45, during which 189 passengers were recorded. Within this peak hour interval, the service frequency was 5 min between 16:00 and 17:30 and 6 min between 17:30 and 18:00. In this comparison, the highest service frequency employed in the operation of the line has the most significant impact on its capacity. Therefore, the frequency is considered to be 6 min.

4.3. Capacity analysis

Following the counting conducted at Yenicuma, identified as the bottleneck station, the highest boarding-alighting counts from the 15-minute peak were determined. The data to be used in the analysis are provided below.

For boarding $b_{15}=93$, and alighting $a_{15}=96$,

Arrays to serve the line $n=1$ ($n=1$ for single vehicles),

When each vehicle arrives at the station, it opens its doors from one side. It has four double-leaf and two single-leaf doors on one side. Therefore, $m=10$ is considered,

Passenger capacity of a tram vehicle in use $Cv=290$ *space,* alighting (t_a) and boarding (t_b)=1.1 seconds/passenger,

Passenger distribution coefficient=1.3 (coefficient of increase in passenger throughput at the busiest gate). This value is assumed to be 1.3 based on the literature and, $t_0=30$ seconds (vehicle waiting time at the station),

$Minht=360$ seconds (intervals of departure of sequences from the terminal station every 6 minutes),

The shortest interval between the departure of a train from Yenicuma and the stop of the next train is *250 seconds,*

The station passenger capacity is

$$Maksf_t = \frac{3600}{4(Minht)} \quad (9)$$

Since $\tau a=\tau b$, calculations can be made simultaneously for boarding- alighting.

$Maksf_t = 3600/(4\times360) = 2.5$ *train/15 min*

$b_{15}+a_{15}= ((93+96))/2.5=75.6$ *passengers/train/15 min*

Critical passenger volume per gate.

$a'+b'= (b_{15}+a_{15})/(n\times m) \quad \xi=75.6/ \quad (1\times10) \quad \times1.3=$ 9.8289 = 9 passengers

The critical downtime of the series is;

$t_s= t_o+(a'+b') \tau b = 30 + (9 \times 1.1) = 39.9$ *seconds.*

$MinhD = ts +$ *minimum headway* on the station.

$MinhD = 39.9 + 250 = 289.9$ *seconds*

When the two headway periods are compared,

Since $MinD < Minht$, *Minht* determines the capacity, and in this case, *Minht* is the critical time.

The station passenger capacity of the line is determined at the frequency of vehicles leaving the terminal.

$CT=4\times Maxf_t\times n\times Cv$ (1 hour capacity is determined by multiplying by 4);

$CT=4\times2.5\times1\times290= 2,900$ space/hour. This result is valid for one direction.

4.4 Results and Discussion

As a result of the calculation, the peak hour passenger counts show that the line has a passenger demand of 2,900 seats/hour in one direction. In the TCDD Final Report, travel data for the year 2050 was assessed based on aggregated demand, with evaluations conducted at the line and station levels. Upon examining the stations, it was found that in the adequacy assessment for the year 2050, Yenicuma Station is spatially insufficient. However, the station's passenger capacity is 3,350 passengers per hour, and it is expected to be adequate until 2027 under the scenario where all lines are active [31]. From this, it can be inferred that, as of today, Yenicuma Station's passenger capacity is sufficient.

Based on this information, although the station's capacity has not yet reached its full potential under current conditions, it is anticipated that a new optimization model for station passenger capacity will be necessary in the future due to increasing travel demand. The rising demand can lead to delays as passengers board and alight from trams, resulting in increased vehicle waiting times and potential declines in service quality due to these disruptions. Consequently, it is crucial to address these challenges to maintain and enhance the efficiency and reliability of the transportation system.

5. Conclusions

Rubber-wheeled vehicles constitute the primary public transportation system in Kocaeli, offering the highest passenger transportation service. However, considering the vehicle structure and capacity of this mode, it fails to meet modern service quality standards such as comfort, safety, and speed expected by passengers today. Using such transportation modes in cities such as Kocaeli, where population and density are high, poses transportation challenges. Consequently, there has been a transition toward a rail system line in Kocaeli, departing from rubber-wheeled public transportation, which proved insufficient due to traffic congestion [32].

Despite the implementation of the rail system in Kocaeli, statistics show that 92.1% of public transportation travel still relies on rubber tire systems [33].

In this study, the station passenger capacity of the Akçaray tram line serving in Kocaeli province was analyzed. As a result of the calculations, it was determined that the passenger demand at the station is 2,900 passengers/hour in one direction during peak hours on December 29, 2022.

However, although the station passenger capacity has not reached its full capacity at present, improvements in the passenger capacity of the stations will be necessary in the future due to increases in travel demand. As a result of this increase, passengers may experience delays in boarding and alighting, leading to longer waiting times at the station and a decrease in service quality due to congestion. Therefore, various improvement recommendations have been proposed to enhance passenger comfort and reduce congestion:

- To reduce congestion on the line, especially during peak hours, additional services can be scheduled. Increasing the frequency of services will reduce the number of passengers waiting at the stations, thus increasing capacity.
- Currently, 14 vehicles are in service. If there are not enough trams available to run additional services during peak hours, additional vehicles can be acquired.
- While minimizing the headways during peak hours, signalization adjustments should be made at level crossings and road intersections to prevent traffic disruptions and maintain operational speed.
- In cases where the stations are insufficient in terms of space to handle congestion, lateral expansion of the platforms can be undertaken where feasible.
- Reducing the headway to 4 minutes during peak hours can prevent capacity shortages resulting from increased passenger demand. However, continuous capacity increases will only be a short-term solution. Long-term solutions require infrastructural adjustments.
- To distribute the congestion across multiple routes, new lines can be added. Expanding the rail network can reduce the use of rubber-tired transportation modes and increase environmentally friendly rail system usage.
- Considering future population growth and travel demands, transitioning to light rail or metro systems may be necessary. This can prevent the cyclical issues in transportation and provide a sustainable long-term solution.

These recommendations aim to increase the capacity of Kocaeli's public transportation system, providing passengers with a more comfortable and safer travel experience. The findings of our study will illuminate future planning and development efforts.

Declaration of Ethical Standards

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Conflict of Interest

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

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