ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

AFRICAN RAILWAY CENTER OF EXCELLENCE

A STUDY OF CROWDING ON LIGHT RAIL TRANSIT; A CASE STUDY OF ADDIS ABABA LIGHT RAIL TRANSIT (AALRT)

A Thesis in Railway Engineering (Civil Infrastructure)

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A Thesis

Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Science

The undersigned have examined the thesis entitled '**A study of crowding on light rail transit; a case study of Addis Ababa Light Rail Transit (AALRT)** presented by **Duncan Mwangi Muturi**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

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UNDERTAKING

I certify that research work titled "**A study of crowding on Light Rail Transit; a case study of Addis Ababa Light Rail Transit (AALRT)**" is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

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ABSTRACT

Crowding on rail vehicles impacts passenger travel experience and ridership growth, often reflecting lack of adequate management in passenger travel on the part of the railway operator. The Addis Ababa Light Rail Transit (AALRT) has experienced passenger crowding especially during evening peak hour which results in poor passenger ridership quality. This research aims to explore possible countermeasures to curb the crowding problem at the AALRT thus improving passenger ridership quality levels. Analytical methods, observation surveys and questionnaires have been used to analyze the magnitude of the crowding problem and the existing operational gaps thus establishing the requisite countermeasures. The results show that by 2018, the E-W line experienced crowding LoS D on station platforms and LoS F inside trains, with the main causes being insufficient trains and inconsistent headways. This crowding translated to an estimated direct economic loss during the evening peak period of 231.46 ETB per working day over the same period. Commuters faced inconveniences such as enduring uncomfortable trips, occasional theft and delays. The countermeasures recommended to curb crowding involve the integration of engineering, non-engineering, policy and psychological interventions. Some of the proposed countermeasures include review of future rolling stock seat arrangement, installation of at-grade pedestrian crossings, implementation of controlled passenger boarding, setting up minimum time to avail stand-by trains and installation of station passenger information systems. Successful application of the measures would eventually reduce and maintain platform and on-train crowding to LoS C and LoS E respectively. This would also reduce the frequency of occurrence of crowding contributors thus mitigating future crowding on the AALRT E-W line. Consequently, better passenger ridership quality would be ensured. African countries keen to develop light rail transit (LRT) to decongest urban roads can benefit from the LRT if it solves crowding problems rather than re-creating them. Therefore, this research is beneficial to developing countries as it examines possible loopholes that would occur in LRT operations and the appropriate measures to curb the crowding problem.

Key Words

Crowding, Light rail transit, Ridership quality level, Peak hour.

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LIST OF ACRONYMS

Term	Explanation / Meaning / Definition
AALRT	Addis Ababa Light Rail Transit
LRT	Light Rail Transit
CREC	China Railway Engineering Corporation
DOC	Degree of Crowding
USA	United States of America
N-S	North-South Line
E-W	East-West Line
AM	Morning
PM	Afternoon
UK	United Kingdom
TCQSM	Transit Capacity and Quality Service Manual
LoS	Level of Service
PiXC	Passenger in Excess Capacity
OCC	Operation Control Centre
P.I.S	Passenger Information System
OCS	Overhead Catenary System
TRB	Transport Research Board
ERA	Ethiopian Road Authority

CHAPTER 1 INTRODUCTION

1.1 Background

Human mobility is of great important to the lifeline of cities around the world. Many transportation modes that include pedestrian, road and rail are becoming increasingly integrated in urban centers to ensure faster, safe and timely movement of populace. However, as population within cities around the world continue to grow, governments have opted for affordable investments in mass transit modes of transport such as bus rapid transit. However, such efforts have still remained insufficient especially when road traffic congestion persists thus the rise in popularity of Light Rail Transit (LRT).

LRT has been in operation since the 1970's in the cities such as New York, and later Shanghai and Tokyo in the 1980's. Passenger transportation in such cities thus became easier, spurring economic and social development. In the recent past, large passenger volumes are reported to use LRT; Metro Rail and Newark Light Rails in USA had over 67.9 and 5.5 million riders respectively, in 2017 [1, 2]. LRT's successful use in the developed world, has lead developing countries in Africa to consider the rail technology as a mass passenger transport solution to the crowded city road networks, with Ethiopia taking the lead in its implementation and use.

Construction of the Addis Ababa Light Transit (AALRT) rail began in 2012 and by the end of 2015, both the East – West (E-W) and North – South (N-S) lines were in operation. The total length of the line is 34.25 km (N-S line is 16.9 km while E-W line is 17.41 km including a common-track section of 2.63km) The E-W line stretches from Ayat, through densely populated areas such as Megenaga to Torhiloch while the N-S line starts at Kality, traverses through Saris, Merkato and terminating at Menelik. Over time, the phenomenal growth in AALRT's ridership has resulted to crowding problem within its initial operational phase at station platform and inside the trains. Crowding on AALRT results to commuters facing problems such as low quality travel experience and safety hazards.

In order to realize AALRT's intended transit benefits into the future, it is critical that suitable countermeasures that could arrest existing crowding problem be examined. In view of the above, a detailed study of existing train operations is needed to better understand the causes of crowding and their magnitude, therefore leading to not only proper crowd curbing measures but also will help improve rider's travel experience and safety.

Maintaining balance between passenger demand volumes and rolling stock supply during rush hour is key to solving the passenger crowding problem on LRT's. In order to achieve this, proper estimates of train ridership demand as well as subsequent provision of adequate train supply capacity by the operator are some of the critical issues that need to be investigated. In this research, analytical methods proposed by the TCQSM have been used to determine the required train numbers while secondary data from the AALRT's operator has been analyzed to determine passenger estimates. However, such a balance may be inhibited in the event infrastructure constraints such as traffic saturated lines, poor conditioned tracks or shared networks exist within an LRT network. Rolling stock supply issue not only depends on the availability of sufficient train numbers but also depends on a variety of factors such as proper serviced and timely operated trains. In the event of proper balance between train numbers and proper supporting operations, crowding on LRT will be inevitable.

Previous research have successfully estimated and forecasted passenger numbers on the Addis Ababa Light Rail Transit (AALRT) but have not highlighted how appropriate train operational balance can be put in place to avoid issues of crowding. Therefore, this research focusses on why crowding persists on the AALRT, despite knowledge of passenger demand and train supply factors. Specific emphasis is laid on how to effectively match the two factors thus mitigating passenger crowding.

Recommendations from this research will prove valuable to future LRT operators in other African cities on how the crowding challenge can be effectively curbed especially in the initial operational term as is the case with AALRT.

1.2 Statement of the problem

Addis Ababa Light Rail Transit (AALRT) operator estimated that over 75 million passengers had used the light rail service since its inception in 2015 to June, 2018; a figure that translates to 115,000 – 120,000 daily passengers [3]. The growth of rail ridership demand over time has resulted to crowding challenges during peak hours within the system.

Crowding on AALRT's platforms and inside trains observed over the evening rush hour has resulted to poor ridership quality levels characterized by issues such as travel delays and compromised passenger safety. During peak hours, many passengers are left stranded on a station platform as train after train crawls past, too full to even attempt getting on. It is not much better for the lucky ones who manage to squeeze themselves into a packed carriage to begin stressful and uncomfortable journeys.

Crowding menace has developed rather too soon on AALRT despite the system being operational for less than four years. Careful observation over the initial operational period reveals that peak-hour passengers could not have exceeded the 2036 long term design capacity of AALRT. In-fact, crowding occurring in the initial term operation period (2018) of the railway line, raises tremendous concerns of the light rail's patronage in the short (2025) and long-term periods. Appropriate mechanisms to curb crowding are urgently required to improve existing passenger travel quality as well as boost economic returns from efficient use of $ 430 million infrastructure; solutions that this thesis will indeed aim to explore and propose.

1.3 Significance of study

LRT crowding such as that experienced on the AALRT's network, is a major cause for concern. Causes, the nature and effects of crowding are examined to determine proper countermeasures to the problem. Upon implementation of recommended countermeasures, crowding is expected to be mitigated thus realizing better passenger ridership quality level as well as increased revenue to the railway operator.

1.4 Research objectives

1.4.1 Main objective

To study passenger crowding for LRT such as the AALRT.

1.4.2 Specific objectives

Specific Objectives covered in this research include to;

1. Analyze the extent of crowding on AALRT's passenger platforms and inside trains.

2. Assess the efficiency of operations on AALRT thus understanding the utilization of available train capacity.
3. Estimate the direct economic loss on AALRT due crowding.
4. Analyze passenger ridership quality levels on AALRT.

1.5 Scope and limitations

Rail passenger crowding is analyzed for a typical LRT thus other types of rail services are outside the scope of investigation.

Passenger crowding on AALRT is most severe during the PM peak period (4-7pm), hence this research concentrates particularly on this rush hour, and specifically on the East - West (E-W) line. Recommendations proposed to tackle crowding will be assumed to apply for AM peak and North-South (N-S) line, which experiences less congestion.

Focus is drawn on how to tackle LRT crowding during the initial operational phase hence AALRT's selection as a typical case study. Crowding in the short and long term operational phases of LRT, is thus not part of the study's scope.

Passenger crowding on LRT has many negative effects, however the proposed research will concentrate on determining both the magnitude of crowding effect to passenger ridership quality and direct economic loss specific to AALRT, due to the study's budget and time constraints. Calculation of indirect economic loss is too complex and time consuming, thus is not part of the research scope.

Several operational issues can affect the level of LRT crowding. As a result, this research shall be specific to only two operational issues due to budget and time constraints. Operational issues that this research will focus on include train supply and passenger management, to which specific countermeasures are suggested.

1.6 Methodology

The study on light rail crowding is conducted as a case study based on AALRT's operations during a typical peak hour. The flow chart below shows the methodology followed in developing this thesis.

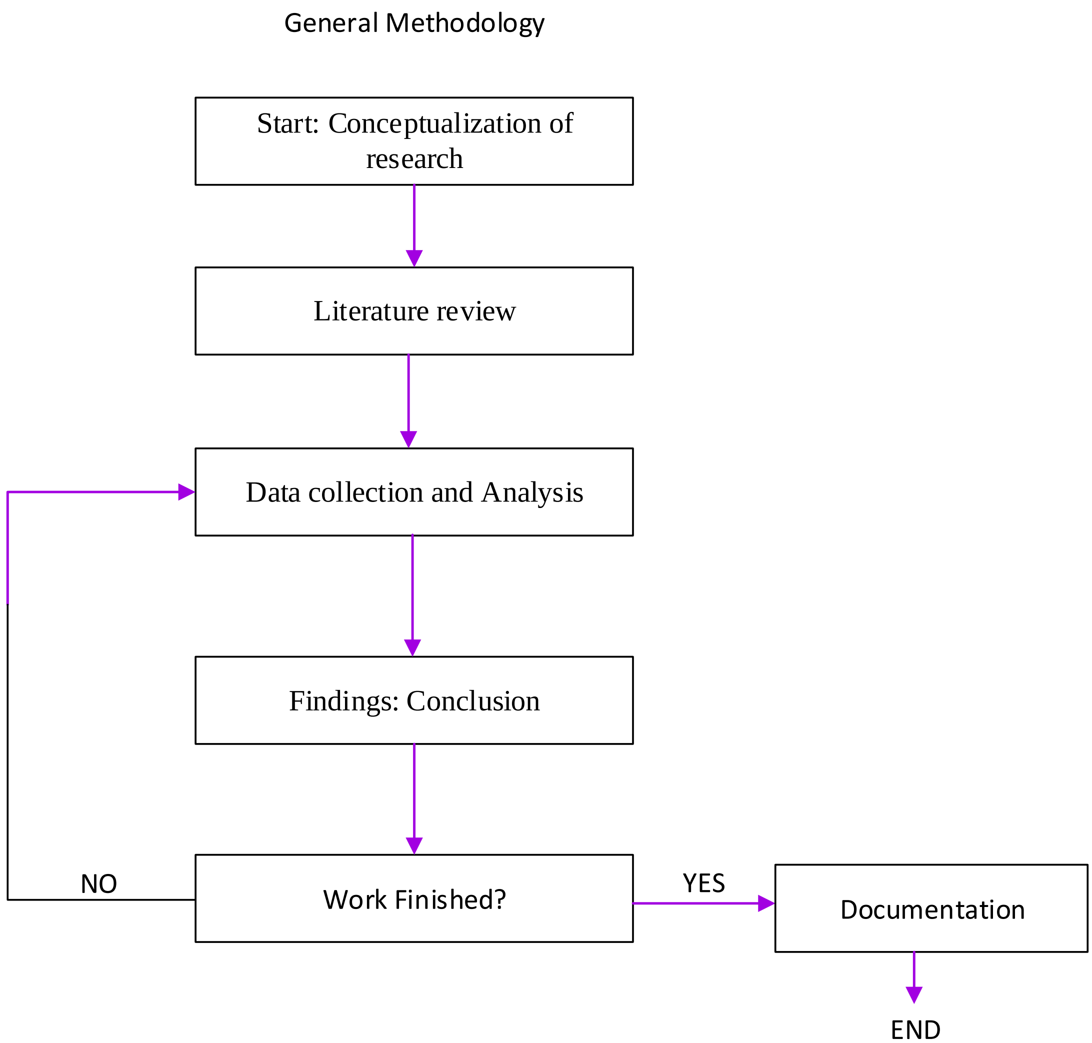

Figure 1 General methodology flow chart (Author, 2019)

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

Rail passenger crowding is an international phenomenon as revealed from studies conducted in cities such as Mumbai [4], London [5, 6] and Sydney [7]. Passenger crowding on both platforms and trains can be mainly attributed to several causes; growth of rail ridership demand over time that eventually approaches design capacity during peak travel periods or special events, passenger behaviour or operational in-efficiencies that trigger interruptions to regular train services.

From a passenger's perspective, experienced crowding leads to increased dissatisfaction during traveling as it increases delay in travel times, generates potential health and safety hazards and degrades operational efficiency. Additionally, crowding is often considered a key service attribute; how customers judge the public transit system along with other factors such as travel time and reliability. From an operator's perspective, the service frequency or vehicle size is significantly influenced by the level of ridership, which sends a signal to respond if the monitored crowding level exceeds the benchmark standard [8].

According to Turner et al, the United Kingdom (UK) Rail Safety and Standards Board stated that understanding the causes, effects and solutions of the rail passenger crowding problem is important [9]. Assessing the level of passenger crowding is critical for rail transit systems, not only to understand customer experience, but also to identify causes and develop corresponding strategies to manage or relieve congestion [10]. London Assembly Transport Committee explicitly stated that rail managements which accept crowding as inevitable are not only short changing the travelling public; they are failing to run the system properly [6]. In respect to this research, two viewpoints were considered while studying crowding for the AALRT; the passenger and operator's viewpoint. The passenger's viewpoint considered the effect of crowding to commuters in terms of ridership quality while that from the operator, considered the direct economic loss incurred.

2.2 Definition

Defining rail crowding is complex based on a variety of standards. According to Evans and Wener, passengers feel crowded because they feel that their personal space or privacy has been invaded by the close presence of others [11]. From the user's perspective, train crowding is characterized by seating availability, standing duration, movement through a crowded train, support structures, and personal space. Density is represented by seating and standing space, whereas perceived crowding is characterized by restrictions to movement, lack of support structures, and invasion of personal space [12].

An explicit definition of crowding in rail transport is however offered by the Strategic Rail Authority who describes train crowding as a situation where “there are no spare seats on long journeys or where standing passengers have less than $0.55m^2$ of space each on short journeys” [13]. In the context

2.3 Nature of passenger crowding

In a study investigating the peak-period commuting pattern, researchers concluded that heavy demands at peak hours and preferred departure times contribute to crowding build-up. More specifically, they found out that the train arriving at the time desired by everyone is utilized by commuters from all stations, which then leads to crowding on the train and at the station [14]. Mohd, M., and N, Diana stated that the inevitable nature of crowding on the rail, especially during rush hour, contributes to its dislike as a preferred travel mode of choice among passengers. Reasons behind passengers’ dislike for crowding go far beyond the simple physical discomfort that is caused by having to stand or to share a limited space with several passengers. Increased anxiety, a feeling of privacy invasion, possible ill health and perceptions of risk to personal safety are other reasons that passenger’s dislike crowded trains [15].

Commuters can react to train crowding by changing their travel times, using another departure or arrival station, switching to another mode of transport, and positioning themselves on the platform in such a way that they line up with the position of train doors [16, 17]. London Assembly Transport Committee reported a number of sad strategies that passengers use to cope with crowding; passengers who have to tolerate relatively crowded trains on a daily basis are likely to view their journey as a series of competitive situations in which they have to engage in a “survival-of-the-fittest” attitude or adopt a “ruthless and selfish tube persona” such as grabbing seats at the expense of pregnant women and people carrying babies [6].

2.4 Effects of passenger crowding

2.4.1 Economy

The City of London in 2003, is reported to have incurred an estimated annual loss of about £230 million due to delays in public transport. This is equal to about £750[1] per year per working person in London, or about £1 million per business day for the entire city [18]. Crowding in public transport is also the cause of real and significant economic costs due to late arrival at work, a loss of productivity, absence due to sickness, missed and rescheduled meetings as well as lost business [6].

2.4.2 Tourism

Crowding in light rail during peak tourist seasons is of significant concern. Local economies which depend on tourism will be severely damaged if visitors find the transport so bad that they are discouraged from returning, or from recommending a visit to others. Capacity must be provided to deal with seasonal peaks in demand as well as daily commuting patterns [6].

2.4.3 Health

In a report by the House of Commons Transport Committee (Seventh report of the Session 2002-2003) on the impact of rail crowding, it can be read that if a public transport system is not efficient, employees will arrive at their workplace being tired, stressed and uncomfortable [19]. Previous studies have reported that the incidence of influenza is higher among rail passengers whose journey is most crowded (that is, a loading factor of 70% or more) in comparison to those whose loading is less [20].

Crowding is also associated with some physiological discomfort variables such as heat. Significant positive association exists between crowd density and passengers' thermal strain [21]. Additionally, a study by Nicol et al. revealed that passengers in ventilated but crowded trains may experience an undesirable and potentially dangerous level of discomfort after 30 minutes, with standing passengers commonly finding these conditions more severe. The study thus recommended that the globe temperature in a carriage should not exceed 30°C in any case, with a physiological limit for safety of 30.6°C [22]. London rail commuters often found their journeys

[1] 1 $ = £ 0.79 in 2019

extremely uncomfortable and perhaps even dangerous. Passengers reported that they regularly saw people fainting on crowded trains, especially during the summer [6].

2.4.4 Safety

Thomas et al. identified crowding as one of the main safety concerns among rail passenger [23], a fact supported by Passenger Focus which further noted people can be injured due to crowding on trains [5]. Mohd, M., and N, Diana summarized the specific hazards identified in relation to platform and on-train crowding as accidents due to congested pathways or constricted platforms and injuries due to crowded stairs, escalators, elevators, ramps, or packed transfer stations [15]. Altogether, it appeared that many of the incidents caused by crowding fell into six categories: (a) slip, trip, or fall; (b) caught in the doors; (c) crushing; (d) struck by or against objects; (e) faint or collapse; and (f) strain [12]. Witnesses, according to the London Assembly Transport Committee reported being hurt by closing train doors because trains were too crowded, and seeing people fall into the gap between the train and the platform [6]. Mohd, M and N, Diana further noted that crowding is also linked to pickpockets, accidents and hygiene concern. All these influences reduce the welfare of public transport users [15].

2.5 Effects of passenger crowding

Mohd, M., and N, Diana stated that rail passenger crowding has been regarded as too complex to be measured, as it is subjective and multi-faceted [15]. Similar sentiments were also echoed in the Transit Capacity and Quality Service Manual (TCQSM), that acknowledged the difficulty of measuring passenger crowding consistently as car models and seat configurations vary too much [24].

Rail crowding is defined more often as a quantitative and objectively measurable experience [15]. Any attempt to investigate and conceptualize rail crowding should encompass two components of crowding: (a.) density and the available space, which represent the objective components; and (b.) perception of both the available space in the physical condition and the number of people present, which characterize the subjective elements [9]. Comprehensive measure based on both subjective and objective elements of crowding is thus warranted [15]. In the course of this research, both subjective and objective elements of passenger crowding are evaluated to comprehensively asses crowding.

2.5.1 Quantitative measures

Two broad measures that are employed to determine crowding level primarily involve measurements of passenger density and train capacity. Passenger density is usually determined by calculating the average number of passengers per unit area on station platforms or on-board a train, expressed as passengers per square-metre or foot [25], while train capacity is generally defined as the estimation of the maximum number of passengers that can be carried in one hour, in one direction on a single track [26]. The TCQSM manual was developed in the United States as a guidance and reference for quantitative measures to passenger crowding, and is briefly discussed below.

2.5.1.1 Transit Capacity and Quality of Service Manual (TCQSM)

TCQSM contains official definitions of station capacity, pedestrian levels of service (LOS), line capacity, and how to determine person capacity [8]. Guidelines published in the TCQSM [24] that define rail transit capacities and establish thresholds to measure passenger crowding include:

- Line capacity - the maximum number of trains that can be operated on a segment of track per time period (usually one hour).

- Person capacity - the maximum number of people that can be on board a train on a segment of track per time period (usually one hour).

- Station design capacity that is calculated by passenger demand during peak travel periods, demand during special events, and demand during emergency situations.

- Pedestrian Level Of Service (LOS) that is determined by the amount of standing space, the perceived comfort and safety, and the maneuverability in the pedestrian circulation area of a station. LOS is graded from A-F where A is equal to unimpeded movements and F is equal to seriously constrained movements. Maximum pedestrian capacity is usually LOS E or F but typically stations are not designed for maximum capacity so as to be more comfortable to passengers.

The following procedure was followed as set out in TCQSM 2013, to determine the number of trains for a given passenger demand.

a. Determine the current maximum evening rush hour cross-sectional passenger flow volume.

Current evening rush hour cross-sectional passenger flow volume can be determined through two main ways. First, through extensive passenger flow survey that examine both directional, spatial and time passenger flow of train movements [27]. Secondly, maximum evening rush hour cross-sectional flow can be extrapolated from existing passenger flow as a percentage of either total daily passenger flow or the maximum daily cross-sectional flow. An extensive passenger flow survey to establish the existing maximum evening rush hour cross-sectional passenger volumes is time consuming and requires financial resources beyond the scope of this project.

In order to capture recent crowding levels on the AALRT E-W line at the end of the initial term, the last three months of October – December 2018 weekly passenger flow volumes were considered to compute the average daily passenger flow volumes. A percentage of the total daily flow, stated for the AALRT's E-W line in the design manual, was then applied to the average daily passenger flow to obtain the maximum existing evening rush hour cross-sectional passenger flow volume.

b. Compute the required line capacity for the AALRT's E-W line based on passenger flow.

Required line capacity refers to the number of trains that pass at the station with the largest number of passenger volume per hour. TCQSM 2013 developed the equation below for computing line capacity;

$$\textbf{Line capacity} = \frac{\textbf{Maximum passenger flow}}{\textbf{Peak hour factor} * \textbf{Train capacity}} = \frac{P_{max}}{PHF * C_V} \text{ .... } \textit{Equation 1}$$

Where;

P_{max} = maximum cross-sectional passenger/hr flow

PHF = Peak hour factor

C_V = Vehicle Capacity (Seated and Standing passengers)

Peak hour factor

Peak hour factor (PHF) is also known as the load diversity factor. Passengers distribute themselves unevenly inside train cars. Uneven loading entails both irregular passenger loading within a train car or within the cars themselves. PHF accounts for uneven loading between trains during peak hour. Load diversity factor is hence used to adjust passenger volumes to a more practicable capacity. PHF varies depending on the nature of train service as seen in table 1 below.

Table 1 PHF for various rail services (TCRP, 1996)

TRAIN SERVICE	PHF
Rail Rapid Transit	0.8
Light Rail	0.75
Commuter Rail	0.6

PHF, in the case of light rail transit, varies from one train operator to another depending on passenger demand [28]. Table 2 below highlights typical variations of peak hour factor on various North American Light Rail services.

Table 2 Passenger loading factor on selected North America rail system (TCQSM, 2004)

CITY	PHF
Calgary	0.62
Denver	0.75
Philadelphia	0.75
Portland	0.8

In the case of AALRT, no particular PHF value exists. Load diversity factor of 0.9 can instead be used as recommended for developing cities such as Addis-Ababa.

