UAD Universitas Ahmad Dahlan

IJIO
(*International Journal of Industrial Optimization*)
ISSN 2723-3022 (online) | 2714-6006 (printed)
Vol 5, No. 1, 31-44
https://doi.org/10.12928/ijio.v5i1.7963

Queuing analysis and optimization of public vehicle transport stations: a case of South West Ethiopia region vehicle stations

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ARTICLE INFO

Article history
Received: April 15, 2023
Revised: August 18, 2023
Accepted: September 19, 2023

Keywords
Arena 14 automatic rockwell;
Queue system;
Transport services;
Vehicle stations.

ABSTRACT

Modern urban environments present a dynamically growing field where, notwithstanding shared goals, several mutually conflicting interests frequently collide. However, it has a big impact on the city's socioeconomic standing, waiting lines and queues are common occurrences. This results in extremely long lines for vehicles and people on incongruous routes, service coagulation, customer murmuring, unhappiness, complaints, and looking for other options, sometimes illegally. The root cause is corruption, which leads to traffic jams, stops and packs vehicles beyond their safe carrying capacity, and violates passengers' human rights and freedoms. This study focused on optimizing the time passengers had to wait in public vehicle stations. This applied research employed both data-gathering sources and mixed approaches. Then, 166 samples of key informants of transport stations were taken using the Slovin sampling formula. The time vehicles, including the drivers and auxiliary drivers 'Weyala', had to wait was also studied. To maximize the service level at vehicle stations, a queuing model was subsequently devised 'Menaharya'. Time, cost, and quality encompass performance, scope, and suitability for the intended purposes. The study also focused on determining the minimal response time required for passengers and vehicles queuing to reach their ultimate destinations within the transportation stations in Tepi, Mizan, and Bonga. A new bus station system was modeled and simulated by Arena simulation software in the chosen study area. 84% improvement on cost reduced by 56.25%, time 4 hours to 1.5 hours, quality, safety and designed load performance calculations employed. Stakeholders are asked to implement the model and monitor the results obtained.

1. Introduction

Waiting in lines and queues is a common occurrence. Clients remain in the queue, identified by the maximum number of clients permitted to hold, before being serviced. The model's queuing analysis results have significant practical implications for resolving the issue at banks, airports, and stations [1]. The history of human life was made more accessible by modern transportation services. The world as a whole has many different sorts of transportation methods. Land transportation is one of them and a significant contributor to the ratio. Vehicle transportation offers mail services, passenger services, and loading little freight. However, government employees mostly manage passenger service in bus or vehicle terminals. Because of this, this mode of transportation benefits society by reducing the time people need to walk, increasing profitability due to time savings, improving people's productivity, reducing weariness, and improving user comfort. This is all about how speeding up performance in land transportation simplifies daily life. When resources are used wisely and safety is managed effectively, the transportation sector's end goal is reached quickly [2].

However, the purpose of the relevance above is disrupted and twisted in numerous ways in the current scenario. The initial restrictions currently in place are needless, extremely long lines for automobiles and passengers on illogical routes. Here, service coagulation occurs. Customer slander, complaints, unhappiness, and looking for other private options or alternatives may occasionally lead to unlawful activity. It suggests that, aside from being optionless, the challenge level is excessively controlled. Because of this, the public's perception of the worth and reliability of government offices is occasionally diminished. The root of this issue was corruption, which leads to traffic jams, high transportation expenses, stopping, over-loading vehicles, and freedom-violating behavior. Because of this, reality suggests that this study begins to feel animosity toward the industry and the suffering of the lower classes of society [3]-[42]. The station/transport service's mission was to eliminate similar challenges. It demonstrates/identifies ways to improve the current situation and bring it closer to the intended outcome or ideal. It’s the responsibility of a scientist or academic to assist by identifying the underlying reasons for the apparent issue and outlining solutions for the transport services. Bus and vehicle stations are another form of public transportation service. Mainly the systemic quandary requires careful monitoring, in-depth investigation, and the development of mechanisms that can be proved.

Three restrictions measure the effectiveness of each project type offered by corporations [43]. Time, money, and quality encompass performance, scope, and suitability for the original intended purpose. They are frequently linked to suffering a loss. Anytime there is a line, there will always be a delay, which is true. There will be an overrun if there is a delay in addition to the cost [24]. When two items are dealt with simultaneously, the earliest and latest tasks will differ due to the passage of time. The earliest has been subjected to deterioration and obsolescence of goods over time, which results in a depreciation rate, and on another component, the time worth of money has altered due to inflation. It should examine the existing gap because industrialization may be challenging to accomplish. Thus, it becomes necessary to look into why, despite government efforts, there remains a long line at Menahariya.

The research gap in this topic emerges from the need to address the practical challenges related to queuing systems in the context of transportation services, particularly at bus and vehicle terminals. While the importance of efficient queuing systems in enhancing service quality and customer satisfaction is acknowledged, there is a lack of in-depth investigation into the issues these terminals face, including long lines, service disruptions, and customer dissatisfaction. Prior research has primarily focused on traffic jams and congestion, overlooking the unique challenges present at transportation stations [42]. This gap highlights the need for a dedicated study that delves into the complexities of queuing at such terminals and offers solutions to improve the current situation.

The main objective of this study was to investigate the minimum response time for the passengers and vehicles queued to the final destination in the selected three SW Ethiopia vehicle stations (such as Tepi, Bonga & Mizan). The specific objectives of the study were:

- To determine the root causes of the queue in public vehicle stations.
- To estimate the vehicle and passengers' daily size in those three stations.
- To optimize the service time of vehicle stations in the selected towns of Tepi, Bonga & Mizan.
- To model the appropriate kind of queuing system to implement in Menaharia.
- To adopt and adapt the new system/model in Ethiopia's neighboring town stations.

The research contributes to proposing a new queuing system model tailored to address the challenges faced at bus and vehicle terminals [43]. Additionally, it reviews several models previously used by researchers, demonstrating a comprehensive understanding of the existing literature in this field. The study also seeks to identify the root causes of queuing issues, estimate passenger and vehicle volumes, optimize service times, and propose an appropriate queuing system for implementation [44].

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By focusing on these specific objectives, the research aims to provide practical insights and solutions to enhance the efficiency and effectiveness of transportation services in the selected towns of Tepi, Bonga, and Mizan in the SW Ethiopia region. Overall, the research seeks to bridge the existing gap in understanding queuing dynamics at transportation stations and offers valuable recommendations for improvement [45].

1.1. Queuing Theory in Vehicle Services

Stochastic service system theory, sometimes called queueing theory, is a mathematical theory and approach to studying queueing systems. It is based on the study of the probability regularity of various queuing systems to tackle the problems of optimal design and optimal control of each queuing system. The time passengers wait increases the service desk's utilization rate and results in the more effective use of social and public resources [3]. A curbside bus stop's bus queue time estimation is crucial for assessing a bus system's efficiency, dependability, and effectiveness. Considering the no overtaking and limited overtaking principles, departing buses and served buses on upstream berths form an overflow line [2], [3].The impact of transport service challenges to the passenger community. If one were to record the arrival and departure times of every customer over a very long period, perhaps many years, one could evaluate the behavior of an existing service facility that caters to a specific type of customer. For certain actual systems, such data are present. Numerous permanently mounted car detectors are attached to every computer-controlled traffic signal system. There are probably one or more detectors upstream of every given traffic signal (server) and downstream detectors that may be close to the next downstream signal. When a car passes, these detectors send an electrical pulse to the computer. Although they might be stored on a magnetic tape, most of these data are deleted after usage. Any airport also records every flight, including gate positions, arrival and departure times from the runway, and other aircraft movements [4]. One of the most important factors influencing customer satisfaction with public transportation is waiting (B., 12). According to [5] and [37]-[40], a heavy traffic queueing system has a server occupancy rate just below unity. This phenomenon is present in contemporary computer and telecommunication systems. Following is a description of the various types of challenges involved in simulating the SCM system using queues other than the M/M/1 queue [5]:

Poisson arrival process and exponentially dispersed service times are characteristics of M/M/1 queues. The M/M/1 queuing model's state description is straightforward because all that is required to represent the system state is a single number [36]. Because the exponential service-time distribution requires less memory, this is feasible. The general state description would need details on both the number in the system and the amount of service already rendered to the customer presently being serviced for M/G/1 queues, where the arrival process is Poisson but service times have a general (arbitrary) distribution [23].

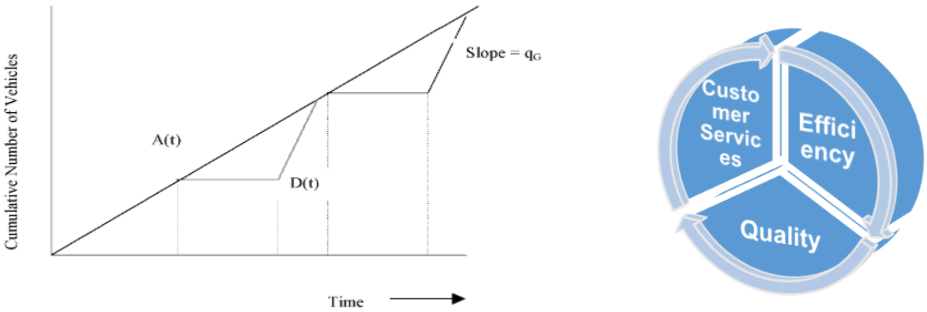

Fig. 1. Queuing Model and Quality of Service [6],[22]

ვ - arrival rate; μ - service rate; n - number of servers (provider); ȡ - system utilization; 1 / μ - service time; P0 - the probability of 0 units in the system; and Pk =-the probability of k units in a system. First, we define ρ, often known as traffic intensity or occupancy. It is calculated by dividing the average service rate (mu,) by the average arrival rate (lambda,). The average service rate should always be higher than the average arrival rate for a stable system [35].

In Kendall's notation, this talks about M/M/1 and M/M/2 queues. The number at the end indicates the number of servers, and the first letter indicates the estimated distribution of times between customer arrivals. The 2nd letter indicates the distribution of service times. The equations for M/M/k systems in general are significantly more complicated, but they're not bad when k = 2. For an M/M/2 system at a steady state, the expected wait time is presented in Eq.1 [32].

$$W = \frac{\lambda 2}{\mu(4\mu 2-\lambda 2)} \quad (1)$$

and the expected number of customers waiting is referred to Eq. 2 [25].

$$L = \frac{\lambda 3}{\mu(4\mu 2-\lambda 2)} \quad (2)$$

It was noted that L = W means that for both M/M/1 and M/M/2, the anticipated number of patrons waiting in line is times the anticipated wait time. This is known as Little's law and is generally true [27]-[31]. The main attributes of the queuing model are the population source, the number of servers, the arrival with service patterns, and the queue discipline [33].