Vehicle Capacity

The vehicle characteristics for the AALRT are 70% low floor articulated 6 axles modern trams with a vehicle operating speed of 70km/hr. Each unit of vehicle consists of three cars which are bi-directional driving [29]. Table 3 below shows the designed vehicle capacity for train operating on both AALRT's E-W and N-S line.

Table 3 AALRT vehicle capacity (CREC, 2012)

Status	**Seat**	**Standing Capacity**	**Total**
Seat (AW1)	65	0	65
Rated capacity (AW 2) (Standing Capacity 6 persons/ m2	65	189	254
Overcrowding Capacity (AW 3) (Standing Capacity 8 persons/ m2)	65	286	351

Crowding countermeasures, as per the literature review, revealed that a review of seating arrangement inside the rolling stock could increase passenger standing area thereby increase articulation of passengers inside trains as well as commuter carrying capacity.

TCQSM 2013, proposed a straight forward equation to vehicle capacity. In this study, the simplified form of this equation is used as shown in the equation below:

$$\boldsymbol{C_v = \frac{L_c W_c}{S_{sp}} + N\left(1 - \frac{S_a}{S_{sp}}\right)\left(\frac{L_c - D_n D_w - 2D_n S_b}{S_W}\right)} \text{ .... } \textit{Equation 2}$$

Where;

C_v = Vehicle capacity (Passenger)

L_c = Interior length (m)

W_c = Interior width (m)

S_{sp} = Space per standing passenger (m^2)

N = Seating arrangement

S_a = Area of single seat (m^2)

D_n = Number of double stream doors

D_w = Door Width (m)

S_b = Single setback allowance (m)

S_W = Seat pitch, depending on seating arrangement

The following procedure was applied in determining the vehicle capacity using the equation above;

a. Divide the interior area of each car into sections depending on seating arrangements.

b. Determine the interior dimension of the sections in vehicle car L_c and W_c

c. Determine the free wall lengths of the sections by deducting the sum of the door widths plus a setback allowance per double stream door from the interior length; also shown in the formulae below;

$$\boldsymbol{L_w = L_c - D_w * D_n - 2 * D_n * S_b} \text{ .... } \textit{Equation 3}$$

Where;

L_w = Free wall length (m) L_c = Interior wall length (m)

D_w = Door Width (m) D_n = Number of double stream doors

S_b = Single set back allowance (m) assuming two set back allowance at each door.

In articulated light rail vehicles, where seating is allowed in articulated sections, length of these sections should be included in the free wall length.

d. Set a seating arrangement in each section. Seat arrangement is described by;
N = 2 for longitudinal seating
N = 3 for 2 + 1 transverse seating
N = 4 for 2 + 2 transverse seating.
N = 5 for 2 + 3 transverse seating.

e. Seating can then be allocated to Free Wall Length by dividing with the seat pitch;

$$\textit{Allocated seating} = \frac{\boldsymbol{L_w}}{\boldsymbol{S_w}} \text{ .... } \textit{Equation 4}$$

Where

L_w = Free wall length (m) S_w = Seat pitch that depends on seating arrangement

f. Result of the allocated seating, in lowest whole numbers, should then be multiplied by seating arrangement and the result gives the total number of seats.

g. The floor space occupied by seats can then be calculated by multiplying the number of seats by area of single seat depending on seating arrangement.

h. The residual floor area can now be assigned to standing passengers. In light rail vehicles step wells areas and the opening space in the articulated sections may be used by standing passengers in peak hours.

i. The number of standing passengers can be calculated by dividing the available area with the space per standing passenger; (S_{sp}) determined, depending on the quality of the service and the number of passengers considered in one meter square.
j. The vehicle capacity is then the sum of seats and number of standing passengers.

c. Determine suitable headway to be provided for the given line capacity

The headway of the line is computed using the formulae outlined by TCQSM 2013 below.

$$\boldsymbol{Headway} = \frac{\boldsymbol{60(min)}}{\boldsymbol{N}} \text{ .... } \textit{Equation 5}$$

Where;

N = Line capacity for a given cross-sectional flow.

d. Determine station dwell time

TCQSM recommends average station dwell time of 40 seconds. However, existing evening rush hour AALRT's E-W line average dwell time was considered since it factored realistic station durations for train services during crowding conditions.

e. Calculate the train travel time.

Train travel time refers to the time required by a train to travel from station to station and includes the time to accelerate from departing station, deaccelerate to arrival station and travel time with allowable uniform speed in-between. In addition, deceleration and acceleration time to keep the allowable speed at turnouts and at-grade crossings.

Computations of train travel time require a model for the geometric design and elements of the infrastructure, efficiently performed using software or simulation tools, as it incorporates so many factors like the geometry of the line, (curve radius, gradients), station locations, locations of turnout and crossings and the performance of the train used [30]

For this study, simple analytic procedures are followed to calculate the travel time between station since the utilization of simulation tools are beyond the scope and budget of the research.

The summarized steps for calculating train travel time are as follows;

i. Calculate the critical distance between stations (S_c) using the maximum speed allowed V_{max} between stations using the formulae below developed by Vukan [31];

$$\boldsymbol{S_C} = \frac{\boldsymbol{V_{max}^2}}{\boldsymbol{2}}\left(\frac{\boldsymbol{1}}{\boldsymbol{a}} + \frac{\boldsymbol{1}}{\boldsymbol{d}}\right) \text{.... } \textit{Equation 6}$$

Where;

$S_C =$ Critical distance between stations $a =$ Train acceleration rate (m/s^2)

$V_{max} =$ Maximum speed attained by train $d =$ Train deceleration rate (m/s^2)

ii. Calculate travel time using the following cases suggested by Vukan:

a. If station to station distance $S < S_C$, travel time between stations is given by the equation below;

$$\boldsymbol{T_s} = \boldsymbol{t_a} + \boldsymbol{t_d} = \sqrt{\frac{\boldsymbol{2(a+d)S\prime}}{\boldsymbol{ad}}} \text{.... } \textit{Equation 7}$$

Where;

$$t_a = \frac{V'}{3.6a} \ and \ t_d = \frac{V'}{3.6d} \ while \ V' = 3.6 * \sqrt{\frac{2 * a * d * s'}{a * d}}$$

$t_a = time\ to\ accelarate\ to\ maximum\ speed$

$t_d = time\ for\ braking\ or\ deaccelaration$

$V' = maximum\ achievable\ speed\ between\ stations\ in\ km/hr$

b. If station to station distance $S > S_C$, and no at-grade crossing exists, travel time between stations, then;

$$\boldsymbol{T_s} = \frac{\boldsymbol{S}}{\boldsymbol{V_{max}}} + \frac{\boldsymbol{v_{max}}}{\boldsymbol{2}}\left(\frac{\boldsymbol{1}}{\boldsymbol{a}} + \frac{\boldsymbol{1}}{\boldsymbol{d}}\right) \text{.... } \textit{Equation 8}$$

c. If there are at-grade crossings, junction layouts between stations, then additional time is calculated as:

$$\boldsymbol{T_s} = \left[\frac{\boldsymbol{V_{max}}}{\boldsymbol{2}}\left(\frac{\boldsymbol{1}}{\boldsymbol{a}} + \frac{\boldsymbol{1}}{\boldsymbol{d}}\right) + \frac{\boldsymbol{S}}{\boldsymbol{V_{max}}}\right]\left(\frac{\boldsymbol{1}}{\boldsymbol{a}} + \frac{\boldsymbol{1}}{\boldsymbol{d}}\right)\left(\frac{\boldsymbol{V_{max}}}{\boldsymbol{2}} - \boldsymbol{V_2} + \frac{\boldsymbol{V_2^2}}{\boldsymbol{V_{max}}}\right) + \boldsymbol{S_2}\left(\frac{\boldsymbol{1}}{\boldsymbol{v_2}} + \frac{\boldsymbol{1}}{\boldsymbol{v_{max}}}\right) \text{.... } \textit{Equation 9}$$

iii. Calculate the time required by the train to clear out from the platform to the departing station (t_{p1})and to travel its' own length at arrival station (t_{p2}) using the following equations depicted in TCRP manual (1996) and TCQSM 2004 respectively.

$$\boldsymbol{t_{p1}} = \sqrt{\frac{\boldsymbol{2(L+D)}}{\boldsymbol{a(1-0.1G_0)}}}\ (\boldsymbol{sec}) \text{ .... } \textit{Equation 10(a)} \quad \text{and} \quad \boldsymbol{t_{p2}} = \frac{\boldsymbol{V_p}}{\boldsymbol{2d}}\ (\boldsymbol{sec}) \text{ .... } \textit{Equation 10(b)}$$

The values of parameters in the equation are taken from AALRT design and TCQSM manual

Where

L = Length of train

$a =$ Train acceleration rate (m/s^2)

G_0 = Gradient out of the departing station (%)

d = deaccelerating rate

V_p = approach speed to station platform

D = distance from front of stopped train to seconds of station (m)

iv. Calculate the total travel time (TT) between stations using the equation below outlined in TCQSM 2013:

$$\boldsymbol{TT = T_s + t_{p1} + t_{p2}} \text{ .... } \textit{Equation 11}$$

f. Obtain the train turn around and layover time at turn back.

Train turn-around and layover time refers to travel time at the ends of the line to account for the time required to change the direction of the train. Turnaround and layover time must be sufficient to change direction of the train and allow for drivers to change ends, inspect the train and check trains integrity and braking [32]. The maximum layover time at turn backs was calculated using the equation below as outlined in TCQSM 2013;

$$\boldsymbol{t_{lo}} = \sqrt{\frac{\boldsymbol{2(L_t+f_{sa}d_{ts})}}{\boldsymbol{a+d}}} + \sqrt{\frac{\boldsymbol{(L_t+f_{sa}d_{ts})}}{\boldsymbol{2a}}} + \boldsymbol{t_s} + \boldsymbol{L_t} * \boldsymbol{v} \text{ .... } \textit{Equation 12}$$

The values of parameters in the equation are taken from AALRT design and TCQSM manual;

Where

L_t = length of the longest train

a = Initial service acceleration rate

f_{sa} = Switch angle factor

d_{ts} = Track separation

d = Service deceleration rate t_s = Switch throw and lock times

v = Walking speed of the driver when moving from one end of the train to another

g. Calculate the round trip time.

Train round trip time is computed by adding the sum of the travel time between stations, the sum of the dwell time at each station and turn around and layover time at turn backs on the ends of the line [32]. Round trip time can be calculated using the following equation outlined in TCQSM 2013;

$$\boldsymbol{Total\ round\ trip\ time\ =\ \Sigma\, TT +\ \Sigma\, T_d + \Sigma\, t_{lo}} \text{ .... } \textit{Equation 13}$$

Where;

TT = Travel time between stations. t_{lo} = layover time at terminal stations.

T_d = Dwell time between stations.

h. Determine the total number of trains required for the peak period.

$$\boldsymbol{Total\ required\ number\ of\ trains = \frac{Total\ round\ trip\ time}{Headway}} \text{ .... } \textit{Equation 14}$$

"Service spare" trains are kept on standby by some railway companies, in-case a service train becomes defective or a disruption to the service leaves a gap in the headway that needs to be filled temporarily.

Though the TCQSM provides definitions and general guidelines, most agencies seem to set their own measures [8]. As a result, crowding measures vary greatly among cities, systems, and countries. Some of the measurements that are used include:

- Seating capacity and standing capacity.
- Passengers In Excess of Capacity (PIXC).
- Degree of Crowding (DOC).
- Percentage of standard class passengers standing.
- Load Factor (passenger per seat).
- Standing passenger area (space [m^2] per standing passenger).

The measurements listed above are discussed further below.

2.5.1.2 Seating capacity and Standing capacity

Seating capacity and standing capacity are among the variations that have been used to measure passenger density. One example of this variation is the crowding measure currently used by the London Underground, which calculates the percentage chance of being on a train with (i) all seats full; (ii) one person standing for every person sitting; and (iii) two persons standing for every person sitting [33]. According to Britain's department of transport, standing passengers are counted on the train at the busiest point on the route into the city centre during the AM peak and out of the city centre during the PM peak [34]. Standing capacity at peak hour is compared to the train's design standing capacity thus indicating existence of crowding. Zheng, L. and Hensher, D suggested that for short journeys (e.g., commuting services) standing allowance should be treated as an additional component of capacity when defining crowding measures, while for long journeys (e.g. regional services) only the number of seat should be used as the capacity [8].

2.5.1.3 Passengers in Excess of Capacity (PiXC)

PiXC is a crowding measure that applies to all London and United Kingdom South East operators' weekday train services arriving at a London terminus during the morning peak from 07:00 to 09:59, and those departing during the afternoon peak from 16:00 to 18:59 [35]. PiXC is derived from the proportion of passengers on trains in excess of the seating capacity for longer distance services, but also with an allowance for standing passengers on shorter journeys of less than 20 minutes. The acceptable PiXC limit is 4.5% for one peak (morning or afternoon) and 3.0% across both peaks [34].

The PiXC is given in percentages, calculated as the difference between the number of actual passengers and the capacity of the train divided by the actual passenger number. It is zero if the number of passengers is within the capacity. PiXC can be converted into a common measure for crowding, i.e., the number of standing passengers per square meter (standing passengers per m^2). For example, a PiXC of 40 percent is equivalent to five standing passengers per m^2 [6]. Benchmark for train crowding is 2.22 passengers per m^2 for most train operators in the UK. PiXC's strength is attributed to the fact that the method allows standing for journeys of up to 20 minutes as an additional component of capacity [35].

The adequacy and accuracy of PiXC, however, is relatively debatable for several reasons; for instance, it has been noted that PiXC is calculated across the whole of a train operating company's area rather than on particular routes, it is carried out only once a year, and more importantly, it is not a standard measure across all rail systems [12].

2.5.1.4 Degree of Crowding (DoC)

While PiXC measures the degree to which load factor standards are exceeded in practice, DOC relates passenger loading along various percentages of train capacity [36, 37]. The percentage may range from DOC 1 (25% of train capacity with some seats available) to DOC 5 (120% of train capacity where very crowded with passengers inside the car and passengers are forced to press against the windows and doors). Parameters based on the number of passengers per square meter and the amount of standing space available for each passenger are also used to evaluate degree of crowding since they may provide an alternative measurement of discomfort [33, 38]. Table 4 below shows various levels of degree of crowding as outlined by Wardman & Whelan [38]

Table 4 Degree of Crowding (Wardman & Whelan, 2010)

Degree of crowding in vehicle	**Description**	**Train Loading**
1	Some seats are available	25% of train capacity
2	All seats are occupied and some passengers stand	40% of train capacity
3	Crowded with passengers but some spare spaces in the inner part of the car	70% of train capacity
4	Crowded with passengers through-out the car	100% of train capacity
5	Very crowded with passengers inside the car and passengers are forced to press the windows and doors	120% of train capacity

2.5.1.5 Percentage of standard class passengers standing

It is similar to PiXC, with the difference being the use of the planned number of standard class seats as the capacity for a rail service which has no allowance for standing. The main weakness with the method is that capacity includes only for the number of seats and no allowance is provided for standing [8].

2.5.1.6 Load factor (passenger per seat)

Load Factor is calculated as the number of passengers divided by the number of seats. A load factor of 1.0 indicates that all seats are occupied. With regard to load factor, different benchmarks are defined according to the nature of the service—for example, 1.0 for long-distance commute trips and high-speed mixed-traffic operations, 2.0 for inner-city rail service, and in between for other services [24]. Thresholds for the LoS with respect to in-transit crowding, outlined in the TCQSM, are shown in Table 5 below.

Table 5 LoS crowding thresholds (TCQSM, 2013)

LOS	Load Factor	Standing Passenger Area		Comments
	(Passenger/seat)	(sq ft/passenger)	(sq m/passenger)	
A	0.0 - 0.50	> 10.80^	> 1.0^	No passenger need sit next to another
B	0.51 - 0.75	8.2 - 10.8^	0.76 - 1.0^	Passengers can choose where to seat
C	0.76 - 1.0	5.5 - 8.1^	0.51 - 0.75^	All passengers can sit
D	1.01 - 1.25	3.9 - 5.4	0.36 - 0.50	Comfortable standee load
E	1.26 - 1.50	2.2 - 3.8	0.2 - 0.35	Maximum schedule load
F	> 1.50	< 2.2	< 0.20	Crush load

At LoS levels A, B, and C (>0.51 m²per standing passenger), all passengers can sit, while some passengers need to stand at LoS D. LoS E is the defined crowding threshold, i.e., 0.20–0.35 m² per standing passenger, which is equivalent to 2.86–5 standing passengers per m². LoS F (>5 standing passengers per m²) represents crush loading levels.

2.5.1.7 Standing passenger area (space [m²] per standing passenger)

It is used in the USA and can be easily converted into the number of standing passengers per square meter (standing passengers per m²) as shown in Table 5 above. As an example, for the crowding level of maximum schedule load (which is the defined crowding threshold), the load factor range is 1.26–1.50 while the corresponding measure of standing passenger area is 0.20–0.35 square meter per standing passenger (or 2.86–5 standing passengers per m²) [8].

2.5.1.8 Station crowding

Station crowding can similarly be analyzed using quantitative methods. In the case of LRT platforms, the average passenger occupancy is first obtained by the following equation;

$$\textbf{Average passenger Occupancy} = \frac{\textbf{Total number of waiting passengers at the platform}}{\textbf{Platform area}} \quad \text{. Equation 15}$$

TCQSM recommends the use of platform crowding LoS scale developed by Fruin [39] seen in the table below.

Table 6 LoS in LRT platforms (Fruin, 1987)

Level of service on platform	Description	Train Loading
A	Large spaces are available, free standing and slightly restricted circulation	> 1.20 sq m/ped
B	Passengers stand randomly on the platform and restricted circulation by disturbing others	1.20 - 0.93 sq m/ped
C	Crowded with passengers, severely restricting circulation but standing without personal contact	0.93 - 0.28 sq m/ped
D	Crowded with passengers through-out the platform, personal contact unavoidable	0.65 - 0.28 sq m/ped
E	Very crowded with passengers, personal space equivalent to the approximate area of the body ellipse	< 0.28 sq m/ped

2.5.2 Qualitative measures

2.5.2.1 Introduction

Cox et al. argued that while the objective definitions of rail crowding based solely on spatial factors may seem to serve the purposes of rail authorities and train operating companies, these definitions remained inconclusive particularly when examining individual, subjective perceptions of crowdedness [40].

Objective treatment of crowding (equivalent to density) cannot fully represent the experience of crowding, given that the perception of crowding is subjective [9, 41]. Public transport operators/authorities should conduct perception surveys to obtain information on passenger’s subjective evaluations of crowding, in addition to the objective measures (e.g., density). Through surveys on perceived crowding, transport authorities/operators can obtain the real experiences of passengers, which can be used to design more appealing measures to capture crowding. Incorporating subjective measures of crowding can contribute to (a.) more accurate representation of crowding; which would help operators manage and reduce crowding in time by implementing strategies such as increasing the frequency of service and using larger vehicles, and (b.) a better understanding of crowding; beneficial to the design of more appealing public transport systems to attract more users [8].

2.5.2.2 Qualitative Survey Instrument

Mohd, M., and N, Diana developed an instrument capable of capturing the subjective components of crowding among rail passengers. This survey instrument has three different scales, namely (a.) evaluation of the psychosocial aspects of the crowded situation — "How crowded is the train that you are on today?"; (b.) affective reactions to the crowded situation —"How do you feel inside the train that you commute on today"?; and (c.) evaluation of the ambient environment of the crowded situation —"The physical environment inside the train that you commute on today," [8].

Each of the three scales has its subscale. The first subscale evaluates the psychosocial aspect of the crowded situation as "dense", "disorderly", "confining", "chaotic", "cluttered", "disturbing", and "unpleasant". Items strongly associated with the behavioural constraint, interference, and stress levels that serve as indicators of the effective reactions of the crowded situation component are contained in subscale 2. Subscale 3 comprises of items that describe the physical-environmental dimension of the setting and relate to noise, heat, ventilation, and air quality [8].

Adequacy and validity of the instrument was tested on 525 rail commuters in Kuala Lumpar using rigorous statistical analysis. Result obtained from the statistical analysis showed that the instrument developed in Mohd et al is capable of measuring reliably and validly different psychological components that construct the experience of crowding [41]. Mohd's instrument is thus used on the AALRT as a measure of subjective components of passenger crowding.

2.6 Past countermeasures to crowding

Crowding experiences in the 1990's within the UK led to the invention of several measures that have helped alleviate rail passenger crowding. Mohd et al have categorized the measures into four broad categories [41] that include;

2.6.1 Psychological measures.

In a study investigating crowding effects at the mass transit railway stations in Hong Kong, Lam, Cheung, and Lam found that passengers are willing to travel with an additional travel penalty such as experiencing body contact with other passengers when the in-vehicle travel times are 10 to 20 minutes [42]. Passengers cope with crowding by making sacrifices that they would not usually consider – as in this case, losing personal space and a longer waiting time [8].

In a report that investigates passengers' experiences of crowding and line closures on the London Underground, the London Assembly Transport report noted that along with using behavioural coping strategies, cognitive and physiological mental coping strategies are also used to cope with crowding. These strategies include psyching oneself up for the "struggle to clamber on board", changing one's reaction to the journey by ceasing to worry about it, engaging in positive affirmations to replace negative thoughts about the journey, thinking positively and making the most of the commuting situation, and meditating or praying, to relax [6].

2.6.2 Non – engineering interventions

Non-engineering intervention strategies focusing on psychological, social, and organisational factors are also potentially feasible for reducing rail passenger crowding [15]. Some examples of non-engineering interventions previously suggested include re-shaping passengers' expectations of rail travel by educating them to better plan for and cope with their journeys, and improving the quality of the overall social and ambient physical environment of the transportation infrastructure [43]. Additional suggestions also included providing service modifications in terms of the information delivery system for waiting passengers about the levels of crowding on trains and at platforms as well as information about potential alternative routes or modes of transport. Staff training in crowd management and crowd control, which may include but not limited to trainings on the basics of normal and emergency crowd movement and assembly, incident handling, and communications procedures, are also highly recommended [44].

2.6.3 Policy measures

The third category of rail crowding mitigation concerns policy measures. These measures, which were proposed in three studies, involve policies such as the setting of a new rolling stock strategy [19], increasing the modal shift from rail to other forms of transport [44] and developing a standard procedure for documenting and investigating incidents of crowding-related events and risks as well as implementing good practice approaches in crowd management and crowd control on the railways [9]. While policy measures are important elements of any crowding reduction strategy, they often require strong political will for their implementation. Furthermore, many policy reforms need a set of long-term strategic frameworks for changing the regulatory, institutional, operational, and physical structures in the overall rail industry [8].

2.6.4 Engineering interventions

Wener & Evans and Wener et al. [45, 46] suggested that introduction of a direct service to particular destinations would significantly reduce the trip time. Two studies by London Assembly Transport committee also suggested that crowding can be alleviated by interventions such as reviewing the balance of seats and standing space coupled with provision of first-class coaches, improving timetabling and passenger information, introducing new rail lines, improving train design, providing better information about crowding levels on trains and alternative options for passengers who want to avoid it, and implementing better management of line upgrades [6, 44]. Traveler tolerance of crowding can be improved through better design or better services [8]. Evans and Wener recommended that public transport designers should provide pairs of proximate seats, rather than three across seating; meanwhile, larger carriages or vehicles should be used to help compensate for the loss of seat space [11]. Cox et al. suggested that design innovations should focus on passenger control over elements such as space, choice of seat, point of entry and exit, and others that enhance their perceptions of safety and security [40]. In addition to the design of the carriage, Thompson et al. suggested a number of ways that may relieve or improve the tolerance of crowding. Suggested ways included provision of better service, such as improving air quality and air circulation, establishing optimum frequency of trains, improving quality of communication, and improving cleanliness (especially of handholds and floors) [47].

Additionally, engineering interventions involving additional rolling stock, infrastructure upgrades, network expansion, the introduction of new or alternative transportation modes, simplified fares and ticketing structure and, reliability and service frequency improvements are needed to relieve current train crowding issues as well as to allow for future rail expansion [5, 19, 33]. Therefore, efforts to alleviate crowding and improve passenger comfort and safety, should be geared towards promoting efficient seating systems, accessible train and station designs, adaptive and reliable scheduling systems, and effective coordination of modes in addition to increasing the amount of rolling stock and the overall capacity of the network [15].