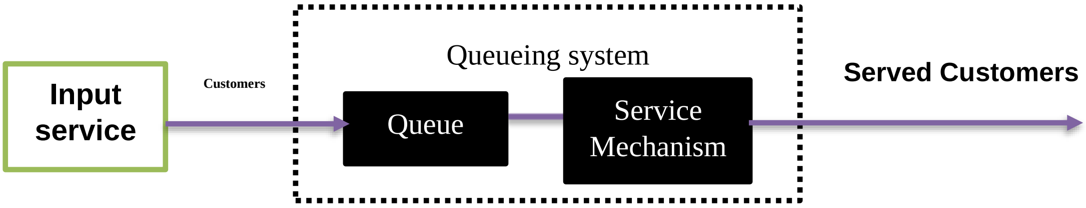

Fig. 2. The basic queuing processes [7]

The system utilization measurement shows how active versus idle the servers are. It represents a system that minimizes the total cost of waiting times and available capacity. The average arrival time and service rates must be stable in queue modeling to support the underlying presumption that the system is in a steady state [8].

2. Method

This applied type of study presents mixed research approaches. Both kinds of data sources were used in this study. Primary data was gathered from Passengers, drivers, and transport officials/administrations (such as traffic police, transport synchronization officers, and other notable key informants of the sector). Secondary data sources were obtained from brochures, magazines, the internet, reference books, journals, 48 articles, previous research works, and companies' written documents.

The determination of the number of samples was calculated using the Slovin formula is showed in Eq. 3 [9].

$$S = N/1 + Ne^2 \quad (3)$$

where; n = some samples N = number of population e = error rate, taken at 5% (0.05). Hence there were 28376 which is N, hence the Slovin formula n becomes 166 samples. So the designed questionnaires were distributed to those respondents. Three sites were selected for air quality monitoring to represent the study area and surroundings and show locations of monitoring stations at the three sites. Passengers, officers, and drivers (operators) are this investigation's study variables (population). There were three behavioral categories for travelers; Prospective buyers (merchants), Squeeze travelers, and Sporadic visitors.

Assumptions: There is only one server and a restricted number of distinct components, hence there are three serving lines at each station for nine waiting lines.

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The map in Fig. 4 of this study shows the study sites of each adjacent town vehicle station in SWE State. Bonga to Mizan 115 km, Mizan to Tepi 50 kms apart, and Tepi to Bonga 163km. Bonga has three service lines, ie. Tepi, Jimma, and Mizan, as shown in Fig. 3. Tepi has Mizan, Bonga, and Masha windows of services in the new model method. Meanwhile, Mizan has Dimma, Tepi, and Bonga routes of service lines [26]. Fig. 5 presents graphical methodology and framework of the study.

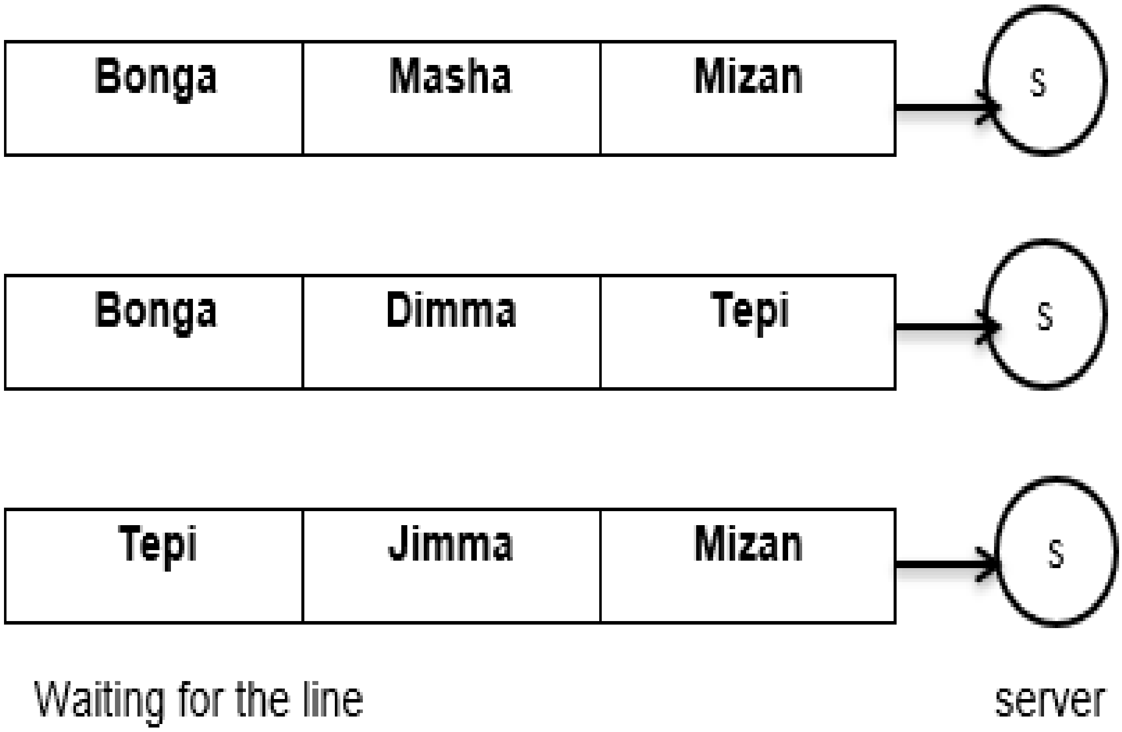

Fig. 3. 40 Cars Limited System Capacity Waiting in Line in Each Town Bus Station [10]