2.7 Conclusions

The following are conclusions drawn from the literature review above:

i. Crowding is a critical issue in rail passenger transport with the potential to affect the economy, tourism, health and safety aspects of the human life. Tackling rail passenger crowding is thus an important endeavor in improving individual's and society's well-being.

ii. Public transport operators/authorities should conduct perception surveys to obtain information on passenger subjective evaluations of crowding, in addition to the objective measures. Subjective measures provide a more accurate representation and a better understanding of crowding, beneficial to the design of more appealing public transport systems to attract more users. It is therefore imperative that this research reviews both objective and subjective crowding measures on AALRT.

iii. Various measures exist, despite their strengths and weaknesses, to measure quantitatively passenger crowding. The load factor method, supported by table 2, is used to measure crowding objectively in this research. Not only does the method quantify standing passengers who readily indicate congestion on the train, but also quantifies crowding amongst seated passengers; an accurate measure of AALRT's on-train crowding where initial observations on E-W lines depicted that during the PM peak, passengers share seats. Use of the load factor method thus captures crowding on train seats further revealing magnitude of passengers' discomfort.

iv. Subjective crowding measures are difficult to examine. However, by using the tested survey instrument developed by Mohd, M., and N, Diana in this research, it is possible to capture qualitative light rail passenger components in quantitative terms.

v. Successful crowd mitigation involves an integration of psychological, policy, non-engineering and engineering measures. Crowding countermeasures suggested for the AALRT thus include and comprehensively integrate all the four categories.

CHAPTER 3 RESEARCH METHODOLOGY

3.1. Study area

The AALRT is a 34.1 km light rail system comprised of N-S line from Kality to Menelik II and E-W line from Ayat to Torhiloch. The study area was limited to a 16.998 km stretch on the E-W line with 22 stations. Daily operations occur between 6 am to 10 pm with two peak periods; the morning peak (7 am – 10 am) and the evening peak (4 pm – 7 pm). Figure 2 below shows the as-built layout of the AALRT.

Figure 2 As-built AALRT layout (Ethiopian Railway Corporation, 2018)

3.2. Research approach

This research followed a deductive approach where researchers find out the cause of something based on the evidence or information gathered. The reason for this choice is because crowding on AALRT could be best analyzed by studying how it occurred during the evening rush hour so as to find solutions to solving the crowding phenomenon. Therefore, study emphasis was placed in obtaining the causes of crowding on AALRT through analysis of train operations over this rush hour period to determine the gaps that existed which contributed to the crowding situation. Gaps identified thus pointed out to the proper countermeasures needed to curb future crowding, particularly in the future short-term operations of AALRT.

3.3 Research design

The purpose of this research is to investigate crowding on AALRT. In order to achieve this aim, both descriptive and quantitative research methods are employed. Descriptive research is concerned with describing the particular characteristics of a particular individual or group. In this study, visual observations have been undertaken to observe the nature of crowding condition on the AALRT thus describing its nature of occurrence. Opinions of commuters on crowding conditions were also collected to describe their feelings concerning the ridership quality on AALRT trains over the evening rush hour.

Quantitative research methods were used to determine factual assessment of crowding on AALRT. Analytical analysis was deployed to assess quantitative aspects of the crowding situation such as its degree of occurrence on both station platforms and inside trains, the economic loss attributed to crowding as well as the degree of passenger ridership quality on the AALRT E-W line over evening rush hour. The flow chart below shows the research design used for this study;

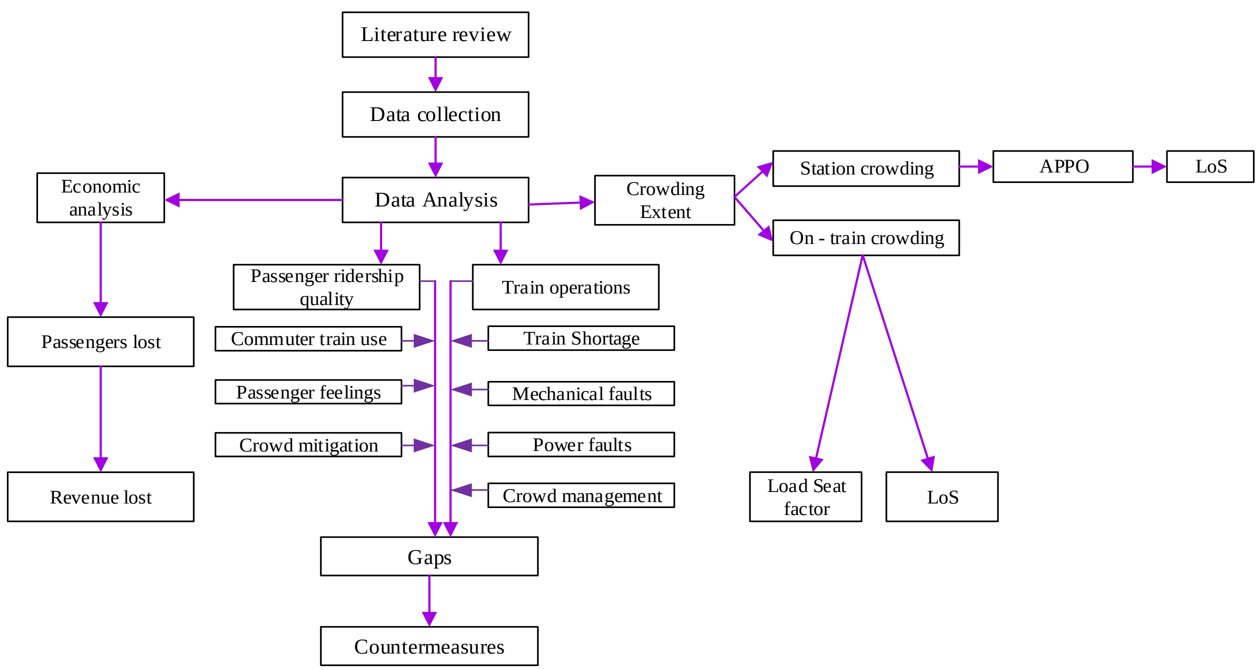

Figure 3 Research design flow chart

3.4 Sources of data and research instrument

Both primary and secondary data sources were adopted for this research. Primary data sources used included raw data collected on actual train operations, (train's arrival and departure time at platforms and train numbers), passenger tally, observations on crowd management measures and train operational behaviour, and passenger's opinion on crowding. Two questionnaires and manual passenger counts were adopted as a tool for collecting primary data. The first questionnaire was designed to collect data on commuter train use over the evening rush hour as well their feelings on ridership quality experience. Three main issues were tackled by the questionnaire; initial section (question 1-6) tackled the first issue aimed at gathering commuter's use of the train service and perceived levels of on-train crowding. Questions in this section covered issues such as duration of rail service use, frequency of commute, waiting time per train, typical seating availability, frequency of train delays on working commuters and quantifying on-train crowding levels. The second section (question 7-9) addressed passenger's feelings, which also formed the second main issue. Questions under this section focused on passenger's travel experience in terms of personal space, physical environment inside the train as well as passenger psychological feelings concerning the crowding level experienced. The questionnaire inquired of ways to mitigate crowding as the third issue. An open-ended question (question 10) sought passengers' feedback on what they felt was the best way to curb train crowding. Passenger questionnaire used in this study is attached in Appendix A.

The second questionnaire was formulated to collect data on train operations from the AALRT operator. Manual passenger counts, conducted through assistance by experienced AALRT enumerators, was conducted to obtain data used to assess crowding levels at both station and inside trains. Train operator questionnaire used in this study is attached in Appendix B.

Secondary sources used in this research included research journals, books and official documents from the AALRT operator. Extensive literature review was conducted to comprehend the research objectives clearly. Review of previous articles facilitated understanding on how crowding on LRT would be factually assessed and how previous countermeasures used in other LRT networks were integrated to solve the crowding situation.

3.5 Research population and sample size

3.5.1 Data sampling method

Daily evening peak AALRT's E-W line passengers formed the study population for this research. Simple random sampling method was used to select questionnaire respondents since all commuters travelling on any given train had an equal chance of experiencing crowding.

Train stations where manual passenger counts occurred were selected through purposeful sampling. The criteria used to the selecting stations was where most passengers alighted from determined through a prior preliminary survey. On-train crowding assessment required a survey of trains operating during the evening rush hour. A maximum of six trains passed each station within an hour, thus all trains were included in the survey in-order to capture maximum commuter flow data.

3.5.2 Sampling size

The commuter sample size for the questionnaire was obtained using the formula:

$$n = \frac{X^2 * N * P * (1 - P)}{((N - 1) * \ ME^2) + (P * X^2 * (1 - P)} \ldots . Equation\ 16$$

Where

n = Sample Size

P = Population proportion (0.5)

$X^2 = Chi$-Square at 95% confidence level (3.841)

ME = Margin of Error (0.05)

N = Population Size (350,000 passengers/week on the E-W line)

The sample size for questionnaire survey calculated from the above formula is 384 passengers.

3.5.3 Data collection procedure

Manual passenger count at Torhiloch's platform was carried out with the help of 2 enumerators. Passenger counts were collected at an interval of two minutes to accurately capture commuter arrival rate and crowding at the platform. Data collected was entered into the platform survey data sheet attached in Appendix C. Similarly, on-train crowding commuter counts were conducted by a team of 7to 13 experienced enumerators deployed on the two respective AALRT routes. Data collection involved the physical counting and recording of alighting passengers from trains at the selected stations. Data was filled on passenger survey sheets, similar to the one included in Appendix A. Passenger questionnaires were distributed on station platforms and inside the train over the evening rush hour by 3 enumerators. In all the survey exercises, experienced enumerators were sourced from the AALRT operator staff and positioned at station exits to ensure accurate commuter count. Furthermore, prior to both surveys, enumerators were adequately briefed to ensure complete understanding of the survey and its procedures.

3.6 Research analysis

In order to efficiently use the line capacity of a transit system, there is need to balance the passenger demand with sufficient rolling stock. Analytical analysis of the required number of trains used equations provided in the TCQSM 2013. The procedure set out in this manual for calculating the required number of trains was used because;

i. Though the TCQSM manual was developed for the North American condition that is different from the Ethiopian one, the analytical equations are developed using basic distance, time, and speed equations used in the general law of motion. Therefore, the analytical equations can be directly applied in Ethiopia in the case of AALRT. Where specific analytical equations lack, other alternative proposed equations from previous studies can be used. Input parameters of the equations could be taken from actual AALRT design.
ii. Most of the analysis involves computation easily carried out by Microsoft Excel sheet without applying simulation tools.
iii. TCQSM provides default values where such lack on the AALRT design thus facilitating accurate calculations.

To analyze the extent of crowding on passenger platforms, a suitable and representative station experiencing critical crowding was selected and surveys conducted on the operational characteristics. The platform surface area was obtained from the AALRT design manual thus the calculation of average pedestrian occupancy and later platform LoS obtained. Presence of crowding is identified by LoS D. Platform crowding over a two minutes period was plotted accordingly to observe the nature and magnitude of crowding on the selected platform.

On-train crowding inside train was determined by analytically computing both the seat load factor as well the standing area per passenger thus determining the existing on-train crowding LoS. Presence of crowding is identified by LoS E; defined as the crowding threshold while LoS F indicates a crush loading level.

Direct economic loss assessment was through analytical analysis whereby the number of passengers lost were determined through obtaining the difference of the designed estimated actual passenger flow in the evening rush hour. Passengers lost in the context of this research refer to un-serviced commuters expected to use the AALRT, but could not due to crowding conditions. Revenue that would have been generated as well as the change in operational costs to service the lost passengers was then calculated, whereby the difference of the two yielded the direct economic loss.

Train supply and passenger management were evaluated to determine the efficiency levels of operations on the E-W line. Train supply operations, in the context of this research, implies provision of adequate and timely train service over the evening rush hour. Parameters used to measure train supply efficiency included availability of adequate number of train sets, frequency of faults affecting train supply during operations, and train delays. Passenger management, in the context of this research, refers to orderly commuter movement on station platforms and during train boarding whose inefficiency would cause unnecessary station crowding. Efficiency of passenger management was assessed through observing the nature and occurrence of passenger boarding activity at platforms and articulation of commuters inside trains.

This study attempted to fully assess the feelings passenger ridership quality in great depths. In designing the research questionnaire, most questions were adopted from Mohd Mahudin et al. (2012) [15] who developed, tested and validated an instrument for measuring subjective components on crowded light rail networks such as the quality of passenger ridership. The developed instrument utilized questionnaires which this research partially adapted. Partial adaptation of the questionnaires was inevitable since part of Mohd's study focused on spillover effects of crowding on individual well-being and organisational behaviour, an aspect outside the scope of this study.

Analytical analysis of questionnaire responses and plot of results obtained was carried out using MS Excel software. Statistics (SPSS -23) was used to co-relate key relationships of on-train crowding levels to passenger's feeling using the cross-tab feature. The following steps were followed to obtain required results;

a. Define the variable name – achieved through labelling each question as the variable.
b. Define the variable value – the possible questionnaire response choices to the variables were assigned a specific value that would denote the exact answer provided by the commuter.
c. Define the variable measure – defined as nominal since the desired feedback was in form of a Yes or No response by the passengers.
d. Input each questionnaire's response on SPSS data view.
e. Relate key on-train crowding responses to the physical environment or passenger feelings using the cross-tab feature.
f. Obtain the percentage proportion degree of responses for normal, very and extreme conditions to each of the correlated situations to reveal the magnitude of relationship among variables.
g. Discuss the relationships between various variables as per the observations noted over the evening rush hour period.

CHAPTER 4 RESULTS AND DISCUSSIONS

4.1 Determining extent of crowding

4.1.1 Passenger platform crowding

Secondary data on daily passenger flow revealed that Torhiloch station ranked top at the end of 2018 with a daily passenger flow of 957156 passengers between October and December.

Torhiloch station platform size was 60m by 2.5m according to the CREC 2012, AALRT schematic design report [48] However, since passengers stand away from the yellow safety line, the available platform width for standing was actually 1.9m. Platform standing area was hence calculated to be 114 m^2. AALRT's platform occupancy design for Torhiloch platform was $0.5m^2$ per standing passenger [49]. Manual passenger counts was undertaken from Monday to Friday. Timkat celebrations held on Friday implied data collected on that particular day, accounted for special days. Results of the station passenger survey carried out are attached in Appendix D.

Visual observation conducted at Torhiloch platform indicated the presence of two main operational problems; train mix and poor headway maintenance.

Train-mix challenge –Several unit trains dropped off passengers upon arriving at Torhiloch and started the return journey without serving a single commuter. Other unit trains carried a portion of already queuing passengers while leaving the rest to wait for successive trains. Increased passenger waiting time was thus observed to occur on the platform due to this train operational behaviour. Table 7 below summarizes case examples of this behaviour.

Table 7 Train mix challenge case scenarios (Author, 2019)

Day	Train No.	Station Arr. – Dept. Time	Unserved commuters	Passengers left after partial carrying of commuters	Increased waiting time (min)
Tuesday	109	16:23 - 16:25	213		19
	102	16:55 - 16:59		47	2
	106/121	18:02 -18:06		48	12
Wednesday	111	17:19 - 17:20	249		15
	119/120	17:22 - 17:26		62	7
	109	17:47 - 17:50		69	8
	101	18:08 - 18:13		83	6

Headway maintenance challenge – Passenger waiting times were reduced whenever trains arrived with shorter headway. A case example can be seen in Appendix D where on Wednesday between 18:14 – 18:26 pm, a commuter waiting time of 18 minutes was followed by train no. 102 and 114/118 with a 2 minute interval, resulting to the latter train waiting on the track while the former train serviced alighting and boarding passengers. Maintaining consistent train headways was hence a challenge during the evening rush hour. In-order to observe the influence of train arrival time on the length of passenger waiting time, train headways were computed to represent passenger waiting durations. Table 8 below shows the computed average at Torhiloch station.

Table 8 Average headways at evening peak on Torhiloch platform (Author, 2019)

	Average Headway			
No	Day	Total Headway (min)	No. of Trains	Average Headway (min)
1	Monday	104	13	8
2	Tuesday	108	13	8.3
3	Wednesday	109	14	7.8
4	Thursday	108	12	9
5	Friday	94	13	7.2
	Weekly Total and Average	523	65	8.1

The surveyed average weekly train headway of 8 minutes and 6 seconds was above the design target of 6 minutes according to CREC 2012 design [48] for the end of 2018.

Plotted results of the surveyed daily headway variation between successive trains are attached in Appendix E. Train headways were highly erratic; varying from a low of 2 minutes to a high of 20 minutes further proving that maintaining constant train headways was a challenge on the E-W line during the evening peak hour.

Maintaining constant and appropriate train headways is key to successful crowd mitigation over evening peak. Observed headways frequently extended above the design headway of 6 minutes thus impacting passenger travel time through lengthy waiting times at station platform. Similarly, crush loading occurred inside trains upon arrival of the next train after a lengthy waiting time.

Torhiloch's platform LoS

The average pedestrian occupancy was calculated using equation 15 above. Torhiloch station platform area was then divided by the result obtained to determine the corresponding passenger numbers for the various LoS as shown in Table 9 below.

Table 9 Corresponding passenger numbers for various LoS (Author, 2019)

LOS	Area in m^2/Pass.	Corresponding No. of Pass.	Corresponding range of Pass.
LOS A	> 1.2	95	1-95
LOS B	1.2 - 0.93	123	96-123
LOS C	0.93 - 0.65	175	124-175
LOS D	0.65 - 0.28	407	176-407
LOS E	< 0.28	408	Above 408

Table 10 summarizes the results of the evaluation of the daily occurrence of various LoS on Torhiloch platform.

Table 10 Frequency of LoS occurrence at Torhiloch platform (Author, 2019)

DAY	LOS ANALYSIS									
	A	%	B	%	C	%	D	%	E	%
MONDAY	2	13.3	1	6.7	5	33.3	7	46.7	0	0.0
TUESDAY	2	14.3	2	14.3	5	35.7	5	35.7	0	0.0
WEDNESDAY	1	6.7	2	13.3	3	20.0	8	53.3	1	6.7
THURSDAY	1	7.1	0	0.0	4	28.6	9	64.3	0	0.0
FRIDAY	8	57.1	1	7.1	5	35.7	0	0.0	0	0.0

Crowding was observed to be severe on Thursday with 64.3% of total rush hour time experiencing crowding LoS D. Tuesday experienced the minimal crowding with crowding LoS D accounting for 35.7% of total rush hour time.

Friday was a special day as previously mentioned thus crowding occurring on that day was different from that encountered on typical working days. Table 11 below summarizes the frequency of occurrence of different LoS levels occurring at Torhiloch platform on typical working days over the evening peak period.

Table 11 LoS frequency of occurrence (%) at Torhiloch platform (Author, 2019)

MON-THUR	% Frequency of LoS Occurrence
LOS A	19.44
LOS B	8.33
LOS C	30.56
LOS D	40.28
LOS E	1.39
Total	**100.0**

Torhiloch station frequently experienced LoS D crowding during PM peak during a typical working week.

Evening Peak hour passenger flow occurrence

Passenger flow at Torhiloch station was highest between 5 – 6 pm, thus the peak hour. Figures 3 and 4 below show the time distribution of platform crowding over a 2-minute period over the peak hour.

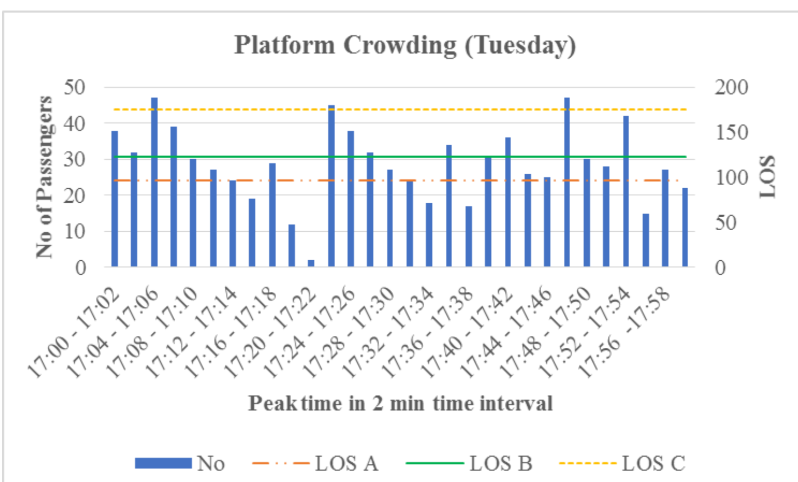

Figure 4 Greatest platform crowding levels (Author, 2019)

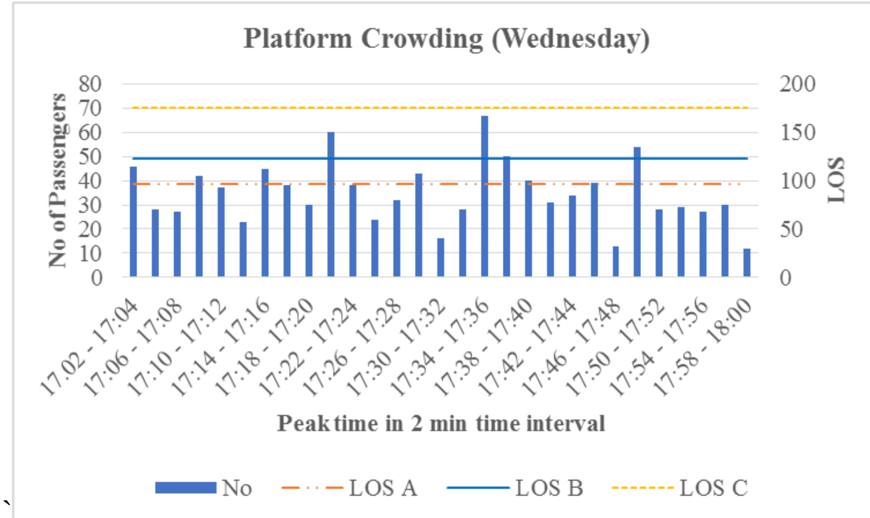

Figure 5 Least platform crowding levels (Author, 2019)

Torhiloch's least platform crowding LoS over a 2 – minute interval period occurred on Wednesday between LoS B and C while the greatest crowding level occurred on Tuesday, beyond LoS C.

From the data analysis and findings carried out in section 4.1 above, the following observations were made:

Torhiloch's station platform crowding excessively occurred between 5 – 6 pm; the time when majority of Addis Ababa's working-class commuters left work places. LoS D crowding was most common at 42.28%. The designed platform crowding level was 0.5m^2/standing passenger thus within the LoS C range according to table 6 above. Crowding condition of LoS D and E at Torhiloch platform was clear evidence that crowding was occurring at the platform. Urgent measures to mitigate crowding on AALRT E-W line at the end of initial operational term were needed before worse crowding levels could occur over the short- and long-term operational periods.

"Train rescheduling" practice along the E-W line occurred because unit trains could not accommodate all the waiting passengers at once. This practice was the result of using a mix of both unit and coupled trains throughout the evening peak hour as seen on table 7 above. "Train re-scheduling" operations further resulted to unsatisfactory service provision to commuters. Unsatisfactory train service was characterized by passengers being left to wait further on platform without being serviced by unit trains arriving at the station. Moreover, upon boarding the unit train at evening rush hour, it would only take several passengers boarding at three – four successive stations to have the train crowded. Commuters were observed to squeeze inside the train thus experiencing more tedious journeys. Platform crowding occurred as a result of such operations that were further coupled by failure to maintain constant headways. Long passenger waiting times and occasional train queuing on the track thus occurred. Evening rush hour train operations necessitated use of coupled trains that doubled available passenger standing area compared to that offered on unit trains. Increased passenger standing area meant more passengers would be carried by coupled train at an instant thus reducing significantly the magnitude and frequency of platform crowding.

Only 51% of trains surveyed attained the design headway of 6 minutes at the end of initial term operations. A wide gap thus existed in train operations management. Future headways need to be reduced from the average duration of 8.1 minutes to at least 6 minutes. Reduced headways implied that trains would arrive much faster at stations to service waiting commuters, eventually reducing platform crowding levels.

Fluctuations in headway predominantly caused occurrence of platform crowding LoS D and E, especially when trains delayed above 15 minutes between 5 to 6 pm. LoS C platform crowding occurring within 2 minutes of passenger waiting time between 5 to 6 pm revealed that over 124 passengers could arrive at the station within the short time at the end of 2018. Maintenance of consistent train headways, within the recommended value during evening rush hour train operations, would imply shorter and pre-determined passenger waiting times at platforms. Crowding at platforms would thus be eliminated in the long run.