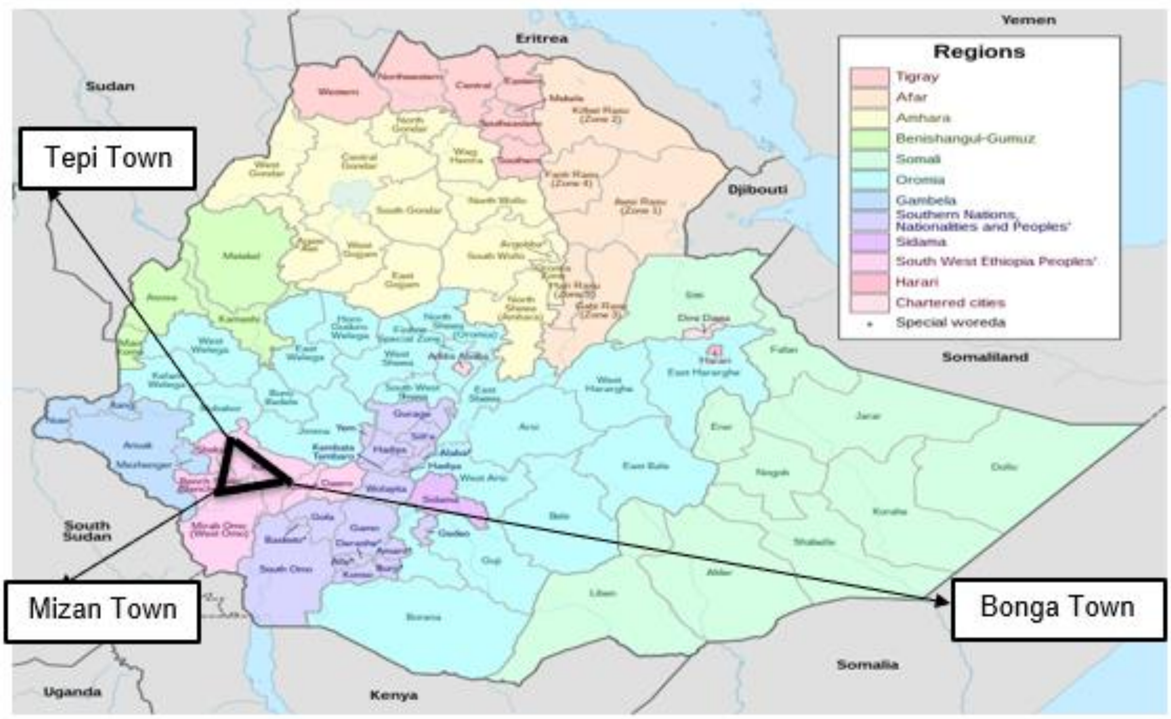

Fig. 4. Study Area Map from Ethiopia Locations [7]-[10]

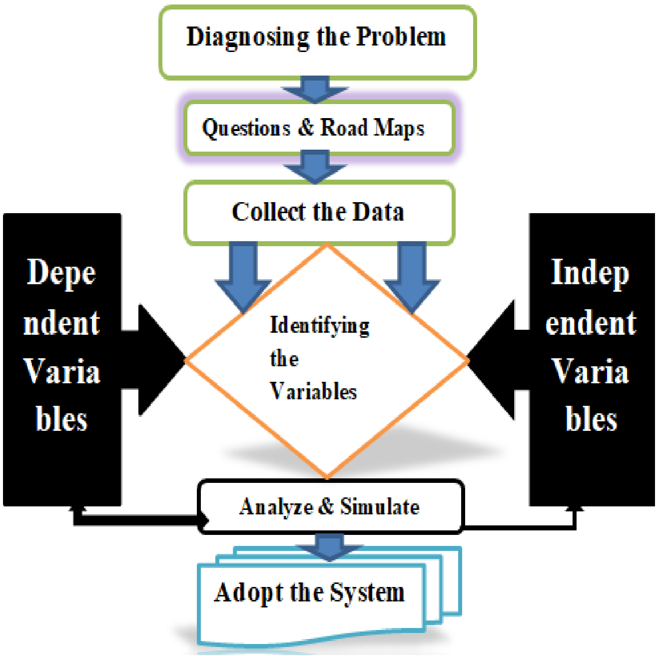

Fig. 5. Graphical methodology and framework of the study

3. Results and Discussion

Simple Microsoft Word and queuing analysis for a single or several servers assessed the primary data gathered and software outcomes. How to differentiate between arrival time, response rate, service line, and other associated information would be determined. Nonpublic fear trucks are not included in the types of vehicles considered comparison of SDD (system design and development) [11].