4.1.2 Train wagon crowding

Train loading factor and on – train crowding LoS

Purposeful survey was conducted to determine the most loaded train points as well as stations that most passengers alighted from. The table below summarizes the findings from the survey.

Table 12 Purposeful survey result for AALRT stations during evening peak (Author, 2019)

RESULTS FROM PLERIMINARY SURVEY ON AALRT E-W LINE			
No	Route	Crowded point	Stations with significant alighting passengers
1	Torhiloch - Ayat	Bambis - Gurd Shola 1	Gurd Shola 1, Megenaga, Civil Service College, Management Institute, St. Michael, Meri and Ayat
2	Ayat - Torhiloch	Civil Service - St. Lideta	St. Lideta, Coca-Cola, Torhiloch

Manual passenger count results for on-train commuters on both Ayat – Torhiloch and Torhiloch - - Ayat routes are attached in Appendix F.

4.1.2.1 LoS analysis

Frequency of occurrence of the various crowding LoS in appendix F was analyzed and summarized in table 13 below.

Table 13 Frequency of daily occurrence of on-train LoS on E-W Line (Author, 2019)

ROUTE	**DAY**	``					
AYAT – TORHILOCH	MON	LoS	B	C	D	E	F
		%	0	7.69	15.38	38.46	38.46
AYAT – TORHILOCH	TUE	LoS	B	C	D	E	F
		%	7.14	0.00	7.14	28.57	57.14
TORHILOCH – AYAT	WED	LoS	B	C	D	E	F
		%	0.00	0.00	7.14	7.14	85.71
TORHILOCH – AYAT	THUR	LoS	B	C	D	E	F
		%	0	0	0	13.33	86.67

4.1.2.2 Crowding Analysis

Fruin stated that on-train crowding is indicated by LoS E and F [39]. The table 14 below gives the average percentage frequency of LoS E and F occurring on AALRT's E-W route.

Table 14 Frequency of weekly occurrence for on-train crowding LoS (Author, 2019)

AVERAGE OCCURRENCE FOR CROWDING LoS ON EACH OF E-W ROUTE			
ROUTE	DAY	``% OCCURRENCE OF CROWDING	
AYAT – TORHILOCH	MON	LoS	E & F
		%	76.92
AYAT - TORHILOCH	TUE	LoS	E & F
		%	85.71
AVERAGE FOR AYAT – TORHILOCH		%	81.32
TORHILOCH - AYAT	WED	LoS	E & F
		%	92.85
TORHILOCH - AYAT	THUR	LoS	E & F
		%	100
AVERAGE FOR TORHILOCH - AYAT		%	96.43

Significant variation of crowding LoS occurred over the evening rush hour. For example, Tuesday LoS levels varied between LoS B, D, E and F indicating a great imbalance in passenger numbers inside successive trains.

Over 75 % percent of trains operating on either E-W line routes during evening rush were crowded according to results on table 14 above. Crush loading indicated by crowding LoS F frequently occurred on the Torhiloch - Ayat route at the end of 2018. Immediate measures to tackle crowding conditions during the evening peak were further confirmed to be a necessity.

Torhiloch – Ayat route was more crowded than the Ayat – Torhiloch route as trains on the former route experienced an average of 86.19% crush load. The later route was less crush loaded at an average of 47.8%. The most common passenger flow direction during the evening rush hour period was the Torhiloch – Ayat route; a finding that further supports the selection of Torhiloch station's platform as the most crowded during PM peak hour.

On-train crowding lead to passengers sharing seats inside the train during evening rush hour hence resulting to seat load factor of 1.42 in 42 out of the 56 trains surveyed (75%). Commuters on the evening peak trains were hence likely to experience very uncomfortable trips.

From the results stated above, the following discussions were made;

AALRT's E-W line on-train crowding survey within the evening peak hour revealed that most common passenger flow direction was Torhiloch – Ayat. The finding was supported by the fact that Torhiloch and Ayat areas are Addis Ababa's industrial and residential areas respectively. Addis Ababa city's spatial arrangement contributed significantly to the observed commuter travel pattern on the E-W line during evening peak. On-train crowding LoS F (crush loading) significantly occurred between 5:00 – 6:00 pm, immediately after Addis Ababa working class commuters left work on the Torhiloch – Ayat route than on the Ayat – Torhiloch route. Future crowd mitigation strategies would thus necessitate planning train timetables in such a manner that more service trains were available on the Torhiloch – Ayat route between 5 – 6 pm than on Ayat – Torhiloch route.

Sharing of seating space among passengers due to insufficient commuter standing space was observed to be a common phenomenon where at least 75 % of all trains on either route had a load seat factor of 1.42. Commuters lucky enough to sit during evening peak on either of the E-W routes indeed experienced very uncomfortable trips. Increasing passenger standing area inside trains could be achieved through use of coupled trains particularly on the Torhiloch – Ayat route between 5 – 6 pm as opposed to the use of unit trains. Furthermore, review of rolling stock seating arrangement, aimed at increasing passenger standing area for future purchased trains, would further mitigate crowding levels inside the train.

Variation in LoS, form one train to another, indicated a highly unbalanced on-train crowding distribution; a behaviour likely to be caused by inconsistent train headways. Passengers were subjected to longer waiting times at platforms followed by a quick arrival of successive trains. Commuters lacking information on subsequent train arrival times, squeezed into the trains on site while latter trains that arrived shortly after ferried fewer passenger. Mitigating crowding inside trains thus required bridging the identified train arrival information gap thus encouraging passengers to spare few minutes to wait for oncoming less crowded trains. Use of station passenger information system (P.I.S) is highly recommended over the short operational term.

4.2 Operation efficiency in relation to capacity

4.2.1 Required number of trains

4.2.1.1 Estimation of current maximum cross-sectional flow.

Analytical calculations to determine the required number of train sets required determination of current maximum passenger flow numbers, obtained as discussed below;

Secondary data on passenger flow numbers for a typical working week at the initial term revealed that the actual daily average passenger flow for the period of October – December 2018 was 66,640 passengers/ working day.

CREC's 2012 AALRT design report stated the maximum cross-sectional flow during evening peak hour was 2223 passengers/hr for the initial operating period (end of 2018), as observed in table 15 below.

Table 15 AALRT's E-W Line passenger forecast (CREC, 2012)

	Passenger flow indicator	Initial stage	Short term	Long term
Daily	Operating length（km））)	17.104		
	Daily passenger traffic volume（10,000 persons/ day）	12.15	24.20	35.38
	Daily turnover volume（10,000 persons, km / day）	72.71	142.98	211.68
	Daily average transport distance（km）	5.98	5.91	5.98
	Load intensity（10,000 persons, km / day）	0.71	1.41	2.07
	Daily maximum cross-section flow（persons / day）	29607	60397	84289
Morning rush-hour	Passenger traffic volume during morning rush-hour（10,000 persons / h）	1.09	2.19	3.22
	Maximum cross-section flow during morning rush-hour（persons / h）	2679	5502	7696
	Turnover volume during morning rush-hour（10,000 persons, km/h）	6.54	12.95	19.25
	Average transport distance during morning rush-hour（km）	5.98	5.91	5.98
Evening rush-hour	Passenger traffic volume during evening rush-hour（10,000 persons / h）	0.91	1.81	2.64
	Maximum cross-section flow during evening rush-hour（persons / h）	2223	4536	6330
	Turnover volume during evening rush-hour（10,000 persons, km /h）	5.42	10.67	15.79
	Average transport distance during evening rush-hour	5.98	5.91	5.98

The stated maximum cross-sectional passenger flow design value could not be used in computing existing passenger flow since it was suggested for planning purposes only and by that time (2012), actual AALRT operations had not commenced. A similar explicit figure from the AALRT operator was also lacking, hence literature review was carried out to determine an appropriate percentage of the evening flow that would be applied to the total daily passenger flow.

AALRT operator scheduled 155 daily trips on the E-W line at the end of December 2018. 61 trips were scheduled and conducted in the evening peak hour alone, representing 39.4% of the total daily scheduled trips. Therefore, the total number of passengers over the evening rush hour from 4 – 7 pm accounted for 26,257 out of the 66,640 average daily passengers.

Total daily hourly distribution proportions for the evening rush hour passenger flow were proportionate to the commuter arrival flow demanding service over the similar period. The table below illustrates the estimated passenger flow percentage distribution over the three hour evening peak at Torhiloch station.

Table 16 Average work-day percentage passenger flow/hr distribution at Torhiloch station (Author, 2019)

TIME	Total Passenger flow (Monday –Thursday)	Average Daily Passenger flow (Monday – Thursday)	% Distribution
4 -5 Pm	3619	905	33.66
5 -6 Pm	4043	1011	37.59
6 -7 Pm	3095	774	28.75
TOTALS	10,757	2689	100

.

Though table 16 above represents boarding commuters at Torhiloch station, the distribution of passenger flow over the evening peak was assumed to be similar through-out E-W line since the 5 – 6 pm travel peaking hour was noted to apply through the whole line as stated in the CREC design report. AALRT's design report [50]does not explicitly state the hourly passenger volumes distribution over the whole E-W line for the evening rush hour period. However, the report notes that majority of Addis Ababa's working commuters were expected to leave work between 5-6 pm thus causing the peak passenger flow/hr proportion of this particular hour to be considerable, as confirmed in 4.1 above.

Work place departure time for Addis Ababa working class has remained unchanged since the publishing of AALRT's design report [48]. Therefore, a reasonable assumption made, was that passenger travel behaviour and distribution over the evening rush hour at Torhiloch station would likely be exhibited over the entire E-W line. The implication of unchanged passenger travel behaviour was that passenger flow distribution over evening peak hour existing at Torhiloch station would likely form the average hourly distribution characteristics for the entire E-W line, hence the following extrapolation of total passengers distribution on the mainline, seen in table 17 below.

Table 17 Estimated evening peak passenger/hr flow distribution on E-W line (Author, 2019)

TIME	% Distribution	Estimated Passenger Volume
4 -5 Pm	33.66	8838
5 -6 Pm	37.59	9870
6 -7 Pm	28.75	7549
TOTALS	100	26,257

The percentage distribution of passengers travelling on the entire E-W line during the 5-6 pm evening rush hour over a typical working week was obtained as follows;

$$\mathbf{5-6\ pm\ \%\ passenger\ flow} = \frac{\mathbf{Passenger\ flow\ for\ 5-6\ pm\ peak}}{\mathbf{Typical\ working\ week\ passenger\ flow}} * \mathbf{100} \text{ .... Equation 1}$$

$$\frac{9870}{66640} * 100 = 14.81\%$$

14.81% of the 66,640 total evening rush hour commuter travelled within the 5 – 6 pm period, contrary to 7.48% of total daily passenger flow expected over similar time period.

Evening peak passenger cross-sectional distribution, occurring at 5 – 6 pm, was stated as 2223 passenger/hr in the CREC design [50] for the 7.48% of total daily commuters. At the end of initial term; 2018, 14.81% of total daily passenger flow were utilizing the E-W line between 5 – 6 pm. Existing cross-sectional passenger flow for the same peak hour was expected to rise by a similar proportion, yielding a peak cross-sectional flow of 4402 passenger/hr.

4.2.1.2 Computational parameters

Parameters used in the analysis of required train numbers by the TCQSM formulas outlined in chapter 2 were as follows:

- PHF = 0.9
- C_V = 508 passengers (Coupled train) (CREC Spec 2013)
- a = service acceleration rate = 1.0m/s^2 (CREC Spec 2013)
- d = service deceleration rate = 1.1m/s^2 (CREC Spec 2013)
- D = Distance from Train Front to end of platform = 30m (CREC Spec 2013)
- Allowable speed near level crossing, junction or turn-out = 20km/hr (AALRT design)
- L_t = length of the longest train = 60m (AALRT Design, 2013)
- f_{sa} = Switch angle factor = 6.09 (TCQSM, 2013)
- d_{ts} = Track separation = 4m (AALRT design, 2013)
- a = Initial service acceleration rate = 1m/s^2 (CREC Spec, 2013)
- d = Service deceleration rate = 1.1m/s^2 (CREC Spec, 2013)
- t_s = Switch throw and lock times = 6 seconds (TCQSM, 2013)
- v = Walking speed of the driver when moving from one end of the train to another assumed as 1 m/s.

The above parameters were used to compute the required number of trains using equations 1,5,12,13 and 14 respectively while the total travel time on E-W line, required as an input parameter in equation 13, was calculated by formulae 6 – 10 using MS Excel software.

The table below summarizes the various results obtained in the calculations attached in Appendix G and H.

Table 18 Results of calculation of required train numbers in 2018 (Author, 2019)

No	Capacity	Value
1	Line Capacity	10 trains/hr
2	Headway	6 minutes
3	Total station dwell time	29.33 minutes
4	Turn around and layover time at turn backs	85 seconds
5	Total travel time between stations	58 minutes
6	Total round trip time	90.16 minutes
7	Required train numbers in 2018	16 trains

The total number of trains required to meet existing (January, 2019) evening peak hour passenger flow demand on AALRT's E-W line were 16 coupled trains operating with an average headway of 6 minutes. Findings made on AALRT's train operations survey revealed that a 6 minutes headway was practically achievable by 2018 as seen in Appendix C.

Crowding impact reduction

43.5% of the total passenger flow commuted on Ayat –Torhiloch route representing 4294 passengers while 56.5% of total passenger flow commuted on the Torhiloch –Ayat route representing 5776 passengers between 5 – 6 pm. The maximum allowed capacity inside the train was 351 passengers/ unit train as observed in table 3 above, or a total of 702 passengers for the coupled train, at full capacity.

The number of trains thus required on a given route was determined to be;

- **Ayat – Torhiloch route** required 7 trains each carrying at-least 614 passengers; 65 seated and 242 standing per coach.
- **Torhiloch to Ayat route** required 9 trains each carrying at-least 642 passengers; 65 seated and 256 passengers standing per coach.

Standing passengers on both routes were below the recommended 286. Trains would thus carry sufficient passengers within crowding threshold E. The computed train distribution on the indeed necessitated timetables during the evening rush hour be planned as to allow more trains on the

Torhiloch-Ayat than Ayat-Torhiloch route to curb crowding from the 5 – 6 pm peaking hour as previously recommended.

Deploying the required number of train sets reduces on-train crowding significantly. First, on-train crowding due to standing passengers was decreased from the crush load LoS F to crowding threshold of LoS E. Crush loading within train sets would be eliminated by 67.86%. Train seat load factor would be maintained at 1 since tendency of passengers sharing seats due to crowded trains would be minimized.

Tuesday and Wednesday's platform crowding during the 5 – 6 pm hour were at minimum and maximum levels respectively. Calculated headway interval of 6 minutes was applied to Tuesday's and Wednesday's 5 – 6 pm peak hour passenger volumes to obtain new platform crowding LoS obtained as seen in appendix I. Torhiloch's platform crowding was thus reduced and re-distributed as shown in figures 5 and 6 below. .

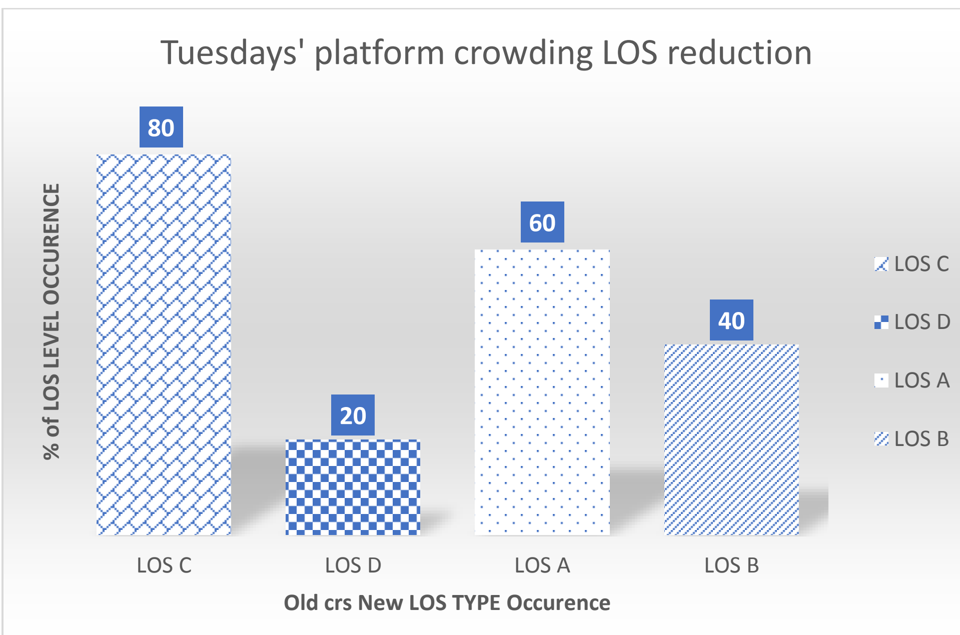

Figure 6 Old versus new Tuesday's platform crowding LoS reduction (Author, 2019)

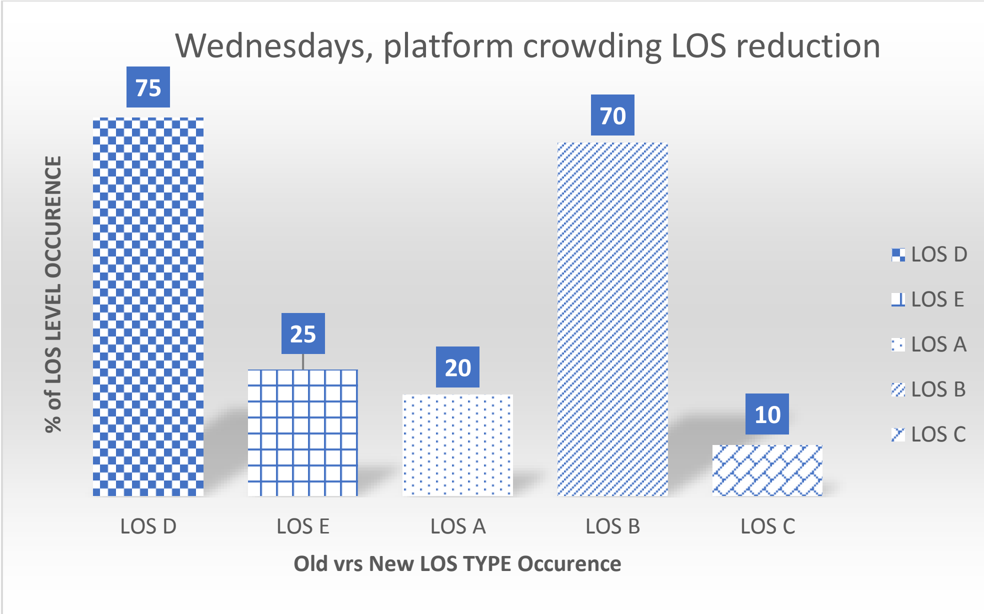

Figure 7 Old versus new Tuesday's platform crowding LoS reduction (Author, 2019)

Tuesday's platform crowding reduced from the previous 80% LoS C and 20% LoS D to 60% LoS A and 40% LoS B respectively. Wednesday's platform crowding levels similarly reduced from the previous 75% LoS D and 25% LoS E to 20% LoS A, 70% LoS B and 10% LoS C.

Deployment of sufficient number of trains on E-W line over the evening rush hour would thus reduce platform crowding range from the previous predominant LoS E - LoS C, to LoS C – LoS A, over the 5-6 pm peaking hour.

Train shortage at end of 2018

Feedback obtained from the operator's questionnaire indicated that only 18 unit trains were available for operations as at January, 2018. A minimum of 6 coupled and 3 unit trains and a maximum of 7 coupled and 2 unit trains were usually deployed daily to the E-W mainline evening peak hour operations. 1 stand-by coupled train was left available at Ayat depot in-case of break-down to service trains. The available trains were thus not sufficient to cater for the existing passenger demand at the end of 2018, which required a further addition of 7 coupled service trains and 1 stand-by train to tackle evening rush hour crowding conditions on E-W line.

Future passenger and train demand

AALRT's actual passenger demand in 2025 was projected through the growth factor method since values for both future and initial operation terms (2025 and 2018) base years could be obtained from the design report as seen in Table 15 above. AALRT design estimates were considered reliable because of the use of parameters such as population, trip attraction and distribution, transportation cost, comfort levels, living standards of Addis Ababa city residents and transport mode distribution. The parameters were considered sufficient to capture the entire travel characteristics on AALRT users over time. Calculation of the passenger flow for the short term period using the growth factor method is attached in appendix J. Maximum cross sectional passenger flow was thus determined to be 8973 passengers/ hr for the evening peak hour.

The new line capacity was calculated using equation 1 and determined to be 20 trains/hr. The required operating headway was calculated using equation 5 and determined to be 3 minutes with a train requirement of 31 trains/hr. While the expected train headway of 3 minutes can be sustained through fixed block operations based on E-W line's minimum controlling headway of 98 seconds [50], an infrastructure challenge existed that would inhibit train operations with the calculated train headway.

AALRT has a shared section of both the N-S and E-W lines between St. Lideta and Stadium whose maximum line capacity is 25 trains/hr, thus a maximum operating headway of 4 minutes and 36 seconds. The total number of trains that would be feasibly operated on the E-W line would thus be 19 trains leading to an additional train requirement of 3 coupled trains by 2025. The minimum practical headway considered in this research was thus considered as 4 minutes and 36 seconds as per the AALRT design [48].

The observed proportion of daily evening peak passenger flow distribution (39.4%) between 5 – 6 pm is assumed to remain constant into the short term period. Justification for the assumption was that according to the CREC 2012 design [50], most working commuters on the E-W line left their work-places at 5 pm, a situation that had remained unchanged by 2019. Therefore, with a limit of 19 coupled trains operating on E-W line, the high passenger demand by 2025 would necessitate crowding countermeasures such as automating the AALRT ticketing system to offer ridership bonus points for passengers choosing to travel after the evening peak hour. Such a reward scheme would attract some passengers off the peak hour thus easing the demand on the future available maximum train numbers.

4.2.2 Operational constraints

4.2.2.1 Introduction

According to the AALRT's operator response from issued questionnaire attached in Appendix J, the main train operational constraints on E-W line during evening rush hour were mechanical faults, power failure and train-roadway vehicle interaction. Each component's impact to crowding was assessed as follows;

4.2.2.2 Mechanical faults

Findings from daily AALRT OCC reports [51] on mechanical faults specifically affecting the evening rush hour operations on a typical working week, at the end of 2018 are summarized in appendix K. A total of 8 hours and 47 minutes of smooth - service interruptions on the entire E-W line during evening rush hour occurred between October – December 2018. Un- smooth service operations refer to increased headways and reduced train capacity on the track.

The table below shows the contribution of each fault to the total time of smooth operational time.

Table 19 Mechanical defect's impact to headway and train reductions (Author, 2019)

Mechanical defect % proportion to headway and train reduction						
Fault	**Breaks**	**Horn**	**Electrics**	**Door**	**AC**	**Total**
Headway	2.28	0.00	3.99	15.21	1.33	22.81
Train Reduction	0.00	16.73	2.85	43.54	14.07	77.19

The common mechanical fault affecting trains during evening peak hour was door-jamming and its proportional impact headway and train reduction was 15.21% and 43.54% of un-smooth service interruption time. Visual observation revealed that passengers forcefully opened train doors during automatically shutting thus resulting to door jams.

Replacement of faulty service trains was a challenge to the AALRT operator as observed from:

- Long time interval taken prior to restoration of normal services upon service train breakdown; the least recorded time was 15 minutes while the longest time was 58 minutes.
- Un-uniform replacement of matching train capacity – Some faulty coupled trains were replaced by unit trains thus reducing train carrying capacity available for standing passengers from 63.2 m^2 to 31.56 m^2 hence encouraging crush loading LoS F to occur inside trains. Reduction of the number of service trains resulted in passengers squeezing on the few available trains thus leading to LoS F in all unit trains operating over the evening rush hour as seen in Appendix F.
- Though mechanical faults occurred and were rectified without taking trains to the depot, pre-existing headways were interfered with. Headway was increased above the recommended 6 minutes resulting to additional train waiting time at station platforms by passengers. Platform crowding over the evening rush hour beyond 6 minutes train waiting time resulted to crowding LoS D and E, 75% over the 5 – 6 pm crowding peak hour as witnessed by the increased passengers queuing on platforms. Furthermore, longer turn-around train trip time due to more travel time in-between stations resulted as later analyzed in the train delay analysis section below. Long travel times likely resulted to immense passenger fatigue and discomfort.

Crowd mitigation strategy such as controlled passenger boarding is a necessity on the AALRT over evening rush hour period, thus reducing curbing the challenge of door failures resulting from chaos witnessed at station platforms. Headway interference and service train capacity reductions attributed to faulty doors would be reduced by over 58%.

4.2.2.3 Power failure

Findings on power failures specifically affecting the evening rush hour operations on a typical working week, at the end of the initial operating term; October – December 2018 are attached in Appendix L. Total time of fault duration and respective cancelled trips in the evening rush hour were analytically analyzed and results summarized in the table below.

Table 20 Power failure effects on PM peak (Author, 2019)

Month	Total affected time	Proportion of time effect (%)	Number of cancelled trips
October	369	6.83	15
November	1263	23.38	375
December	131	2.43	315
Average	587.6	10.88	

An average of 10.88% of the total monthly evening rush hour time was affected by power supply issues in the latter months that marked the end of initial operational period. Similarly, telephone blocking method as well as part route operations ranged from a low of 112 minutes in December 2018 to a high of 1263 minutes in November 2018. Further findings from the observed OCC reports revealed that the total failure of power system resulted to a complete service disruption of 19 minutes, over the same period.

Power failures frequently occurred at EW 2 and EW 7 substations. 15 kV external power frequently turned off resulting to the abnormality of SCADA communication thus affecting signaling operations on section EW 4 – EW 12, in the same frequency of occurrence. Part route operations between affected track sections occurred. Furthermore, extended power fault time durations occurred on the AALRT such as the case from 1st – 8th November 2018.

Part route operations reduce operations on AALRT E – W line to only 6 trains being deployed in a day as opposed to the usual 8 trains as per feedback obtained from the operator. Upon fault rectification, the train numbers are increased. An operational deficiency of over 10 trains thus occurred at the end of the initial term upon occurrence of part route operations. The result of this fault occurrence on crowding is that train headway time is increased to levels of up to over 20 minutes [51]. As previously mentioned, train waiting times above 6 minutes contributed to station platform crowding LoS D and on-train crowding Los F respectively. Commuter dissatisfaction characterized by travel delays witnessed. Absence of station P.I.S further resulted to passengers being clueless on when normal operations resumed thus psychological torture.

Consistent power availability is thus key to eliminate the observed un-smooth operation time thus encouraging consistent headway and use of all available trains within the rush hour.

4.2.2.4 Train – Vehicular and Train – Pedestrian at – grade crossings

Train – Vehicular at – grade crossings exist at Gurd shola 2, Ayat, CMC and Management institute. All stations on the E-W line apart from Tegbared, Mexico, Estifanos, Megenaga and St. Urael have passenger at –grade crossings. Trains are given the right of way over vehicular traffic and pedestrians at all these points. However, traffic snarl ups, occasional vehicular accidents and passengers crossing the rail at these points, severely restrict train movements thus headway disruption.

Total round trip time on E-W line was reported by the AALRT operator to be an average of 90 minutes. Daily OCC reports [51] reported trip time delays were occurring due to crowding on the E-W line. Impact of frequent train delay caused in – consistent headways thus necessitating a trip delay analysis on daily operations between October - December 2018.

4.2.2.5 Delay Analysis

Causes of train delays

Analyzed operator OCC reports [51] and visual observations made during passenger survey during evening rush hour revealed the following causes of train delays other than that attributed to passenger crowding at platforms;

i. Mechanical faults occurring on service trains as discussed in section 4.2.2.2 above.
ii. Power failure problems that interfered with service train operations as discussed in section 4.2.2.3 above.
iii. At- grade crossing as discussed in section 4.2.2.4 above.
iv. Wind-borne foreign material that got stuck on the Overhead Catenary System (OCS). Trains had to wait for the foreign material (plastic paper bags) to be manually removed as they posed a potential damage to the trains' pantograph.
v. Delayed traffic light change to the successive blocks therefore trains suddenly braked while on the line or were forced to wait further at stations for clearance before proceeding with their journeys.

Extra train operational time allowance of up-to 5 minutes delay per trip was provided for by the AALRT operator to factor the unforeseen challenges outlined above.

Train delay magnitude

AALRT Operator feedback to the issued questionnaire revealed that during the 3 months duration (Oct – Dec 2018), 1241 out of 19,065 train headways were missed; denoting an average of about 6.5% of all train trips. OCC daily reports [51] re-viewed over the same time period, further revealed that trains delayed up-to 25 minutes a trip. Trains trips late by 5 – 10 minutes, accounted for 43% of all late trains while those late by over 10 minutes were 57 %. Results of the average time train trip time delay that occurred on typical working days between Oct – Dec 2018 due to station crowding beyond the 5 minutes allowed by the operator, were graphed and attached in Appendix M.

From the graphs above, it was clear that passenger flow over E-W line resulted to inconsistent train delays thus the observed aggregated crowding conditions in subsequent stations as well as inside the train. Average train trips delay ranged between 5 – 20 minutes. The table below summarizes the monthly delay beyond 5 minutes, occurring on the AALRT line between October – December 2018.

Table 21 Average monthly work-day delay time on E-W Line (Author, 2019)

Average Monthly Work-Day Delay Time		
Month	**Route**	**Average Time**
October, 2018	Ayat - Torhiloch	10 min 03 Sec
	Torhiloch - Ayat	10 min 34 sec
November, 2018	Ayat - Torhiloch	8 min 03 sec
	Torhiloch - Ayat	8 min 05 sec
December, 2018	Ayat - Torhiloch	9 min 45 sec
	Torhiloch - Ayat	11 min 07 sec

Average monthly work day recorded delay time on E-W line between October – December 2018, due to crowding ranged between 8 – 11 minutes.

Train delays due to existing crowd conditions at platforms increased station dwell times considerably. Not only did the total delay in train trip time increase from the allowed average of 5 minutes to about 8 – 11 minutes, but also individual recorded train delays exceeded to unprecedented levels of 27 minutes. AALRT's crowd management strategies on passenger platforms during evening rush hour were far from being adequate.

4.2.3 Operation efficiency in crowd management

Crowd management on AALRT's E-W line over the evening rush hour period was observed and the following noted;

i. Crush loading inside trains caused passengers to crowd near the doorways. Passengers found it difficult to access the door on time. Either some boarding passengers who could not access trains quickly were left at station platforms due to elapse of trains' station dwell time or those who attempted to board after the elapse of station dwell time, blocked the train doors from closing thereby increasing the likelihood of damage. Instances in which the train door closure problem persisted, police officers manning the stations intervened by either pushing passengers further inside crowded trains or asking some of the newly boarded passengers to step out the congested carriages, thus uncomfortable journeys.
ii. Stations such as Megenaga and those between St. Lideta to Stadium, there was conspicuous lack of crowd management strategies to forestall the inevitable push and pull among passengers upon train arrivals at platforms.
iii. Large pedestrian flow was noted at track crossing points on majority of at-grade-stations within the evening rush hour. Though oncoming trains were both clearly visible to and would hoot, pedestrians sometimes didn't clear from tracks on time hence their safety was compromised. Safety officers were also noted be either be absent on certain days or arrived late past the start of evening peak time. Trains were forced to break suddenly hence reducing travel speed. Eventually, a negative impact on travel time delay between stations of 3 – 6 minutes above the AALRT's operator allowed time occurred.
iv. Unbalanced passenger boarding among trains resulted to some uncomfortable crush loaded journeys. Passengers contested to get into the first train that arrived after long waiting durations, and upon departing on already crowded trains, successive trains arrived shortly later with fewer passengers on board.

AALRT's crowd management strategies on passenger platforms during evening rush hour were in - adequate. Better crowd control measures were necessitated.

From the findings made above, the following discussions were made;

Though purchasing extra train sets for the AALRT was an expensive undertaking, it was inevitable. Increased train numbers were needed to bridge the gap created by the large passenger demand of 39.4% of all total daily passengers travelling over the evening peak as opposed to the 20.73% expected in the design. Continued passenger crowding would eventually lead to greater frequency of damage doors thus increased station dwell time as train drivers were forced to re – start affected trains to rectify this particular problem. The observed practice was highly un-acceptable. Control of passenger boarding and alighting needed more drastic improvement to eliminate longer train dwell time at stations.

Unavailability of station P.I.S on AALRT could not guarantee passengers patience to await the next train. Therefore, problems such as unbalanced passenger crowding among successive trains and chaotic boarding and alighting at station platforms, occurred. Impact on crowding through mechanical faults occurring over evening peak hour, could be easily reduced through the addition of extra trains and provision of stand-by train to ensure timely replacement of faulty trains. Lengthy power faults durations witnessed on the AALRT intimated that passengers who manage to catch the few trains operating through part route operations could only experience severe crowding inside the trains.

Not only did trip delays exceed the recommended tolerance but also averaged up-to twice the value. Tolerated and increased train time trip delay aggravates crowding during the evening rush hour since train headways continue to fluctuate resulting to continued missed headways. Furthermore, tolerated train delays over the long term period would not be sustainable when the E-W line will expected to have increased commuter demand requiring timely train service. Success in curbing train delays would eliminate increased trip delay time above the recommended tolerance. Furthermore, it would reduce the operator allowed train delay time thus leading to efficient use of the AALRT's E-W line capacity.

Crowding on AALRT's E-W line would only be successfully mitigated upon much stringent control of passenger boarding and alighting at stations. Provision of information to passengers awaiting on station platforms concerning the arrival of successive trains, even when the train already at the station is crowded, would help passengers wait with a degree of certainty hence their patience. Bridging passenger information gap was key to solving unbalanced passenger loading inside trains thus improving the quality of ridership over peak travel periods.

4.3 Direct economic loss attributed to crowding

Analytical computations were used to obtain the direct loss incurred by the operator as a result of crowding. Operational costs required to operate additional rolling stock over the evening rush hour are summarized in the table below.

Table 22 Estimated operational costs for additional rolling stock during PM peak (AALRT, 2019)

Estimated daily AALRT operational costs for E-W Line as at Dec 2018			
No	**Item**	**Cost/day (Birr)**	**Cost/ Evening Peak period**
1	Power	1700.86	680.35
2	Rolling Stock Insurance	50.70	3.17
3	Transport Personnel Salary & Benefits	306.35	153.18
4	Maintenance Personnel Salary & Benefits	260.71	130.36
5	Spare parts	47.65	8.94
	Total Cost	2,366.27	976.00

At the end of 2018, it was estimated that the AALRT operator lost 231.46 birr/evening rush hour/ working day or 60,179.60 birr/year. Table 22 below summarizes the results of the entire computation attached in Appendix N.

Table 23 Results on direct economic loss (Author, 2019)

No	**Required outputs**	**Result**
1	2018 Evening peak designed passenger demand	121, 500 passenger/day
2	Actual evening peak 2018 passenger demand	59, 750 passenger/day
3	Estimated passengers lost	723 passengers
4	Average daily passenger revenue/ working day	3.02 birr/ passenger/day
5	Revenue that would have been accrued	2,183.46 birr
6	Operational cost change	1952 birr
7	Revenue lost	231.46 birr/ evening rush hour/working day

Crowding on E-W line during the evening rush hour was having a negative impact on AALRT's operator revenues. Existence of direct economic loss justified that fact that the AALRT operator's needed to plan for future increase of rolling stock thereby reaping better revenue returns.

Though 231.46 birr/evening rush hour/working day would seem negligible, in reality it was not. The amount didn't include the revenue lost over morning peak hour where a similar or lower passenger flow volumes were expected thus possibly doubling up or incur much more of the revenue lost. Furthermore, passenger numbers were expected rise even further, upon increasing rolling stock since commuters on the E-W line were considered loyal customers by the AALRT operator. Most commuters on E-W line, had expressed previously in operator conducted surveys, their preference in travelling on AALRT over commercial vehicle taxis during rush hours because the former was economical and much faster.

According to the study's objectives, only direct economic loss was computed. However, indirect economic loss due to crowding on the AALRT exists. Indirect economic loss incurred by passengers due to crowding includes both costs on travel time delays and health. Addis Ababa's economy also likely experienced economic loss due to late arrival of commuters going to work, absence due to sickness, missed or re-scheduled meetings as well as lost business. As previously mentioned, calculation of such losses involve complex calculations beyond the scope of this study.

4.4 Passenger ridership quality assessment

4.4.1 Introduction

Study questionnaire was first prepared in English and later translated into Amharic, since the latter is the official working language in Ethiopia. Proof-reading of the Amharic translation was done by the research supervisor. The questionnaire used for the study is attached on appendix O.

A total of 474 respondents participated in this study. From the sample pool, 384 respondents met the inclusion criteria and were therefore included for analysis. The 90 participants excluded in the analysis, were either first time users or had considerable missing data.

4.4.2 Questionnaire analysis

Analysis of the field data survey was done using MS Excel. Commuters' response on the various questions was examined analytically. 0Respective pie charts and bar graphs were plotted to represent the analyzed passenger responses as attached in Appendix O.

Commuter's train use information

40.1% of the passengers surveyed had used the train in the last six months of operation. The rest of the commuters, notably 19.27%, 20.83% and 19.76% stated that they had used the train service for 6 – 12 months, 1-2 years and over 2 years respectively. Conclusions made from this research were thus deemed to be inclusive of the entire commuter population views, hence reliability of findings obtained.

65% of surveyed commuters reported to have regularly used trains 3 or more times a week, while 21% of respondents used the service only once or twice a week. An equal proportion of 7% of surveyed commuters reported to have used the train 1 – 2 times a month and less often, respectively. The random selection of survey respondents thus captured a significant proportion of recent train commuters further justifying their response as credibly representing the crowding levels at the end of AALRT's initial operational term.

Passengers surveyed during the evening rush hour reported various perceived train waiting times. Perceived train waiting times of up-to 5, 10, 15, 20, 25, 30 and over 30 minutes received the following respective percentage responses: 3.13%, 9.11%, 19.01%, 25.52%, 13.28% and 20.83%. The most common passenger waiting time reported was up-to 20 minutes, though train waiting time delays of over 30 minutes accounted for 20.83% of all the responses.

Surveyed commuters gave varying responses to the description of evening rush hour trips over December 2018. Only 8.33% of passenger surveyed admitted that there were always seats available while 10.68% of the respondents stated that there were usually seats available in the train. 14.84% of the respondents stated that they usually stood inside the train though there was space for standing, while 35.94% and 28.13% of the respondents admitted to usually standing inside a crowded and very crowded train respectively. Only 2.08% respondents stated that seat availability varied in the evening rush hour. Majority of the respondents; 64.07% thus reported to have usually stood in crowded trains during evening rush hour trips.

Only 11.46% of respondents reported to have never encountered delays while commuting to work. 51.3% and 27.6% of the surveyed passengers reported to sometimes and often encountering delays respectively. 9.64% of the passenger surveyed reported to always encounter delays while commuting to work. More than half of the surveyed respondents; 88.54% encountered delays while commuting to work in varying frequencies of occurrence.

Commuters surveyed on this study reported various degrees of on-train crowding aided by pictorial diagrams on the study questionnaire. Only 8.33% of respondent stated the lack of crowding issues inside trains. 20.83% of the respondents reported encountering slight crowding. 30.99% of the surveyed commuters noted that trains were crowd while the majority; 39.84% of respondents stated that the train was extremely crowded. Majority of passengers on the AALRT evening rush hour thus consider the trains to be extremely crowded.

From the findings above, the following discussions were made;

Majority of the sampled population, (25.52%) stated that their perceived average train waiting time was up-to 20 minutes, which was quite high compared to the field average sampled waiting time corresponding to train headway time of 8.3 minutes. Since the respondents were mostly weekly users, it is suspected that the variation could be as a result of previous lengthy train waiting times encountered outside the survey week period. 20.83% of respondents stated that train waiting times were over 30 minutes, implying that a significant number of evening rush hour commuters were victims of being left at station platforms due to severe crowding inside passing trains.

78.91% of the total survey respondents admitted to always standing inside the train. While passengers standing was not uncommon in LRT such as AALRT, it was however noteworthy that standing in crowded trains was the common phenomenon. On-train crowding was a significant problem.

91.67% of the total respondents however admitted to existence of crowding issues at the evening rush hour on the AALRT, a finding that supports the results obtained in previous sections of this research that conclude crowding was indeed a major issue to majority of passengers. Furthermore, the computed value was very close to on-train crowding level taken a week before the survey, particularly on the Torhiloch – Ayat route, where congestion found to be at 96.45% thus justifying the reliability of this previously computed value.

Train delays on AALRT affected a significant number of passengers commuting to work. According to the survey, a total of 88.54% of passengers stated that they experienced various levels of delay while using the service when travelling to work. Indeed, countermeasures to minimize travel delay particularly caused by crowding, were inevitable.

4.4.2.1 Passenger's crowding description, physical environment and feelings inside the train

Passengers' response for the top three descriptive categories are summarized in the table below;

Table 24 Percentage proportions of passenger's description of evening crowding on AALRT E-W line (Author, 2019)

PASSENGER DESCRIPTION OF CROWDING ON AALRT E-W LINE IN (%)		
Crowding assessment inside the train		
1	Dense	57.08
2	Confining	57.8
3	Unpleasant	53.13
4	Chaotic	57.81
Description of train's physical environment		
1	Hot	60.94
2	Stuffy	54.42
3	Smelly	47.65
4	Noisy	49.48
Passenger's feelings inside the train		
1	Restricted	61.19
2	Uncomfortable	59.38
3	Frustrated	55.73
4	Stressed	54.43

From the findings made in 4.4.2.1 above, the following discussions were made;

Survey respondents admitted to dense and confining crowding conditions at 57.03% and 57.8% respectively. Over half of the commuters on the AALRT's E-W line over evening rush hour travelled in trains with in-sufficient seating and standing space. Furthermore, an almost similar sized passenger survey response of 53.13% thus found the train journeys over the evening rush hour rather unpleasant. A slightly higher proportion of commuters; 57.81%, reported chaotic levels of crowding. On-train crowding indeed limited commuter space and clearly resulted to rather uncomfortable journeys characterized by the "push and pull" at train door-ways; a situation best described as chaotic. Additional standing space inside train wagons was required to improve evening peak hour travel conditions. A feasible solution to space increment within the train wagons would be a seat configuration adjustment to increase passenger standing area in future purchased rolling stock as well as deployment of additional rolling stock. Section 4.5.1 discussed in detailed these dual complimentary solutions.

Train crowding, as noted in the literature review, affects commuters' health. Passengers inhaling stuffy air could easily suffocate. Half of the surveyed evening rush hour commuters on AALRT E-W line reported to experience reduced fresh air inside the crowded evening rush hour train, thus rating the train as stuffy. This finding intimated that close body contact experienced by passengers inside the crowded train wagons on AALRT reduced fresh air circulation considerably; a fact that agrees with the study conducted by Nicol et al. [22].

60.94% of the surveyed respondents overly rated the train as hot and were uncomfortable with temperatures inside the train carriages. 36.8% of the respondents who rated the train as both extremely and very hot, closely equaled the sum of respondents who advocated for the improvement of air-conditioning inside the train; 32.29%. Passengers were concerned that some of the train sets operating over the evening rush hour had some faulty units of the air-conditioning system, as seen in Appendix K. Reduced air circulation increased health risks to passengers further proving that AALRT's crowding over evening rush hour resulted to poor passenger ridership quality. Tackling crowding would improve the health and safety conditions for commuters utilizing AALRT over evening rush hour. A total of 49.48% of survey respondents rated the train as noisy. Further investigations revealed that most passengers found the volume of the train's P.I.S deployed during the evening rush hour was considerably set to high. Train drivers need to thus be more cautious when setting sufficient volume for the on-train P.I.S.

Passengers were very unhappy with crowding on the AALRT's E-W line. Clearly, more than half of the evening rush hour commuters on the AALRT's E-W line were negatively affected by crowding; an indication that the congestion problem needed swift solutions. Delay in addressing the crowding problem will only lead to a rise of negative passenger feeling level, on an aspired beneficial urban train transit system such as the AALRT; an trend that would be undesirable.

4.4.2.2 Descriptive variable relationships

An IBM SPSS software was used to analyze important descriptive variable relationships to comprehend the inter-relationship of train crowding effects on passengers. Six key relationships were arrived according to results attached in Appendix P. Participants whom encountered the top three levels of crowding description, experienced the following conditions: those whom;

- Travelled under dense crowding conditions and similarly reported that the trains were hot, accounted for 48.34% of the entire respondents.
- Encountered uncomfortable travel conditions in hot carriages were 46.09% of all the respondents.
- Stated as commuting under confining crowding conditions and consequently reported of being uncomfortable accounted for 45.05% of all respondents.
- Commuted in densely crowded trains and further experienced frustrating journeys were 41.15% of the entire respondents.
- Experienced chaotic trains journeys and were equally frustrated accounted for 42.45% of the entire respondents.
- Reported to commute in noisy conditions and were similarly stressed, were 36.45% of entire population sampled.

Variable correlation that yielded results above 35% were considered statistically significant from personal judgement and thus reported. Only six findings, as outlined above, met this threshold since other correlated variables yielded results far less than 35%. Justification for selecting 35% as a measure of significance for reported findings, was based on the fact that results highlighting the magnitude of negative physiological feelings occurred only over three years that marked AALRT initial operational term. At the start of January 2019, AALRT was to serve Addis Ababa city residents for at-least another 21 years as per the AALRT design [50]. The fact that the train service had served less than a third of its operational term and yet the psychological feelings had over the similar period, proportioned to over 35%, indicated concerning levels on the negative feelings among commuters.

Increased rolling stock numbers would increase space in trains thus reversing effects of crowding on commuter feelings. At the start of the short operational period (2019), the AALRT operator was required to provide more trains as per the AALRT's design [50]. However no such plans existed upon inquiry by May 2019. The crowding situation would probably continue until such measures were enforced.

Crowding on AALRT E-W line during the evening rush hour clearly affected passengers' comfort through increased temperatures and reduced carriage space; the latter which most likely affected standing commuters. Possible explanation to the observations made was that crowding lead to close body contact among commuters due to squeezing in packed carriages thus increased temperatures. Not only was crowding LoS F encountered but also train journeys were inevitably uncomfortable thus leading to frustration among AALRT commuters over the evening rush hour. Passengers travelling over evening rush hour required sufficient space and well ventilated trains.

Significant levels of frustration (42.45%) and stress (36.45%) occurred among commuters in the crowded trains at the end of the initial operational term. A feasible explanation for the frustration and stress level observed is that elderly commuters, whom were most likely affected, found it hard to compete with the youthful passengers for space on crowded trains which was only available after the unavoidable "push and pull" witnessed. Furthermore, stress levels likely arose from shouting among passengers due to the chaos encountered as well as the increased volume from the in-built train P.I.S system which was set high enough to pass information on an already crowded noisy train. Observed frustration and stress levels among passenger provided further sufficient proof that crowding was affecting commuter feelings.

Urgent attention was needed on the part of the AALRT operator to curb the rise in negative feelings over the future operational periods, thus improving the quality level of passenger ridership observed. Crowding countermeasures not limited to the increase in train numbers, possible seat review as well as timely operations, would improve both the space inside carriages and service delivery. Consequently, the levels of low passenger ridership quality previously experienced would be reversed. Implementation of these measures were not only justified but also inevitable.

4.4.3.4 Mitigating crowding

In order to further comprehend commuter feelings on crowding, an open ended question was filled. Analytical analysis of responses by passengers revealed the AALRT operator should make significant improvements on three key areas; train maintenance (5.7%), operations (25.5%) and capacity (68.8%). The three key areas were further subdivided into sub-group based on individual commuter responses. Table 25 below shows the results obtained for each category.

Table 25 Passengers' opinion on crowd mitigation (Author, 2019)

Proposed crowd Impact mitigation measures	**% of individual responses**
Improve turn-around time for train breakdown	3.1
Improve ventilation	2.1
Improve On -track train fault handling	0.4
Invest in on-track passenger Information system	13
Improve ticket checks to curb free riders	4.4
Increase ticketers at ticket station	1.7
Improve crowd control on passenger platform and train doors	4.5
Quick response to power black outs	1.2
Swift communication between OCC and train drivers	0.8
Review seats arrangement of rolling stock	1.9
Provide only coupled train during rush hour	3.3
Increase coupling to three coupled trains	4.3
Expand train network beyond terminal stations	1.7
Increase train numbers during peak hour.	24
Increase number of train tracks	1.6
Reduce headways between trains	32
TOTAL	100%

Results obtained for each analysis were graphed and attached similarly in Appendix O. The following discussions were made from the observed findings.