Background elements: batch arrival techniques are used in queuing: clients arrive in groups rather than alone [12]; Bulk service: instead of serving each consumer individually, the server (or each server if there are numerous servers) works in teams [11];

Customers who balk at joining a line typically do so because it is too long to wait in it when they arrive [13]. Reneging: Some additional customers first opt to join a line, but over time grow impatient and ultimately abandon the line before obtaining service if the wait becomes intolerably long [14]. Let 87 be the average number of passengers arriving per hour at the Tepi, Bonga, and Mizan stations, and the average number of customers served per hour at 50. We need 1/1/1 for the system to approach a steady state. In the alternative, the line of clients keeps growing forever. As a result of customers arriving almost as quickly as they can be served, a queue forms. But for now, /=87/50=1.74 denotes a negative. For M/M/1 queue, the expected wait time is once the system reaches a steady state which presented in Eq. (5) [15], and the expected number of customers waiting at any time is referred to Eq. (6) [16].

$$W = \frac{\lambda}{\mu(\mu-\lambda)} \tag{5}$$

$$L = \frac{\lambda 2}{\mu(\mu-\lambda)} \tag{6}$$

However, this does not help much in identifying the distribution of the number of passengers reaching each stop. According to Fig. 6, there were more regular visitors than the average number of visitors. Frequent customers are severely harmed by a lack of transportation options, among other things. Due to their frequent usage of the station, those potential clients must receive priority attention, followed by others in that order based on how frequently they arrive and depart.

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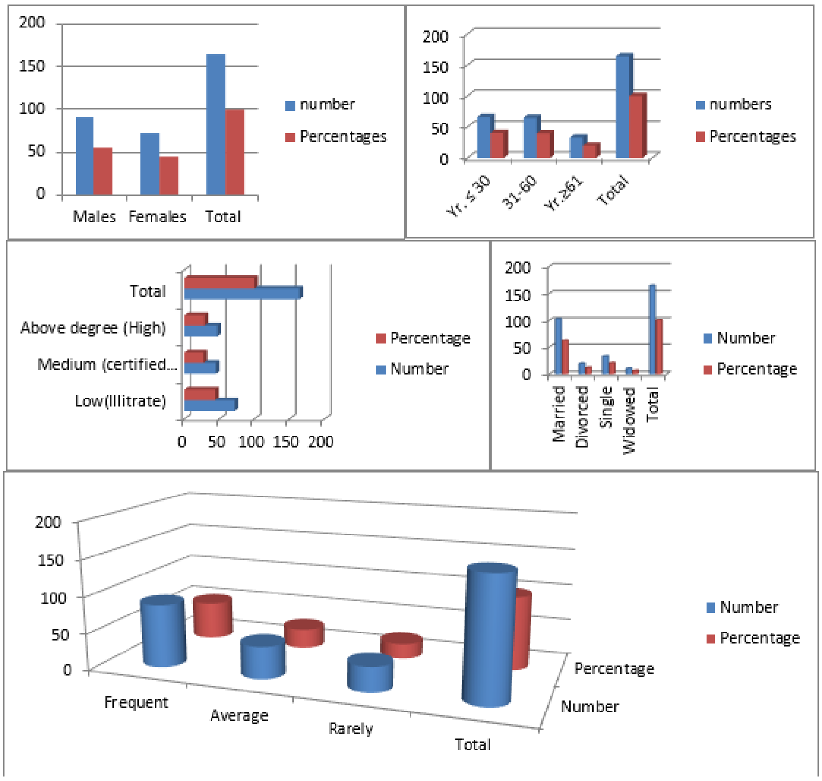

Fig. 6. Vehicle station utilization frequency and demographic data

The issue affects every aspect of the community equally. The economic difference is not conserved from effects, as seen in Fig. 7. Differences in educational status are also unaltered. All areas of the local community are impacted, both directly and indirectly, regardless of distinctions in ethnicity and religion.

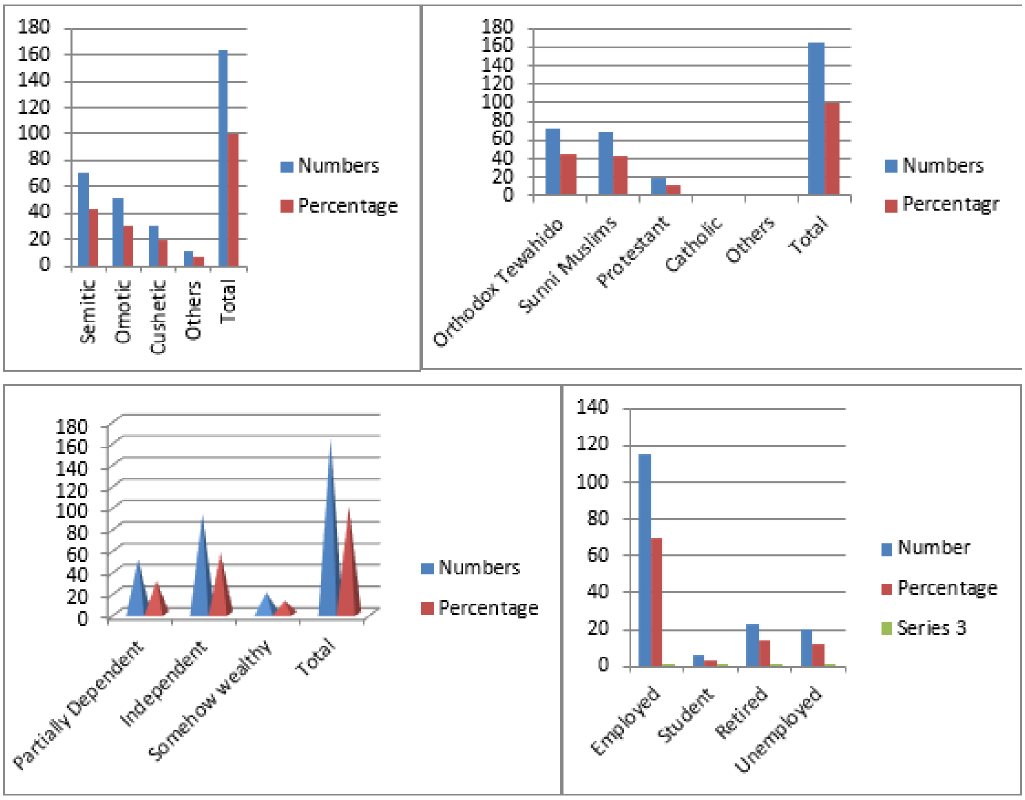

Fig. 7. Impact analyses on religious, ethnicity, economical, and educational level difference

Farmers, mechanics, power plant operators, workers on production lines, on the road, and electricians are a few examples of blue-collar occupations [17], [18], [19]. On the other hand, white-collar professions often involve office work in clerical, administrative, Teachers, professors, researchers, human resources agents, accounting and processing staff, office managers, business executives, public relations and advertising specialists, architects, engineers, stockbrokers, medical experts (including dentists, doctors, and nutritionists), and managerial jobs, among others [20]. Fig. 8 shows that anthropometric isolation and type of profession are not the causes of love. They are affected, whether they are white-collar or blue-collar. Nevertheless, the BMI difference affects them regardless of whether they are overweight or underweight, tall or short.

In public transportation, batch arrivals and service queues, including client reneging and balking, are frequently seen [21]. In this paper, compound Poisson process queues are developed. Impact analysis surveys and system analysis are accomplished by creating new models utilizing the Arena simulation software. According to the poll, the issue with the transport service touched all facets of the community.

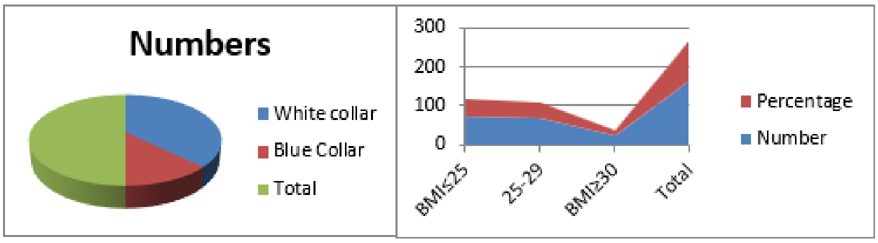

Fig. 8. The impact analysis on profession variation and bmi difference

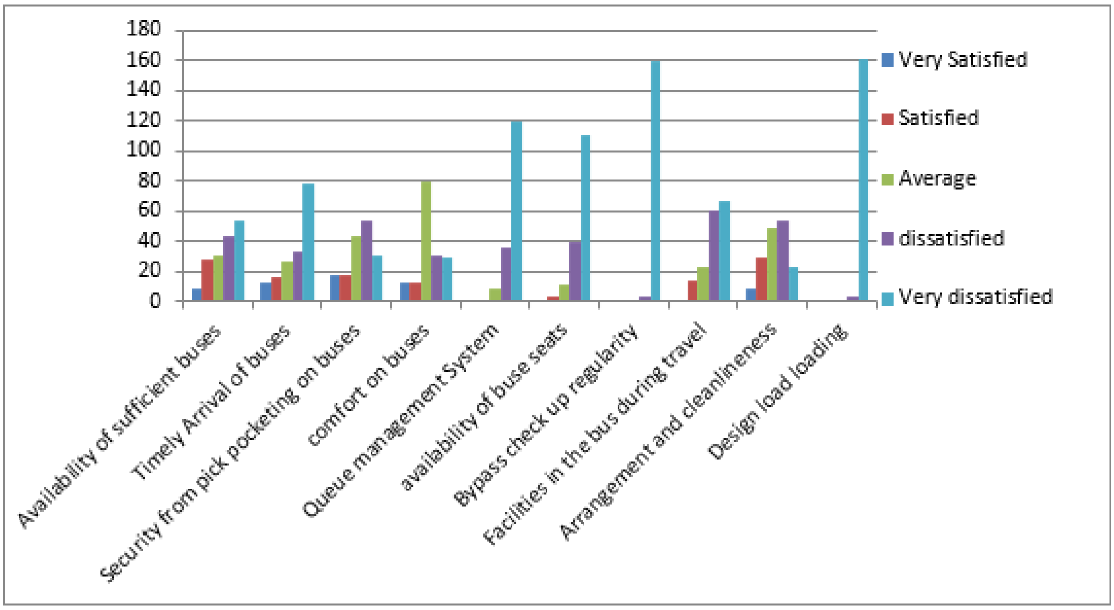

Fig. 9. Likert scale variable showing the graph

It should be noted that small villages without stations are included in the itinerary and could be unsure stations approaching in 10killo meters. The Mizan-Tepi-Bonga system is connected to form a single unit (vehicle station). The interval between arrivals and waiting times is simulated. There are three different waiting queues at each station. The bus type used is only for the benefit of people's passages—model of all three bus stations from Arena 15 Rockwell Automation Simulation software.