Improve maintenance – Passengers appealed for speedy train repairs to minimize train capacity reduction due to train breakdowns. Commuter response intimated an un-acceptable train breakdown frequency on the E-W line mainline. Interestingly, some passengers complained and expressed doubt as to whether the rolling stock in use was actually new or not, (even though it was only in operation for three years), due to frequent train breakdowns while operating on the mainline. 60.94% of passengers stated the trains were hot thus hinting to occasional failure of the rolling stock air-conditioning system as a main challenge affecting the physical environment inside the train.

Improve operations – Lack a station P.I.S created a serious communicating gap on train operations. Passengers stated to sometimes being subjected to longer waiting times at stations without a clue on the estimated train arrival times nor crowding levels inside subsequent trains. Station P.I.S was deemed useful in order to psychologically deal with long train waiting times. Ticket checks needed to be more stringent to crack down on looters/pick pockets taking advantage of the crowding situation. Personnel selling tickets at the station during the evening rush hour needed to be increased to ensure faster service time at pay points thus reducing the chances of commuters rushing to catch departing trains. Finally, few passengers stated that in the event of signaling malfunction, speedy communication between the Operations Control Centre (OCC) and train drivers should be enhanced. Commuters thus hinted that AALRT's use of telephone blocking method deployed upon signal interruption experienced slow communication amongst parties and thus was perceived as a source of train delays.

Improve train capacity- Passengers suggested a review of the trains' seating arrangement to create more room for standing passengers thus reducing on-train crowding levels. Respondents expressed dissatisfaction with the use of unit trains during the evening rush hour. Though the existing platform design could not allow coupling of more than two unit trains, some were of the opinion coupling three unit trains should be introduced during the evening rush hour to curb passenger crowding. Majority of the respondents were unhappy with the few trains availed by the AALRT operator during evening rush-hour and suggested an increase of rolling stock numbers. Some passengers felt that the train network should be extended beyond the existing Ayat and Torhiloch stations (move on to phase 2 of the construction) so that current terminal station platforms (Ayat and Torhiloch) would experience less levels of crowding from commuters arriving through other different transportation modes from areas beyond the two stations. Finally, many passengers expressed disappointment with the fact that the initial promised train waiting times at the commencement of the train operations (6 minutes) were not being adhered to. Passengers thus requested that the train operator adheres to the initial promised station waiting times through increased train frequencies thus shorter waiting times and less station platform crowding.

4.5 Countermeasures to AALRT's crowding

Introduction

An in-depth study on train supply and crowd management issues on AALRT's E-W line at the end of initial operational term highlighted loopholes contributing to crowding, thus pointing out to possible countermeasures. Train supply and crowd management countermeasures are interlinked. Proposed countermeasures on these two issues were hence discussed concurrently. Crowding mitigation measures, as per the conducted literature review, are also categorized as engineering, non- engineering, policy, physiological or a mixture of the two or more segments. Therefore, crowding countermeasures, further outlined below, were discussed in detail either from a specific or mixed category perspective.

4.5.1 Train supply

Findings from this research pointed to two main train supply issues contributing to evening rush hour crowding on AALRT's E-W line; train shortages and in-consistent train headways.

Train supply issue could be tackled by;

a. Adding more rolling stock

From an engineering perspective, detailed calculations revealed that existing rolling stock supply of 18 units was designed against a 20.7% daily passenger demand over the evening rush hour. However, by December 2018, there existed a 39.4% daily passenger demand over the evening rush hour, clearly necessitating more train supply. Commuter travel duration could not be easily re-distributed to other hours outside the evening rush hour since Addis-Ababa's working class left work at 5:00 pm, and were more eager to catch the first available train. 7 coupled trains as well as an additional coupled standby train were required as at January 2019. Sufficiency of rolling stock numbers would have the following multiplier effects;

- Guaranteed availability of sufficient trains thereby eliminating the need of using train mix operations.

- Consistent use of coupled trains resulted to doubling passenger standing space for operational unit trains from 31.56 m^2 to 63.2m^2 hence a twofold increase in commuter carrying capacity.
- Train "rescheduling" practice would be eliminated since all stations are consistently served through use of coupled trains.
- Headway interruption would thus cease upon attain elimination of train 'rescheduling" practice.
- Guarantees availability of a coupled stand-by train that may be quickly deployed to curb un-expected mechanical failures that previously reduced service trains on the mainline.

Maintenance of headways at the recommended 6 minutes with the sufficient rolling stock numbers would;

- Reduce platform crowding from the predominant LoS D to LoS B.
- Reduce on-train congestion from LoS F to LoS E.
- Passengers load seat factor would be constantly maintained at 1 rather than fluctuating between 1 and 1.42. Sharing of seats amongst passenger would be eliminated due to increased spacious standing area hence more comfortable evening rush-hour trips for the few seated commuters.
- Reduction of the previous 15 minutes minimum response time taken to replace service train breakdown to at least 6 minutes, as recommended by this study, would hence be achieved.

Setting up operational policy governing the minimum time required to provide a standby train upon service train failure would;

- Reduce the previous 15 minutes minimum response time taken to replace service train breakdown to at least 6 minutes, as recommended by this study, hence reducing headway interference.
- Set a bar to measure train replacement response time against the pro-activeness of maintenance crew to quickly attend to train capacity lapses.

- Provide a standard against which response time can be measured. Necessary response improvements can thus be made where gaps are observed.

b. Review of train seating arrangement for future rolling stock

Existing on-train crowding gave very little articulation to passengers. Passenger survey carried out on the E-W line revealed that the majority commuters over evening rush hour alighted at the terminal stations as seen in Appendix F implying that door-way congestion greatly impacted time taken passengers alighting at intermediary stations, therefore increasing dwell times. Improvement of passenger articulation inside trains is critical in reducing train dwell times. Passenger articulation improvement could be achieved by seat re – arrangement inside trains or by the marginal reduction of seat numbers to achieve the possible greatest passenger standing area away from train doors. Increased standing area would at-least hold the majority of standing commuters alighting near or at terminal stations hence easing passenger flow problems at the door-way.

Seat arrangement variation

The proposed vehicle on AALRT's schematic design, was first divided into three sections depending on the seating arrangement, shown in figure 9 below.

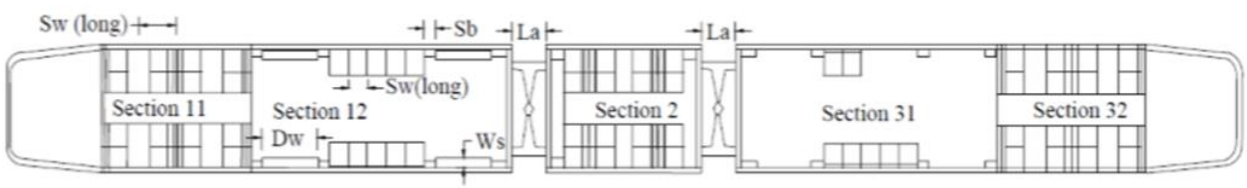

Figure 8 Passenger seat configuration inside trains operating on AALRT's E-W line (AALRT technical vehicle specification)

Analytical assessment of the seat configuration was calculated using equations 2, 3 and 4 above with the parameters obtained from the Technical specifications for vehicles on the AALRT [29]. Calculation of vehicle capacity as well as values of parameters used, is shown in table 26 below.

Table 26 AALRT's vehicle carrying capacity calculation (Author, 2019)

VEHICLE CAPACITY CALCULATION									
Car External Wall thickness (m)	0.05	Internal Partition Wall thickness(m)	0.05	Area of single transverse seat (Sa)(m^2)	0.32	Number of Passengers per m^2	6	Seat pitch transverse (Sw)	0.8
Car internal traversal Wall thickness (m)	0.05	Reduction of width in Articulation	0.4	Area of single longitudinal seat(Sa)(m^2)	0.32	Space per standing passenger (Ssp)(m^2)	0.167	Seat pitch longitudinal (Sw)	0.4
			Car 1		**Car 2**	**Car 3**		**Articulated section**	**Total**
Exterior Dimension per car	Length (m)		9.55		3.6	9.55		1.6	24.3
	Width (m)		2.65		2.65	2.65		2.65	2.65
			Section 11	**Section 12**	**Section 2**	**Section 31**	**Section 32**	**Articulated section**	**Total**
Exterior Dimension per car	Length (m)		3.5	6.05	3.6	6.2	3.35	1.6	22.7
	Width (m)		2.65	2.65	2.65	2.65	2.65	2.65	
Interior Dimension per car	Length (m)		3.4	6	3.5	6.1	3.25	1.6	22.25
	Width (m)		2.55	2.45	2.55	2.45	2.55	1.85	
Interior Area (m2)			8.67	14.7	8.93	14.95	8.29	2.96	55.53
Number of double stream door			0	2	0	2	0	0	4
Door Width (m)			0	1.3	0	1.3	0	0	
Step Well Width (m)			0	0	0	0	0	0	
Single set back allowance in (m)			0	0.2	0	0.2	0	0	
Length at corner not be used for seating (m)			0	0.6	0	0.6	0	0	
Free wall length not used for seating (m)			3.4	2	3.5	2.1	3.25	1.6	
Free wall width not used for seating (m)			2.45	1.95	2.45	2.45	2.45	1.85	

Table 26 continued….

Is seating in articulated allowed (Yes/No)						No	
Seating arrangement (N)	4	2	4	2	4		
	Transverse	Longitudinal	Transverse	Longitudinal	Transverse		
Allocated seating	4	5	4	5	4		
Number of seats	16	10	16	10	16		
Reduced number of seats	0	0	0	3	0		
Total Number of seats	16	10	16	7	16		
Total Area occupied by seats	5.12	3.2	5.12	2.24	5.12		
Is standing on steep allowed ? (Yes/No)	No Steep	No Steep	No Steep	No Steep	No Steep	No Steep	
Standing area available on steep well (m2)	0	0	0	0	0	0	
Total number of standing passengers	21	69	22	76	19	17	221
Total number of seats per car	26		16	23		0	65
Total number of standing passengers/car	90		22	95		17	221
Vehicle capacity	116		38	118		17	286
Passenger/meter	12		10	12		10	
	Total vehicle capacity		289				

The proposed rated vehicle capacity in the CREC's 2012 design was 286 passengers. The capacity for the various train section areas of the vehicle design were also obtained as seen in table 26 above. Analytical calculations were carried out by varying seat arrangement on the various rolling stock sections to check whether the carrying capacity of the train would improve. Computational results obtained are attached in Appendix Q. Summarized results of the seat configuration results are attached on table 27 below.

Table 27 AALRT total train capacity results for various seat configurations (Author, 2019)

No	Option	Total train capacity
1	Option 1	289
2	Option 2	247
3	Option 3	264
4	Option 4	251
5	Option 5	256
6	Option 6	256
7	Option 7	251
8	Option 8	291
9	Option 9	307
10	Option 10	335

Option 1 represented the initial seat arrangement on AALRT vehicles operating on the E-W line. Seat arrangement review based on options 2 – 7 yielded far less number of standing passengers implying decreased passenger standing space. Options 2-7 were thus considered not viable. The train seat configuration was fully optimized. Increase in the train's passenger carrying capacity (increased floor area) occurred only upon seat review arrangements in options 8, 9 and 10, but through a reduction of seats in existing train sets. Passenger articulation on the current train sets could only be further improved by a marginal seat reduction inside the rolling stock.

Option 9 considered reducing seats in section 2 of the train thus yielding a greater train passenger carrying capacity of 307 compared to 291 obtained by option 8. Option 10 of seat arrangement review considered removing all seats within the rolling stock thus yielding to a higher number of passenger carrying capacity than option 1. In this study, option 9 was preferred as a possible seat review for AALRT's future rolling stock, to mitigate on-train crowding impact.

Reasons behind this preference were that while option 10 presented the greatest carrying capacity/floor area increase, it was impractical to remove all seats within the train. Children and elderly commuters would feel disadvantaged by this un-inclusive action since one complete trip time on AALRT was no less than 45 minutes between terminal stations. Increased chances of unbearable and unacceptable fatigue would thus occur.

Seat review for option 8 in train's sections 12 and 31, reduced 17 seats to created room for 19 standing passengers while option 9 eliminated 16 seats at only section 2 of the train, to create room for 31 standing passengers. AALRT's vehicle total passenger carrying capacities for options 8 and 9 were 291 and 304 respectively. Therefore, seat review option 9 lead to a higher increased floor area with removal of fewer seats than option 8. Furthermore, removing seats at section 2 offered the best possible standing area away from train doors for passengers travelling to terminal stations. Passengers travelling to and from intermediary stations would thus have easier access through door-ways upon the timely alert by the trains' internal P.I.S when approaching stations.

Upon seat removal, the floor area in section 2 on existing train sets was determined by taking actual vehicle dimensions of rolling stock operating on the E-W line. Internal length was found to be 3.55m while the internal width was 2.35m thus yielding an area of $8.3425m^2$. Standing passengers that would be accommodated on section 2, was calculated in proportion to the proposed rolling stock and determined to be 50.

From option 1 above, section 2 had initially 16 seated and 22 standing passengers respectively thus a total of 38 passengers. However, upon removing seats on the existing rolling stock, section 2 was able to hold 50 standing passengers, inferring an increase of 12 passengers at the rated standing area capacity of 6 passengers/ m^2 or 0.25 m^2 standing space created per door. Standing area on section 2 would be achieved by raising the floor area to match section 12 and 31 to avoid interfering with the bogie design for future train sets.

Successful use of the new additional area to curb on-train and door way crowding needed back-up communication to encourage passengers to occupy the new area via the P.I.S installed inside the train. On-train P.I.S is inclusive of a train drivers radio and camera. Visual monitoring of passenger crowding inside trains was possible. Coupled with radio communication, train drivers are be able to communicate to passengers in the main train wagons. Passengers proceeding to terminal stations would hence be politely requested to stand on section 2 of the train thus clearing the door-way for commuters from and to intermediary stations. Alternatively, an automatic voice message could be programmed and broadcasted alongside the already existing audio communication relayed by the train's in-built P.I.S. In the course of time, terminal station commuters who lacked seats would adapt to standing at section 2.

4.5.2 Crowd management at train stations

Station dwell times exceeded the maximum recommended 40 seconds headway in some stations due to extended passenger boarding times. Two practical measures are suggested to efficiently address crowd management; controlled passenger boarding activity and the provision of station P.I.S.

4.5.2.1 Controlled passenger boarding

Platform crowding that resulted to passengers dashing at train doors upon train arrivals could be limited by temporarily restricting excess number of commuters from accessing already occupied station platforms.

In Japan's LRT systems, crowd control during evening rush-hours involved deploying station personnel who temporarily blocked passenger from accessing already crowded platform at stations' entry points. Additional arriving passengers wait on open areas adjacent station platforms. Once the waiting passengers on station platform depart, station personnel allowed the next batch of waiting passengers on station platform. Boarding passengers were further trained, over a period of time, to first allow alighting passengers to disembark for the first few seconds by standing at a small distance away from train doors and then later board the train. Dwell times on Japan's busy metros was thus maintained to as low as three minutes despite the large passenger flow greater than of the AALRT.

In the case of AALRT, passenger survey carried out revealed that majority of boarding activities during evening rush hour happened at grade-separated stations, Megenaga as well as Ayat and Torhiloch terminal stations. Grade separated stations, considered to be within "Addis Ababa's CBD" where most evening rush hour trips were generated, were accessed through stairways and lifts and had an open area adjacent to station platform where passengers for both E-W and N-S lines could temporarily stand before accessing station platforms thus safely allowing sufficient number of passengers to access station platforms at a time. However, this method would be successfully deployed upon installation of station P.I.S as discussed in detail further below.

While the AALRT operator enforced passenger queuing at Ayat and Torhiloch to manage passenger boarding, more stringent commuter control is recommended to ensure that the train's station dwell time isn't exceeded as previously observed. Megenaga station is an at-grade station but accessed via stairways and lifts. Similar passenger control recommended for grade separated section can be implemented since a section of its access stair-way could serve as a holding area for extra passengers awaiting trains. Remedial training on train boarding procedures by AALRT operator needed to be conducted regularly to ensure reduction of passenger collision at train doors using personnel deployed at stations.

Controlled passenger boarding would thus yield the following benefits;

- Mitigate passenger collision at train doors.
- Arrest observed passenger behaviour of blocking train doors.
- Manage on-train passenger boarding to ensure on-train crowding is managed maximally at LoS E.

The net impact would thus be reduction in time wastage due to poor crowd control that previously resulted to additional of 5 minutes trip time per train by the AALRT operator. Trip time would thus be sustained at the recommended 90 minutes. Platform crowding would thus be maintained at LoS D due to consistent headways.

4.5.2.2 Station Passenger Information System (P.I.S)

Station P.I.S includes digital signage displays or automatic voice passenger information. Figure 8 below shows a typical P.I.S at use in Manhattan, New York underground station.

Figure 9 Typical Station Passenger Information System (New-York rail)

Bridging passenger information gap through station P.I.S would yield the following benefits;

- Solving the unbalanced passenger loading inside trains, that previously fluctuated from LoS B to Los F. Coupled with use of controlled passenger boarding measures, crowding in trains would be maximally managed at LoS E.
- Use of P.I.S systems would appeal to commuters' physiology by increasing commuters' patience. Controlled passenger boarding operations coupled with increased commuter patience limits chances of crush loading occurring upon the sight of on-coming trains.

4.5.2.3 Minimizing at-grade crossings

Train - pedestrian / vehicular interaction was identified as a source of train trip delay on the AALRT E-W line thus aggravating crowding on stations and inside trains. Minimizing both vehicular or pedestrian – track at grade crossings ensures;

- Travel time between station is consistently maintained within the recommended time of 58 minutes, thus ensuring headway consistency among trains. Consistent headways are a paramount requirement to sustain platform and on-train crowding at LoS D and E respectively.

- Improve safety and save lives by minimize the risk of accident occurrence from train – pedestrian or train – vehicular collisions.

To ensure that the above is possible, the following specific measures are highlighted:

- **Pedestrian re-routing** –Use of footbridges to cross over rails over at-grade stations is recommended. Steel designed footbridge can be easily fabricated to cross above the OCS hence totally preventing passengers from obstructing tracks. Similarly, use of existing stairways/ lifts and zebra crossings already existing underneath Stadium and St. Lideta stations can be used by transferring passengers between E-W and N-S lines.
- **Proper vehicular flow management**
  a. **Vehicular traffic re-routing** –
  At-grade crossings at Ayat and between Gurd shola 1 and 2 can be closed. Vehicles using the Ayat at grade crossing can make route change turning movements at a proposed future grade separated roundabout located at the existing location; 1.7 kilometers from current turning. Vehicles utilizing the at-grade crossing between Gurd Shola 1 and 2 can be re-routed to the crossings existing at the CMC roundabout. Closing the train vehicular intersection points limits the chances of delay occurring especially when vehicles halt on tracks due to traffic jams.

Countermeasures suggested above to curb crowding on AALRT may only be limited in the event of un-foreseen challenges such as sudden and lengthy power failures or the interference of OCS by foreign materials occurred thus leading to further occurrence in train delays. However, where crowding is the only source of train delay within the evening rush hour operational time, as is frequently the case with AALRT's E-W line, then successful implementation of the proposed countermeasures would lead to crowd reduction.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The crowding problem on AALRT can be arrested over the short term period by applying the countermeasures summarized below through an integrated approach;

Train supply issues facing the AALRT's operations during the evening rush hour can be mitigated through provision of additional rolling stock. As at January 2019, seven coupled trains would be needed to meet the passenger demand, and a further three trains, by the end of 2025. Rolling stock increment will have a significant multiplier effect such as reduced headway time from the average of 8.1 minutes to 6 minutes.

However, headway reduction can be successfully achieved through a clear policy on the minimum required time to avail stand-by trains upon breakdown of service trains. The present achievable time of 15 minutes needs to be reduced to 6 -10 minutes in order to maintain the designed headway of 6 minutes.

Measures such as use of station P.I.S coupled with use of controlled passenger boarding guarantee management of crowds on station platforms thus reducing the chaos, damage to rolling stock doors and time wastage witnessed at the end of 2018 on AALRT's E-W line PM peak journeys.

Elimination of seats on the middle section of the rolling stock in future train sets would improve passenger articulation inside the train. Not only would the measure ensure addition of over 2 m^2 space for majority of the standing passengers but also provide a secluded place for majority of commuters travelling to terminal station, thus freeing up door ways for passengers alighting at intermediate stations.

The common rail section of both E-W and N-S line presented an infrastructure challenge that limits further addition of trains to the E-W line beyond 13 trains/hr at a headway of 4 minutes and 36 seconds. Efforts to re-distribute passenger flow over the evening rush hour require the operator to encourage passengers to travel off the peak period through measures such as rewards (tokens, bonus points).

An integrated approach to implementation of the highlighted countermeasures would result to the reduction of train trip time delays, noted to occur over 3 – 6 minutes above the 5 minutes allowed by AALRT's operator due to unforeseen eventualities. Timely and un-interrupted train operations would thus reduce station crowding from LoS D, noted to occur 42.7% of total evening peak time, to LoS C. Additionally, on-train crowding would be reduced from LoS F, observed to occur over 67.8% of total evening peak time, to LoS E. Seat load factor would be minimized from 1.42; that occurred 75% of total evening peak time, to 1 thus comfortable trips.

Elimination of crush crowding leads to increased standing space on trains hence less body contact, eventually resulting to less hot and stuffy train carriages. Furthermore, less noisy train environments thus lower stress journeys would be achieved. These passenger ridership benefits will be a welcome relief to the more than 50% of commuters who expressed negative opinions on evening peak hour crowding on AALRT's line at the end of 2018. Timely train services under crowding LoS E inside trains would provide better ridership qualities thus arresting the commuters lost as a result of crowding leading to a reverse in the loss currently incurred by the AALRT operator.

5.2 Recommendations to curb crowding

The following is a summary of recommendations on crowding mitigation to AALRT's E-W line during evening rush hour as detailed in section 4.5 above;

- **Improving train supply;** achieved through three main ways. First, through addition of the requisite number of rolling stock and secondly, through future purchase of rolling sock that eliminates the current seats on the middle section of unit trains (section 2 of the train in figure 28 above). Finally, future planning of train timetables should provide more service trains on the Torhiloch – Ayat route between 5 – 6 pm, than on Ayat – Torhiloch route.
- **Employing efficient crowd management strategies**;
  Installation and use of station P.I.S as well as controlled passenger boarding can better curb crowding at station platforms. On-train crowding can also be easily managed through use of the existing train's in-built P.I.S that encourages standing passengers to use the future additional space provided through eliminating seats in middle section of the train.

- **Minimizing Train-Pedestrian and Train-Vehicular interactions;** through pedestrian re-routing and proper vehicular flow management. Pedestrian re-routing involves the installation of pedestrian foot bridges over at-grade stations while proper vehicular management entails closing un-necessary at grade vehicular-track intersections between Gurd-shola 1 and 2 as well as at Ayat, and the installation of vehicular fly-over at CMC and Management institute.

5.3 Recommendations for further studies

Crowding LOS scales used in this study to quantify platform and on-train congestion are based on American light rail transit as proposed by Fruin and the TCQSM manual respectively. However, in developing countries such as Ethiopia, where society may perceive and define crowding in a different manner, appropriate local LOS scales needs to be developed. Recommendation is thus made that research on appropriate local LOS scales for both platforms and trains crowding on the AALRT be conducted in the future.

Determining existing commuter demand for light rails requires obtaining maximum passenger flow volume and its location of occurrence, specific to the peak hour under investigation. In this study, a percentage of the daily passenger flow has been used to determine the estimated maximum cross-sectional flow as per AALRT's design for the E-W line during the evening rush hour. Passenger cross-sectional flow for light rails is dynamic; varying both over duration (monthly) and at peak/off-peak hours. Actual maximum passenger flow over the evening peak hour can be determined through extensive passenger flow survey on the track line in terms of both direction and time. Future regular passenger flow studies are thus recommended to determine either precise values or appropriate projection factors of maximum passenger cross-sectional flow for accurate determination of time based passenger demands on AALRT.