Fig. 10 represents a single route among the three station lines, which implies five stations for a 50 km distance vehicle road. Hence, all five stations commonly serve as loading and unloading

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services for picking up the on-road passengers. Hence it serves as by shortening setup time, security issues, and over-tariff payments & it could avoid over-capacity load because of standardization.

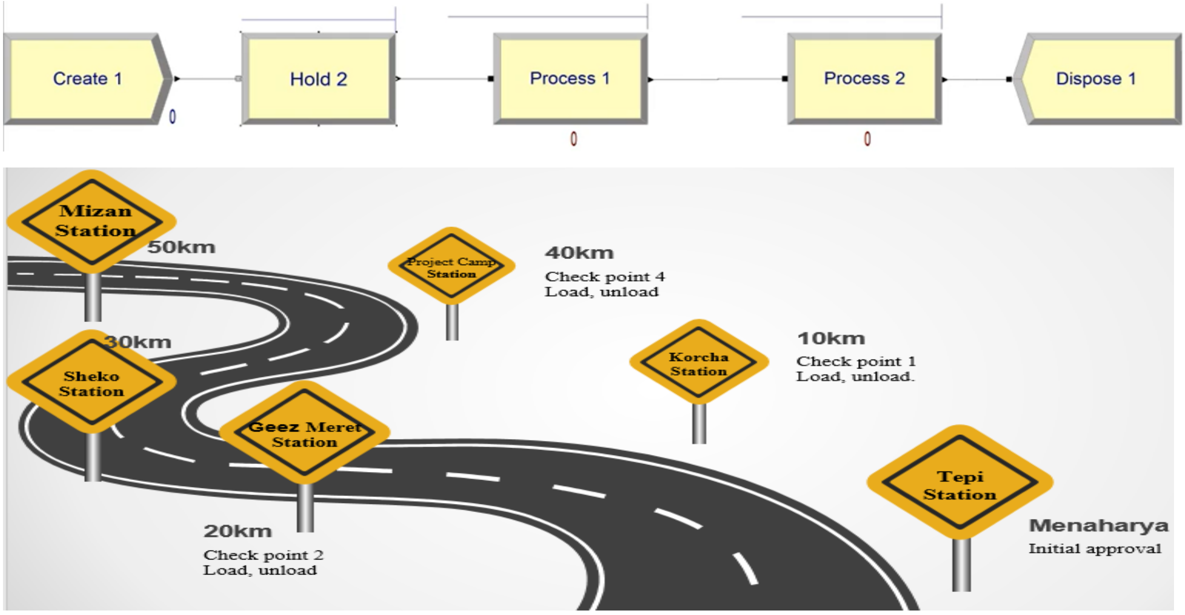

Fig. 10. Consistent stations of 50 km per each 10kms gap in a new model

Station service lines and check up in the three different town stations are synchronized together. And the disposes in Fig. 11 signifies the station in Tepi with three departure stations, Mizan with three departures, and Bonga with three departure stations, a total of nine stations networked. The inspection symbol also represented the station per 10km gaps altogether connected. And one vehicle station in one town will be manipulated in a single authorized center. Vehicles or other parties never decide on it except contracts get approval for exit or entry into the system.

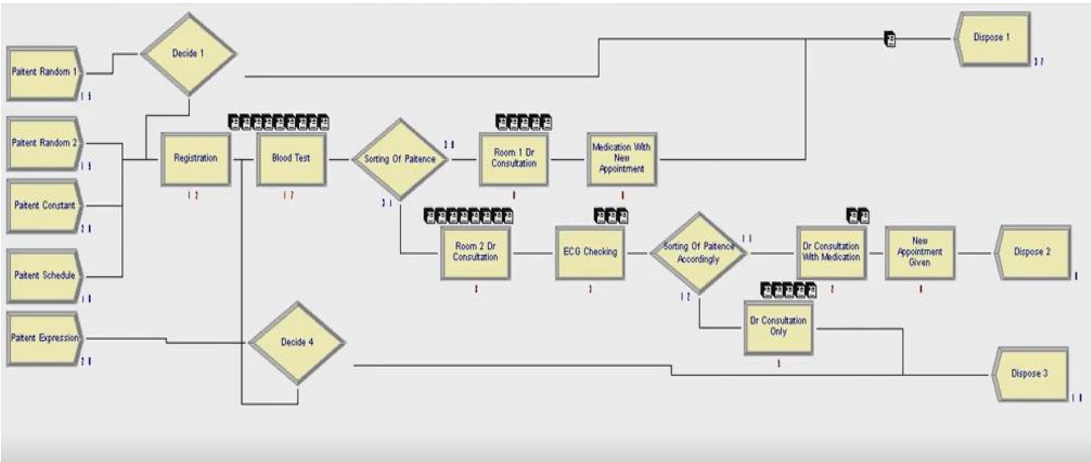

Fig. 11. The new model transportation queuing entire system model

The figure above and Table 1 respectively show the new model diagram into three selected cite zones resulting from changes in triple constraints. i.e. 84% improvement on the existing system. Improvements in time 5hrs per round trip cost 72 ETB saved, and the newly modeled service system will render speedy, safe, and comfortable services. Despite the diversity of people's backgrounds, the issue is widespread. The entire community is impacted, whether directly or indirectly. Impact on both sexes, all age groups, all occupations, as well as their current level of education and financial situation. Therefore, the stakeholders must maintain the system in a well-researched manner. This project attempted to address fundamental community issues by creating a new car station management system. All stakeholders and shareholders in the transportation industry come together due to the integration of crucibles and work for change for the benefit of all. Lastly, this research puts two critical recommendations. The first one correctly applies Fig. 11 instead of an existing system and implements it by creating awareness for the stakeholders. The 2nd also policy and further research development attention is highly needed.