In determining line capacity for AALRT's E-W line, a reasonable value for passenger loading diversity factor (PHF) that represents uneven distribution of commuting passengers during evening peak hour within the vehicle itself, is required. This is determined by carrying out actual train passenger loading surveys on the AALRT. In this study, PHF based on the practice of other developing countries is used. Further detailed study on PHF based on passenger loading characteristics on AALRT is recommended.

Power failure frequently occurring on AALRT between EW 2 – EW 7 was attributed to electric cables frequently burning out as per feedback received from the AALRT operator upon further inquiry. Future studies are thus recommended to determine appropriate solutions to this frequent problem so as to minimizing train service interruptions given the existence of a dedicated 15 kV power line for AALRT's E-W line.

Direct economic loss has been computed by estimating number of passengers lost as at 2018 using estimates in the AALRT design as bench mark. In this case, actual operational conditions are factored in. Recommendation is however made that the approach of computing direct economic loss could also include be to first obtain the available capacity over the same period. Later, the number of passengers could be determined from the available capacity and finally multiplied by average revenue accrued from a passenger. In the latter case, the ideal value for the direct economic loss would be obtained.

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APPENDIX

1. Appendix A – AALRT passenger questionnaire (English)
   – AALRT passenger questionnaire (Amharic)
2. Appendix B – AALRT operator questionnaire
3. Appendix C – Torhiloch platform crowding data
4. Appendix D – Torhiloch platform crowding LoS
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7. Appendix G – Calculation of total travel time between stations
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ADDISABABA LIGHT RAIL TRANSIT PLATFORM SURVEY DATA SHEET

DATE: ______________________

TIME:______________________

PLATFORM NAME:_________________________

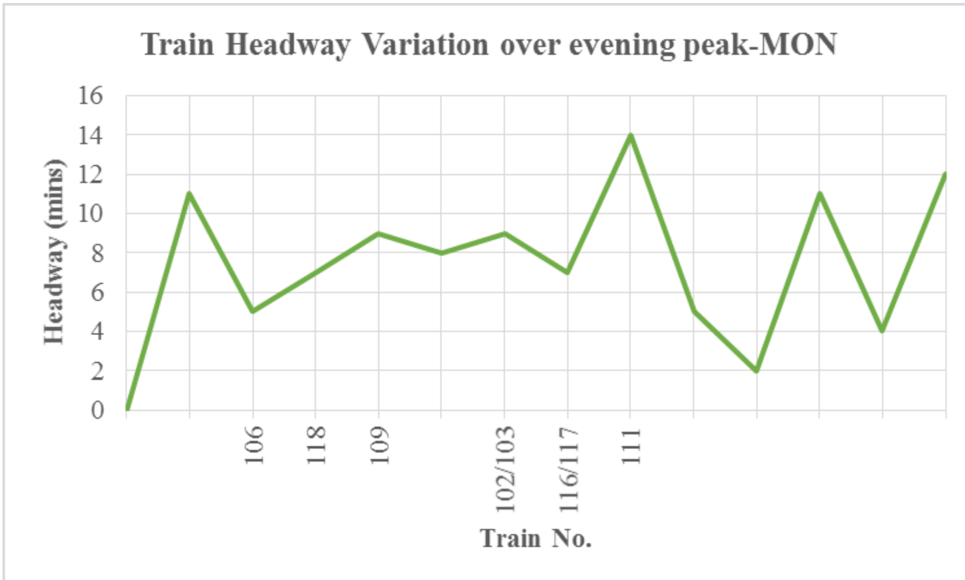
PLATFORM SIZE: L: ____ W: ____ A:_______

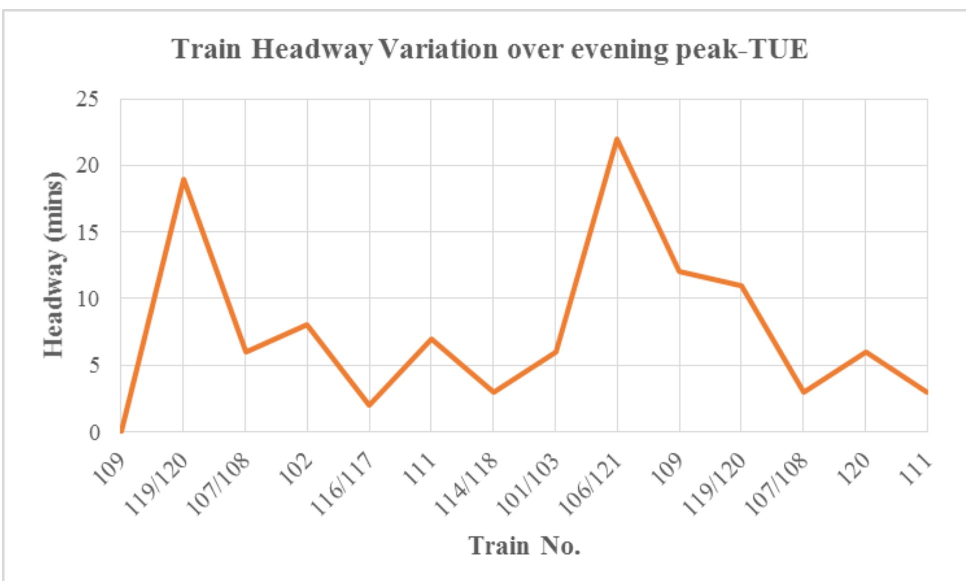
Train Info.	TIME	Pass No.	TIME	Pass No.	TIME	Pass No.	TIME	Pass No.
ARRIVAL								
DEPATURE								
ARRIVAL								
DEPATURE								
ARRIVAL								
DEPATURE								
ARRIVAL								
DEPATURE								
ARRIVAL								
DEPATURE								

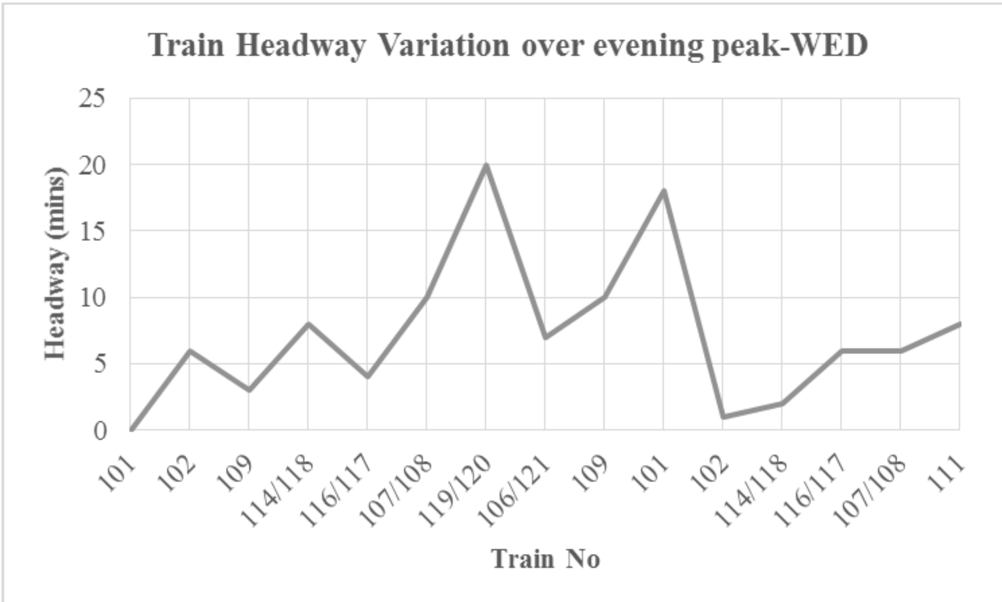
Appendix B : Torhiloch platform crowding data

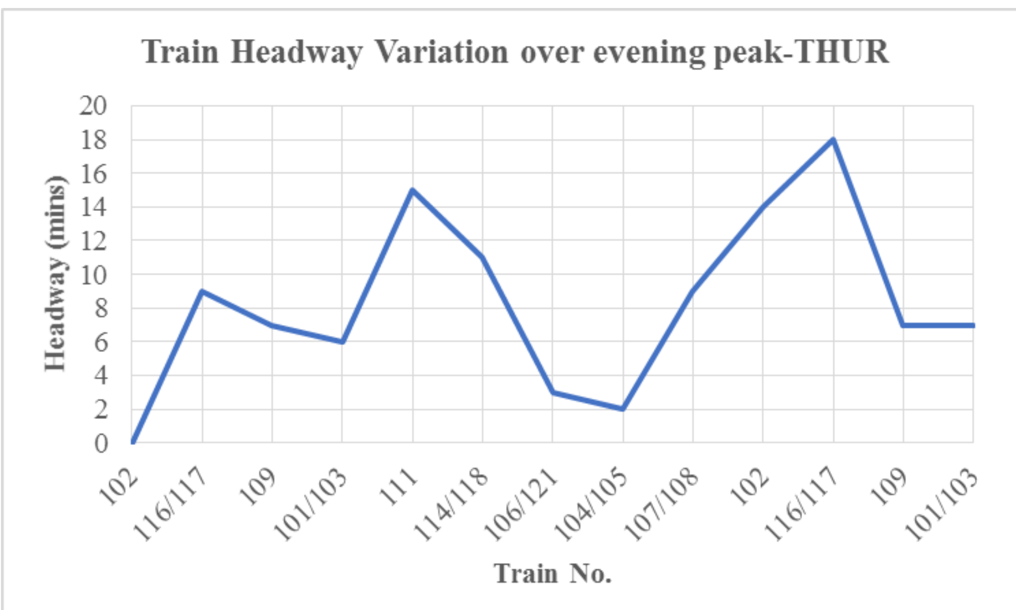
DAY	Torhiloch platform crowding data															
MONDAY	Crowding duration	16:00 - 16:12	16:14 - 16:26	16:28 - 16:36	16:38 - 16:48	16:50 - 17:00	17:02 - 17:12	17:14 - 17:28	17:30 - 17:42	17:44 - 17:58	18:00 - 18:08	18:10 - 18:14	18:16 - 18:28	18:30 - 18:38	18:40-18:54	18:56 - 19:00
	N	189	160	125	202	183	207	251	255	276	114	77	203	142	146	76
	Train No.			106	118	109		102/103	116/117	111						
	Arr-Dep time for Train	16:09 - 16:13	16:24 - 16:27	16:32 - 16:37	16:44 - 16:48	16:57 - 17:00	17:08 - 17:13	17:22 - 17:28	17:35 - 17:42	17:56 - 17:59	18:04 - 18:09	18:11 - 18:14	18:25 - 18:29	18:33 - 18:39	18:51-18:55	
	Headway		11	5	7	9	8	9	7	14	5	2	11	4	12	
	Dwell Time	4	3	5	4	3	5	6	7	3	5	3	4	6	4	
TUESDAY	Crowding duration	16:00 - 16:10	16:12 - 16:36	16:38 - 16:46	16:48 - 16:58	17:00 - 17:08	17:10 - 17:20	17:22 - 17:30	17:32 - 17:40	17:42 - 18:06	18:08 - 18:22	18:24 - 18:38	18:40 - 18:44	18:46 - 18:54	18:56 - 19:00	
	N	101	355	171	218	156	141	144	125	378	217	224	77	120	47	
	Train No.	109	119/120	107/108	102	116/117	111	114/118	101/103	106/121	109	119/120	107/108	120	111	
	Arr-Dep time	16:08 - 16:11	16:30 - 16:36	16:42 - 16:47	16:55 - 16:59	17:01 - 17:08	17:15 - 17:20	17:23 - 17:30	17:36 - 17:40	18:02 - 18:06	18:18 - 18:22	18:33 - 18:38	18:41 - 18:44	18:50 - 18:54	18:57 - 19:00	
	Headway		19	6	8	2	7	3	6	22	12	11	3	6	3	
	Dwell Time	3	6	5	4	7	5	7	4	4	6	5	3	4	3	
WEDNESDAY	Crowding duration	16:00 - 16:06	16:08 - 16:16	16:18 - 16:24	16:26 - 16:38	16:40 - 16:48	16:50 - 17:02	17:04 - 17:26	17:28 - 17:36	17:38 - 17:50	17:52 - 18:12	18:14 - 18:18	18:20 - 18:26	18:28 - 18:38	18:40 - 18:50	18:52 - 19:00
	N	193	146	109	210	183	212	428	185	261	348	77	95	166	184	132
	Train No.	101	102	109	114/118	116/117	107/108	119/120	106/121	109	101	102	114/118	116/117	107/108	111
	Arr-Dep time	16:03 - 16:06	16:12 - 16:16	16:19 - 16:24	16:32 - 16:38	16:42 - 16:49	16:59 - 17:02	17:22 - 17:26	17:33 - 17:37	17:47 - 17:50	18:08 - 18:13	18:14 - 18:18	18:20 - 18:26	18:32 - 18:38	18:44 - 18:50	18:58 - 19:00
	Headway		6	3	8	4	10	20	7	10	18	1	2	6	6	8
	Dwell Time	3	4	5	6	7	3	4	4	3	5	4	6	6	6	2
THURSDAY	Crowding duration	16:00 - 16:14	16:16 - 16:26	16:28 - 16:36	16:38 - 16:50	16:52 - 17:08	17:10 - 17:24	17:26 - 17:34	17:36 - 17:38	17:40 - 17:50	17:52 - 18:06	18:08 - 18:26	18:28 - 18:36	18:38 - 18:46	18:48 - 19:00	
	N	206	189	147	185	288	332	203	138	247	180	335	80	124	170	
	Train No.	102	116/117	109	101/103	111	114/118	106/121	104/105	107/108	102	116/117	109	101/103		
	Arr-Dep time	16:12 - 16:15	16:24 - 16:27	16:34 - 16:37	16:43 - 16:50	17:05 - 17:08	17:19 - 17:24	17:27 - 17:34	17:36 - 17:38	17:47 - 17:50	18:04 - 18:06	18:24 - 18:27	18:34 - 18:36	18:43 - 18:46		
	Headway		9	7	6	15	11	3	2	9	14	18	7	7		
	Dwell Time	3	3	3	7	3	5	7	2	3	2	3	2	3		
FRIDAY	Crowding duration	16:00 - 16:08	16:10 - 16:24	16:26 - 16:38	16:40 - 16:56	16:58 - 17:06	17:08 - 17:18	17:20 - 17:26	17:28 - 17:46	17:48 - 17:54	17:54 - 18:14	18:16 - 18:26	18:28 - 18:40	18:42 - 18:48	18:50 - 19:00	
	N	42	93	117	126	95	114	72	172	45	129	89	134	62	74	
	Train No.	119/120	101/103	106/121	114/118	107/108	111	109	104/105	119/120	101/103	106/121	114/118	107/108	111	
	Arr-Dep time	16:04 - 16:09	16:20 - 16:24	16:26 - 16:39	16:50 - 16:56	16:58 - 17:07	17:14 - 17:18	17:22 - 17:26	17:42 - 17:46	17:50 - 17:54	18:02 - 18:14	18:22 - 18:26	18:36 - 18:40	18:43 - 18:49	18:57 - 19:00	
	Headway		11	2	11	2	7	4	16	4	8	8	10	3	8	
	Dwell Time	5	4	13	6	9	4	4	4	4	12	4	4	6	3	

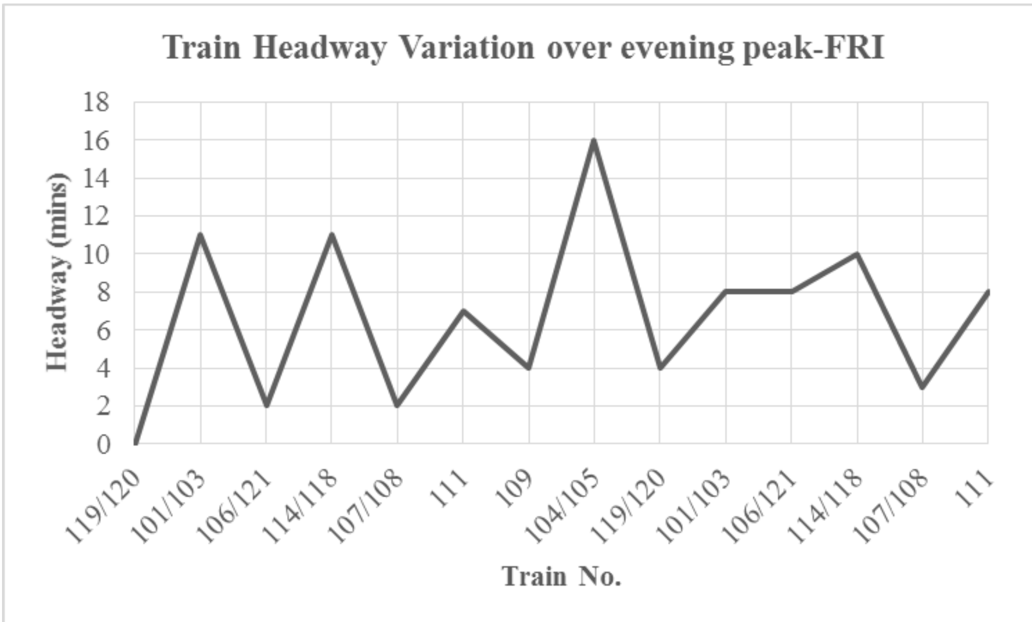
Appendix C: Headway variation on E-W line during evening rush hour






Train Headway Variation over evening peak-WED
25
20
15
10
5
0
Headway (mins)
101
102
109
114/118
116/117
107/108
119/120
106/121
109
101
102
114/118
116/117
107/108
111
Train No


Train Headway Variation over evening peak-THUR
20
18
16
14
12
10
8
6
4
2
0
Headway (mins)
102
116/117
109
101/103
111
114/118
106/121
104/105
107/108
102
116/117
109
101/103
Train No.



Train Headway Variation over evening peak-FRI
Headway (mins)
0
2
4
6
8
10
12
14
16
18
119/120
101/103
106/121
114/118
107/108
111
109
104/105
119/120
101/103
106/121
114/118
107/108
111
Train No.

Appendix D : Torhiloch platform LoS

Torhiloch Platform Crowding LOS																
MONDAY	Time	16:00 - 16:12	16:14 - 16:26	16:28 - 16:36	16:38 - 16:48	16:50 - 17:00	17:02 - 17:12	17:14 - 17:28	17:30 - 17:42	17:44 - 17:58	18:00 - 18:08	18:10 - 18:14	18:16 - 18:28	18:30 - 18:38	18:40- 18:54	18:56 - 19:00
	Total Passengers	189	160	125	202	183	207	251	255	276	114	77	203	142	146	76
	LOS as per table 11	C	C	C	D	D	D	D	D	D	B	A	D	C	C	A
	Actual Platform Area (m^2)	114	114	114	114	114	114	114	114	114	114	114	114	114	114	114
	Actual Area/Passenger	0.60	0.71	0.91	0.56	0.62	0.55	0.45	0.45	0.41	1.00	1.48	0.56	0.80	0.78	1.50
	Actual LOS	C	C	C	D	D	D	D	D	D	B	A	D	C	C	A
TUESDAY	Time	16:00 - 16:10	16:12 - 16:36	16:38 - 16:46	16:48 - 16:58	17:00 - 17:08	17:10 - 17:20	17:22 - 17:30	17:32 - 17:40	17:42 - 18:06	18:08 - 18:22	18:24 - 18:38	18:40 - 18:44	18:46 - 18:54	18:56 - 19:00	
	Total Passengers	101	355	171	218	156	141	144	125	378	217	224	77	120	47	
	LOS as per table 11	B	D	C	D	C	C	C	C	D	D	D	A	B	A	
	Actual Platform Area (m^2)	114	114	114	114	114	114	114	114	114	114	114	114	114	114	
	Actual Area/Passenger	1.13	0.32	0.67	0.52	0.73	0.81	0.79	0.91	0.30	0.53	0.51	1.48	0.95	2.43	
	Actual LOS	B	D	C	D	C	C	C	C	D	D	D	A	B	A	
WEDNESDAY	Time	16:00 - 16:06	16:08 - 16:16	16:18 - 16:24	16:26 - 16:38	16:40 - 16:48	16:50 - 17:02	17:04 - 17:26	17:28 - 17:36	17:38 - 17:50	17:52 - 18:12	18:14 - 18:18	18:20 - 18:26	18:28 - 18:38	18:40 - 18:50	18:52 - 19:00
	Total Passengers	193	146	109	210	183	212	428	185	261	348	77	95	166	184	132
	LOS as per table 11	D	C	B	D	D	D	E	D	D	D	A	B	C	D	C
	Actual Platform Area (m^2)	114	114	114	114	114	114	114	114	114	114	114	114	114	114	114
	Actual Area/Passenger	0.59	0.78	1.05	0.54	0.62	0.54	0.27	0.62	0.44	0.33	1.48	1.20	0.69	0.62	0.86
	Actual LOS	D	C	B	D	D	D	E	D	D	D	A	B	C	D	C
THURSDAY	Time	16:00 - 16:14	16:16 - 16:26	16:28 - 16:36	16:38 - 16:50	16:52 - 17:08	17:10 - 17:24	17:26 - 17:34	17:36 - 17:38	17:40 - 17:50	17:52 - 18:06	18:08 - 18:26	18:28 - 18:36	18:38 - 18:46	18:48 - 19:00	
	Total Passengers	206	189	147	185	288	332	203	138	247	180	335	80	124	170	
	LOS as per table 11	D	D	C	D	D	D	D	C	D	D	D	A	C	C	
	Actual Platform Area (m^2)	114	114	114	114	114	114	114	114	114	114	114	114	114	114	
	Actual Area/Passenger	0.55	0.60	0.78	0.62	0.40	0.34	0.56	0.83	0.46	0.63	0.34	1.43	0.92	0.67	
	Actual LOS	D	D	C	D	D	D	D	C	D	D	D	A	C	C	
FRIDAY	Time	16:00 - 16:08	16:10 - 16:24	16:26 - 16:38	16:40 - 16:56	16:58 - 17:06	17:08 - 17:18	17:20 - 17:26	17:28 - 17:46	17:48 - 17:54	17:54 - 18:14	18:16 - 18:26	18:28 - 18:40	18:42 - 18:48	18:50 - 19:00	
	Total Passengers	42	93	117	126	95	114	72	172	45	129	89	134	62	74	
	LOS as per table 11	A	A	B	C	A	C	A	C	A	C	A	C	A	A	
	Actual Platform Area (m^2)	114	114	114	114	114	114	114	114	114	114	114	114	114	114	
	Actual Area/Passenger	2.71	1.23	0.97	0.90	1.20	1.00	1.58	0.66	2.53	0.88	1.28	0.85	1.84	1.54	
	Actual LOS	A	A	B	C	B	B	A	C	A	C	A	C	A	A	

Appendix E: On-train LoS crowding results.