In the single round trip from Tepi to Mizan identified from the new system. Cost 100 Birr over tariff minus 64Birr normal tariff, 36*2=72ETB. On each day, the bus will have at least 7 rounds since it will make a significant financial change, while the benefit goes to passengers. Especially prospective buyers will benefit. The time will be saved 5hr/round, safety, and comfortability increase. Findings of the new vehicle station systems were mainly 4; such as the existing single route station system changed to triple route and 3 lines of services. As a result, the queue of vehicles and passengers has become very fast as shown in Table 1. The response rate is also controllable enough. The second finding would be check-in (*mewucha*) from the station, which includes design load, the passenger's tariff, frights with the type, availability of sufficient fuel for the journey, driving license, bolo, and other legal dressing formalities. The 3rd finding was loading, unloading, and traffic police check stations in each 10 km gap. This implies no bus stop unless 10km or unpredicted mishaps. And the 4th finding is the modeling of the new station system integrated with the connecting ways of each station and validated using arena simulation software.

Table 1. Isuzu bus 50 km driving comparison of two systems

Comparison factors	Previous station service system	New model
Waiting time	High	Low
Response rate	Less, passive	High, fast
Queue length	Long & unpredictable	Short and controllable
Similarity	16	84%different
Tariff	100ETB	64ETB
Arrival time	3-4hr.s	1hr to 1.5hr
Design load per vehicle	112man + 100kg fright	42man+40kg
Security	Risky	Comfortable
Occurrence of corruption	High	Low/ absent

Hence, the implication and explanation of these findings addressed the triple constraints of from previous literatures, such as time, cost, and performance [46-50]. Hence, resource optimization is included in the model, which helps increase passenger satisfaction. But the previous station was very disorganized.

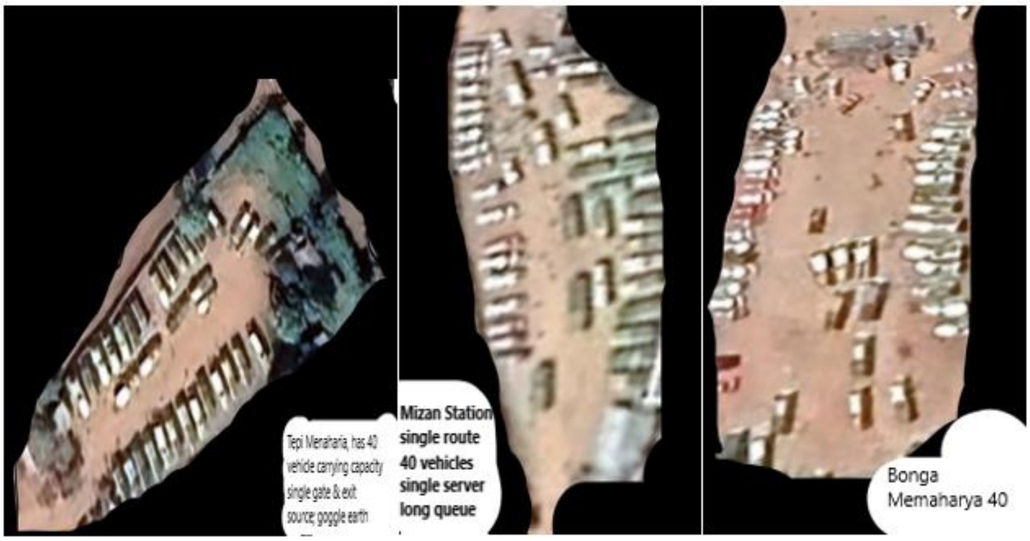

Fig. 12. Existing station system by the Ministry of Transport Ethiopia [22]

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4. Conclusion

In the context of rapidly evolving urban environments with conflicting interests, the presence of long waiting lines and queues significantly impacts the socioeconomic status of cities. These queues often lead to extended waiting times for vehicles and passengers on inefficient routes, resulting in service disruptions, customer dissatisfaction, complaints, and even illegal activities. The underlying cause of this problem is corruption, which manifests in traffic congestion, overloading of vehicles, and violating passengers' rights and freedoms. This study tackled the challenge of optimizing passenger waiting times at public transportation stations through applied research that combined data collection from various sources and mixed methodologies. Key informant samples from transport stations were collected, and the study also examined the waiting times for vehicles, including drivers and auxiliary drivers ('Weyala'). A queuing model named 'Menaharya' was developed to enhance the service quality at vehicle stations, focusing on time, cost, and quality considerations encompassing performance, scope, and suitability. Furthermore, the research aimed to determine the minimum response time required for passengers and vehicles in queues to reach their final destinations within transportation stations located in Tepi, Mizan, and Bonga. An innovative bus station system was designed and simulated using Arena simulation software, resulting in an impressive 84% cost reduction, a 56.25% decrease in time from 4 hours to 1.5 hours, and improvements in quality, safety, and designed load performance. The study concludes by urging stakeholders to implement the proposed model and closely monitor the achieved results, ultimately benefiting urban transportation systems. For future research, this research can be done by employing other methods to solve this complex problem.

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