Monday: 21st January											
Train No.	No. of Alighting Passengers										
	St. Lideta	Coca-Cola	Torhiloch	**Totals**	Arr. At St. Lideta	Arr. At. Torhiloch	Seated Passengers	Standing Passengers	Seat Load Factor	Standing Passenger Area	Crowding Classification
105/106	44	57	371	472	16:03	16:10	184	288	1.42	0.22	E
107/108	69	38	381	488	16:22	16:28	184	304	1.42	0.21	E
114/118	58	52	317	427	16:33	16:41	184	243	1.42	0.26	E
116/117	35	43	197	275	16:42	16:48	130	145	1.00	0.43	D
119/120	49	51	281	381	16:57	17:03	130	251	1.00	0.25	E
111	45	32	294	371	17:16	17:22	92	279	1.42	0.11	F
101/103	52	46	402	500	17:22	17:28	184	316	1.42	0.20	E
109	50	33	391	474	17:52	18:02	92	382	1.42	0.08	F
104/105	69	78	570	717	18:08	18:16	184	533	1.42	0.12	F
107/108	64	66	623	753	18:19	18:24	184	569	1.42	0.11	F
114/118	23	14	177	214	18:25	18:33	130	84	1.00	0.75	C
116/117	18	28	254	300	18:31	18:31	130	170	1.00	0.37	D
115	29	18	342	389	18:42	18:47	92	297	1.42	0.11	F

Tuesday: 22nd January											
Train No.	No. of Alighting Passengers										
	St. Lideta	Coca-Cola	Torhiloch	**Totals**	Arr. At St. Lideta	Arr. At. Torhiloch	Seated Passengers	Standing Passengers	Seat Load Factor	Standing Passenger Area	Crowding Classification
105/104	51	28	224	303	16:00	16:05	130	173	1.00	0.36	D
102	37	29	225	291	16:12	16:16	92	199	1.42	0.16	F
101/103	44	31	277	352	16:23	16:28	130	222	1.00	0.28	E
107/108	46	26	260	332	16:35	16:40	130	202	1.00	0.31	E
111	35	29	258	322	16:52	16:57	92	230	1.42	0.14	F
114/118	45	72	386	503	17:04	17:10	130	373	1.00	0.17	F
116/117	41	36	310	387	17:14	17:20	130	257	1.00	0.25	E
109	46	27	321	394	17:30	17:35	92	302	1.42	0.10	F
119/120	61	76	496	633	17:45	17:51	184	449	1.42	0.14	F
104/105	46	38	265	349	17:51	17:57	130	219	1.00	0.29	E
102	43	30	422	495	18:16	18:22	92	403	1.42	0.08	F
101/103	32	61	631	724	18:23	18:28	184	540	1.42	0.12	F
107/108	14	21	189	224	18:26	18:35	130	94	1.00	0.67	B
111	38	23	334	395	18:46	18:52	92	303	1.42	0.10	F

Wednesday: 23rd January																
Train No.	No. of Alighting Passengers															
	Megenaga	Gurd Shola 1	Mgmt. Institute	Civil Service	St Michael	CMC	Meri	Ayat	**Totals**	Arr. At Megenaga	Arr. At. Ayat	Seated Passengers	Standing Passengers	Seat Load Factor	Standing Passenger Area	Crowding Classification
111	0	55	27	25	45	61	63	164	440	16:00	16:25	92	348	1.42	0.09	F
116/117	35	54	13	12	69	32	41	150	406	16:12	16:28	130	276	1.00	0.23	E
114/118	0	101	18	38	55	93	121	296	722	16:23	16:50	184	538	1.42	0.12	F
119/120	17	32	9	7	84	21	22	90	282	16:35	16:54	130	152	1.00	0.41	D
109	0	64	28	24	33	71	80	174	474	16:52	17:14	92	382	1.42	0.08	F
104/105	0	61	15	29	92	59	34	250	540	17:04	17:17	184	356	1.42	0.18	F
102	0	47	45	22	23	55	70	197	459	17:14	17:28	92	367	1.42	0.09	F
107/108	0	93	14	40	69	98	115	329	758	17:30	17:45	184	574	1.42	0.11	F
101/103	46	97	41	34	51	60	65	301	695	17:45	17:49	184	511	1.42	0.12	F
111	0	4	12	6	28	14	80	158	302	17:51	18:17	92	210	1.42	0.15	F
116/117	0	103	35	33	63	85	130	291	740	18:16	18:27	184	556	1.42	0.11	F
114/118	0	138	39	38	67	112	102	368	864	18:23	18:58	184	680	1.42	0.09	F
119/120	58	96	25	19	72	120	101	353	844	18:26	19:00	184	660	1.42	0.10	F
109	0	31	17	10	13	33	29	247	380	18:46	19:10	92	288	1.42	0.11	F

Thursday: 24th January																
Train No.	No. of Alighting Passengers															
	Megenaga	Gurd Shola 1	Mgmt. Institute	Civil Service	St Michael	CMC	Meri	Ayat	**Totals**	Arr. At Megenaga	Arr. At. Ayat	Seated Passengers	Standing Passengers	Seat Load Factor	Standing Passenger Area	Crowding Classification
119/120	3	74	35	28	47	66	60	209	487	16:08	16:35	184	303	1.42	0.21	E
107/108	44	38	13	19	19	57	36	108	321	16:12	16:45	130	191	1.00	0.33	E
102	0	55	12	26	36	59	80	183	439	16:34	17:02	92	347	1.42	0.09	F
114/118	18	95	21	33	39	68	85	205	543	16:40	17:11	184	359	1.42	0.18	F
104/105	2	86	9	27	43	78	95	322	653	16:57	17:22	184	469	1.42	0.13	F
109	0	56	13	25	23	35	55	177	371	17:08	17:33	92	279	1.42	0.11	F
101/103	0	115	16	42	58	122	150	341	828	17:32	18:01	184	644	1.42	0.10	F
111	59	70	8	14	25	47	82	118	415	17:37	18:03	92	323	1.42	0.10	F
116/117	60	105	4	43	61	83	192	352	896	17:49	18:23	184	712	1.42	0.09	F
119/120	48	130	12	14	54	52	52	294	644	17:54	18:27	184	460	1.42	0.14	F
107/108	0	98	19	26	57	82	107	280	650	18:06	18:37	184	466	1.42	0.14	F
102	0	70	16	11	29	53	91	161	415	18:29	18:55	92	323	1.42	0.10	F
114/118	22	82	25	23	68	121	100	398	814	18:42	19:10	184	630	1.42	0.10	F
104/105	12	50	11	16	71	135	60	297	641	18:47	19:13	184	457	1.42	0.14	F
109	0	25	22	15	30	49	63	244	426	18:58	19:23	92	334	1.42	0.09	F

Appendix F: Calculation of required train numbers

Estimated current maximum cross-sectional passenger flow

End of 2018 – 4402 passengers/hr

Line capacity

$$Line\ Capacity = \frac{P_{max}}{PHF * C_V} = \frac{4402}{0.9 * 508} = 9.63\ or\ 10\ trains/hr$$

Headway

$$Headway = \frac{60(min)}{N} = \frac{3600\ sec}{10} = 360\,\text{sec} = 6\ minutes$$

Station dwell time

$$\text{Total dwell time (min)} = \text{Number of stations} * Dwell\ time/\ Station$$

$$\frac{1760}{60}\text{(min)} = (22)2 * 40\ sec = 29.33\ \text{minutes}$$

Turn- around and lay over time at turn backs

$$t_{lo} = \sqrt{\frac{2(L_t + f_{sa}d_{ts})}{a+d}} + \sqrt{\frac{(L_t + f_{sa}d_{ts})}{2a}} + t_s + L_t * v =$$

$$\sqrt{\frac{2(60 + 6.09 * 4)}{1 + 1.1}} + \sqrt{\frac{(60 + 6.09 * 4)}{2 * 1}} + 6 + 60 * 1 = 81.45\ approximately\ 85\ seconds$$

Total travel time between stations = 58 min (Consistent with AALRT E-W line operations) – see Appendix G

Total round trip time

$$Total\ round\ trip\ time = \Sigma\, TT + \Sigma\, T_d + \Sigma\, t_{lo}$$

$$Total\ round\ trip\ time = 58 + 29.33 + 2\,(\frac{85}{60}) = 90.16\ minutes$$

Appendix G; Total travel time between stations

	Station Interval		Gradient Out	Station to station length	Max Speed (Km/hr)	Critical Distance	Allowable average speed (Km/hr)	Station to Station Travel Time (Sec)	Travel time at departing and arrival stations	Number of Turn-outs and Junctions	Number of level Crossings	Distance travel in Level Crossing	Additional time at crossing	Total Travel Time
	From	To	Go	S	Vmax	Sc	V	Ts	tp1+tp2				tL	TT (Sec)
1	Start	EW1	1	152	20	29.66	20	32.66	12.6	1	0	0	5.30	50.55
2	EW1	EW2	-0.5	1200	65	311.18	65	83.70	12.3	1	1	30	27.26	123.30
3	EW2	EW3	-1	1032	65	311.18	65	74.39	13.2	0	1	174	31.58	119.16
4	EW3	EW4	0.6	763	65	311.18	65	59.49	13.4	0	0	0	0.00	72.93
5	EW4	EW5	1	800	65	311.18	65	61.54	13.4	0	1	30	13.63	88.61
6	EW5	EW6	1	665	65	311.18	65	54.07	12.6	0	0	0	0.00	66.70
7	EW6	EW7	-0.4	910	65	311.18	65	67.63	12.3	0	1	145	27.96	107.93
8	EW7	EW8	-1	1026	65	311.18	65	74.06	12.7	1	1	30	27.26	114.06
9	EW8	EW9	-0.2	769	65	311.18	65	59.83	13.3	0	0	0	0.00	73.08
10	EW9	EW10	0.7	716	65	311.18	65	56.89	13.3	0	0	0	0.00	70.14
11	EW10	EW11	0.7	686	65	311.18	65	55.23	12.7	0	0	0	0.00	67.97
12	EW11	EW12	-0.2	627	65	311.18	65	51.96	12.3	0	0	0	0.00	64.30
13	EW12	EW13	-1	974	65	311.18	65	71.18	12.4	0	0	0	0.00	83.57
14	EW13	EW14	-0.9	615	65	311.18	65	51.30	12.3	0	0	0	0.00	63.63
15	EW14	EW15	-1	533	65	311.18	65	46.75	12.3	1	0	0	13.63	72.72
16	EW15	EW16	0	580	65	311.18	65	49.36	12.8	1	0	0	13.63	75.84
17	EW16	EW17	0.2	385	65	311.18	65	38.56	13	0	0	0	0.00	51.52
18	EW17	EW18	0.4	500	60	265.15	60	45.91	13.1	0	0	0	0.00	58.98
19	EW18	EW19	0.2	628	60	265.15	60	53.59	13	0	0	0	0.00	66.55
20	EW19	EW20	-1	675	65	311.18	65	54.62	12.3	0	0	0	0.00	66.96

21	EW20	EW21	0.5	672	65	311.18	65	54.45	13.1	1	0	0	13.63	81.22
22	EW21	EW22	-0.85	699	50	184.13	50	63.59	12.4	1	0	0	10.13	86.13
23	EW22	EW21	-0.45	699	50	184.13	50	63.59	12.6	1	0	0	10.13	86.33
24	EW21	EW20	0.85	672	65	311.18	65	54.45	12.6	1	0	0	13.63	80.67
25	EW20	EW19	-0.5	675	65	311.18	65	54.62	13.4	0	0	0	0.00	68.06
26	EW19	EW18	1	628	60	265.15	60	53.59	12.7	0	0	0	0.00	66.33
27	EW18	EW17	-0.2	500	60	265.15	60	45.91	12.6	0	0	0	0.00	58.34
28	EW17	EW16	-0.4	385	50	184.13	50	40.98	12.7	0	0	0	0.00	53.72
29	EW16	EW15	-0.2	580	65	311.18	65	49.36	12.8	1	0	0	13.63	75.84
30	EW15	EW14	0	533	65	311.18	65	46.75	13.4	1	0	0	13.63	73.83
31	EW14	EW13	1	615	65	311.18	65	51.30	13.4	0	0	0	0.00	64.67
32	EW13	EW12	0.9	974	65	311.18	65	71.18	13.4	0	0	0	0.00	84.62
33	EW12	EW11	1	627	65	311.18	65	51.96	13	0	0	0	0.00	64.92
34	EW11	EW10	0.2	686	65	311.18	65	55.23	12.5	0	0	0	0.00	67.71
35	EW10	EW9	-0.7	716	65	311.18	65	56.89	12.5	0	0	0	0.00	69.37
36	EW9	EW8	-0.7	769	65	311.18	65	59.83	13	0	0	0	0.00	72.79
37	EW8	EW7	0.2	1026	65	311.18	65	74.06	13.4	1	1	30	27.96	114.76
38	EW7	EW6	1	910	65	311.18	65	67.63	13.1	0	1	145	13.63	108.67
39	EW6	EW5	0.4	665	65	311.18	65	54.07	12.3	0	0	0	0.00	66.40
40	EW5	EW4	-1	800	65	311.18	65	61.54	12.3	0	1	30	13.68	87.51
41	EW4	EW3	-1	763	65	311.18	65	59.49	12.5	0	0	0	0.00	72.03
42	EW3	EW2	-0.6	1032	65	311.18	65	74.39	13.4	0	1	174	31.58	119.41
43	EW2	EW1	1	1200	65	311.18	65	83.70	13.1	1	1	30	27.26	124.09
44	EW1	Start	0.5	152	20	29.46	20	32.66	12.8	1	0	0	5.30	50.81
											Total travel time between Stations			57.61
														58 Min

Appendix H: Torhiloch platform LoS redistribution

Torhiloch platform LoS redistribution											
ACTUAL LoS ON TUESDAY	Time	17:00 - 17:08	17:10 - 17:20	17:22 - 17:30	17:32 - 17:40	17:42 - 18:06					
	Total Passengers	156	141	144	125	378					
	LoS	C	C	C	C	D					
EXPECTED LoS ON TUESDAY	Time	17:00 – 17:06	17:06 - 17:12	17:12 - 17:18	17:18 - 17:24	17:24 – 17:30	17:30 – 17:36	17:36 – 17:42	17:42 – 17:48	17:48 – 17:54	17:54 – 18:00
	Total Passengers	117	96	72	59	97	76	84	98	100	64
	LoS	B	B	A	A	A	A	A	B	B	A
ACTUAL LoS ON WEDNESDAY	Time	17:04 - 17:26	17:28 - 17:36	17:38 - 17:50	17:52 - 18:12						
	Total Passengers	428	185	261	348						
	LoS	E	D	D	D						
EXPECTED LoS ON WEDNESDAY	Time	17:00 – 17:06	17:06 - 17:12	17:12 - 17:18	17:18 - 17:24	17:24 – 17:30	17:30 – 17:36	17:36 – 17:42	17:42 – 17:48	17:48 – 17:54	17:54 – 18:00
	Total Passengers	103	106	106	128	99	111	121	86	111	69
	LoS	B	B	B	C	B	B	B	A	B	A

<u>Appendix I: Estimation of daily evening rush hour cross-sectional passenger flow.</u>

Growth factor method was used as shown below;

$$\boldsymbol{V^{\wedge}{}_i = V_i * G_i}$$

Where;

- $V^{\wedge}{}_i = Future\ Passenger\ flow\ Volumes$
- $V_i = Current\ passenger\ flow\ Volume$
- $G_i = Expansion\ Growth\ Factor$

Growth factor was determined as follows;

$$\boldsymbol{G_i = \frac{Designed\ Passenger\ flow\ volumes\ by\ 2025}{Designed\ passenger\ flow\ volumes\ in\ 2018}}$$

Daily passenger flow forecast (AALRT CREC 2012 design)

2018 - 121,500 persons / day

2025 - 242,000 persons/day

<u>Actual/existing daily passenger flow</u>

$$= \frac{Total\ number\ of\ passengers\ in\ 2018}{No.of\ operational\ days} = \frac{21{,}825{,}181}{365} = 59{,}750\ passengers/day.$$

<u>Estimated average daily passenger flow by 2025</u>

$$\boldsymbol{Daily\ passenger\ flow = \frac{Designed\ Passenger\ flow\ by\ 2025}{Designed\ passenger\ flow\ in\ 2018} * Average\ daily\ passenger\ flow\ in\ 2018}$$

$$\frac{242{,}000}{121500} * 59{,}750 = 119{,}009\ \text{Passengers/day.}$$

<u>Estimated average passenger number in a typical working week;</u>

66,640 passengers/working week between October – December 2018 (AALRT Passenger flow data)

<u>Future passenger flow for a typical working week</u>

$\frac{119{,}009*66640}{59750}$ = 132,733 passenger/working day.

Total passenger flow during the evening hour in 2025

$$Estimated\ short\ term\ daily\ evening\ rush\ hour\ passenger\ flow = \frac{\boldsymbol{Short\ term\ passenger\ traffic\ volume\ at\ PM\ peak}}{\boldsymbol{Initial\ term\ passenger\ traffic\ volume\ at\ PM\ peak}} * \boldsymbol{existing\ traffic\ volume\ during\ PM\ peak}$$

$$\frac{18100}{9000} * 26257 = 52{,}806\frac{passengers}{pm\ peak\ hr}\ by\ 2025.$$

Expected proportion of evening to daily commuters in 2025

$$\boldsymbol{Estimated\ proportion\ of\ evening\ rush\ hour\ commuters\ to\ daily\ commuters} = \frac{\boldsymbol{Evening\ rush-hour\ commuters\ by\ 2025}}{\boldsymbol{Total\ evening\ rush\ hour\ commuters\ by\ 2025}} * \boldsymbol{100}$$

$$\frac{52{,}806}{119{,}009} * 100 = 44.37\%$$

Typical working week average passenger flow over evening rush hour in 2025

$$\boldsymbol{Estimated\ passenger\ flow\ over\ evening\ rush\ hour} = \boldsymbol{Expected\ proportion\ of\ evening\ to\ daily\ commuters} * \boldsymbol{Expected\ future\ passenger\ flow\ for\ a\ typical\ working\ week}$$

$$0.4437 * 132{,}733 = 58{,}894\frac{passengers}{working\ day}$$

Expected % proportional passenger flow for the evening peak in 2025

18,100 p/hr – 2025 (CREC 2012 design) thus 54,300 p/evening rush hr.

242,000 p/day – 2025 (CREC 2012 design)

Thus;

$$\%\ \boldsymbol{of\ PM\ peak\ passengers\ in\ 2025} = \frac{\boldsymbol{Total\ estimated\ evening\ passenger\ flow\ by\ 2025}}{\boldsymbol{Total\ daily\ PM\ peak\ passenger\ flow\ by\ 2025}} * \boldsymbol{100}$$

$$\frac{54{,}300}{242{,}000} * 100 = 22.44\ \%$$

Passenger cross-sectional flow for 22.44% daily passengers = 4536/hr passengers (CREC 2012 design)

Thus, proportional cross-sectional flow for the expected 44.37% = 8973/hr passengers.

ADDIS ABABA INSTITUTE OF TECHNOLOGY (AAiT)

AFRICAN RAILWAY CENTER OF EXCELLENCE (ARCE)

AALRT OPERATOR QUESTIONNAIRE

You are invited to participate in this research because of your role as the AALRT operator. Your input is essential in determining the source and solution of the Overcrowding problem on the AALRT.

PURPOSE OF QUESTIONNAIRE

The purpose of this questionnaire is to gather information about AALRT's (1) Ridership (2) Key operational issues (3) Strategic issues and future planning to tackle the overcrowding challenge. Data gathered from this questionnaire will be used for academic purpose only.

Response to this questionnaire can be emailed to: dancanmmuturi12@gmail.com

You can also contact me on +251788727542 on any questions concerning this questionnaire

Responses to this questionnaire will be treated in the strictest confidence. Your support is greatly appreciated.

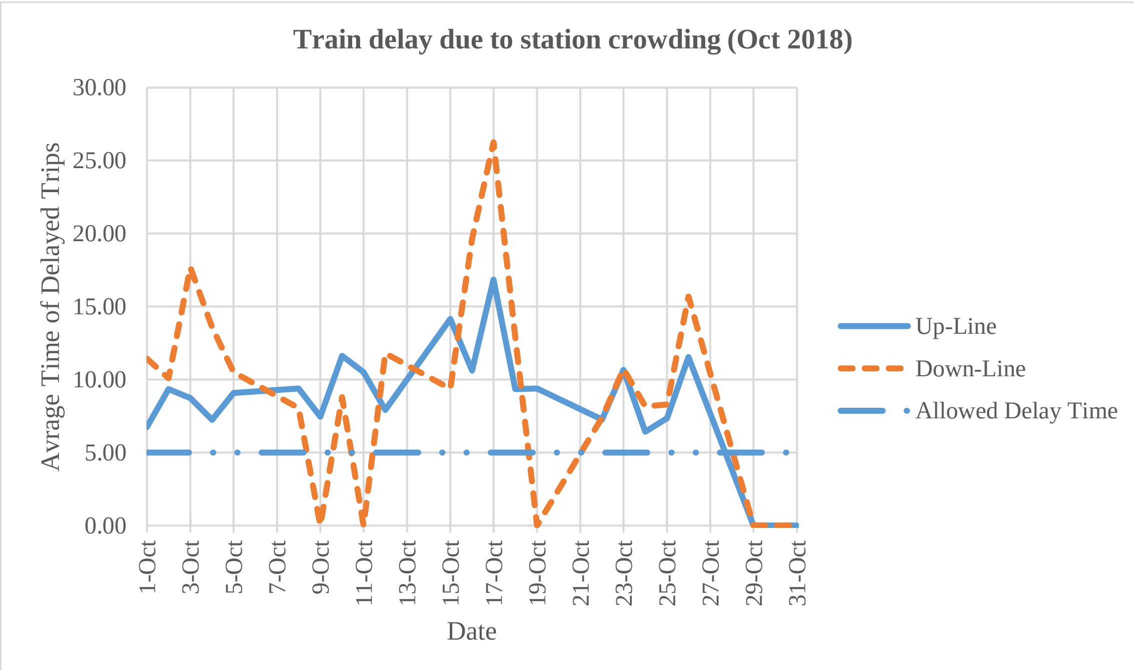
1. Can you provide me with peak ridership statistics on AALRT's EW line?
2. Which section of the EW line do you consider severely congested?
3. Can you provide me with data on the following items during PM peak periods for the EW route for Oct 2018-Jan 2019:
    a. Frequency of trains
    b. Waiting time
    c. Dwell times
    d. Headway of trains
    e. Number or percentage of missed headways
    f. Number or percentage of train services cancelled
    g. Cause and number or percentage of train break downs
    h. Station/platform on the E-W line that experiences severe passenger crowding and respective platform layout drawings.
4. Can you provide me with initial assessment of AALRT's passenger data for the initial period (end of 2018) and the last three months (Oct –Dec 2018) monthly ridership statistics?
5. Can you provide me with layout drawings of AALRT's train wagons on the E-W line?
6. What are the three frequent challenges that cause service interruptions along AALRT's EW line especially during peak hour? Do you have summary data that shows percentage of each challenge in relationship to service interruptions between Oct 2018`-Jan 2019?
7. What is the
    I. Operational cost incurred to run a single train set per day?
    II. Average revenue for one train set and two train set on each route during peak hour when there is lack of service interruptions? When Service Interruptions are present?
    III. Average daily revenue per passenger per day on the EW line?
8. What's your opinion on the causes of passenger crowding during peak times?

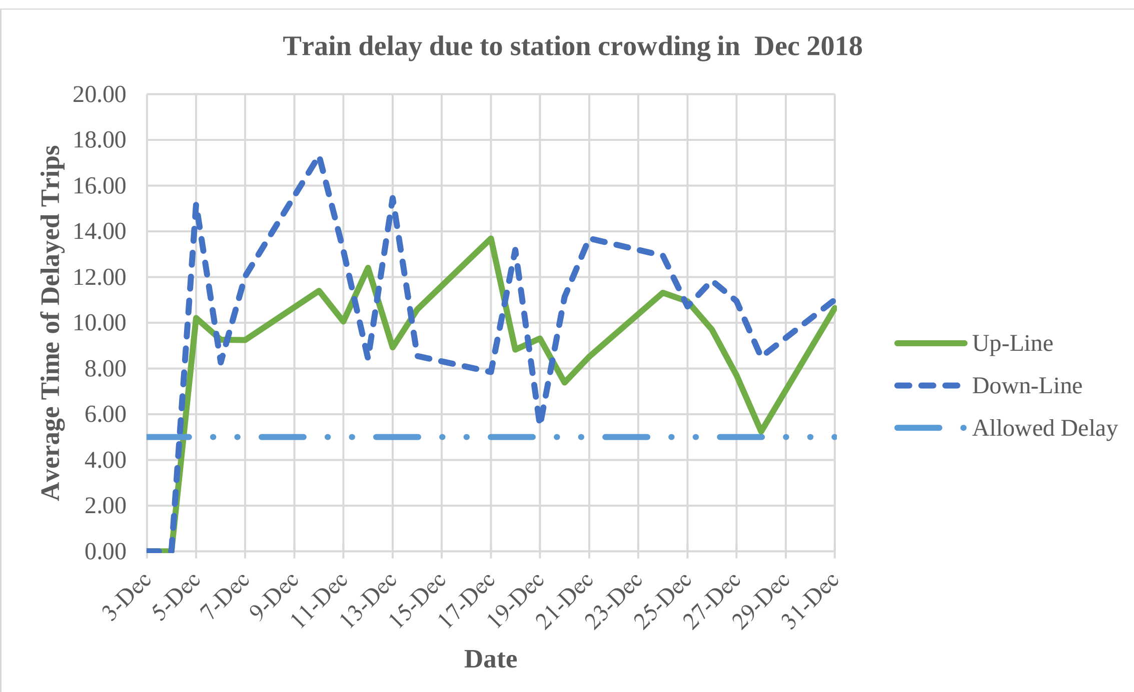
Thanks you very much for taking time to complete this questionnaire.

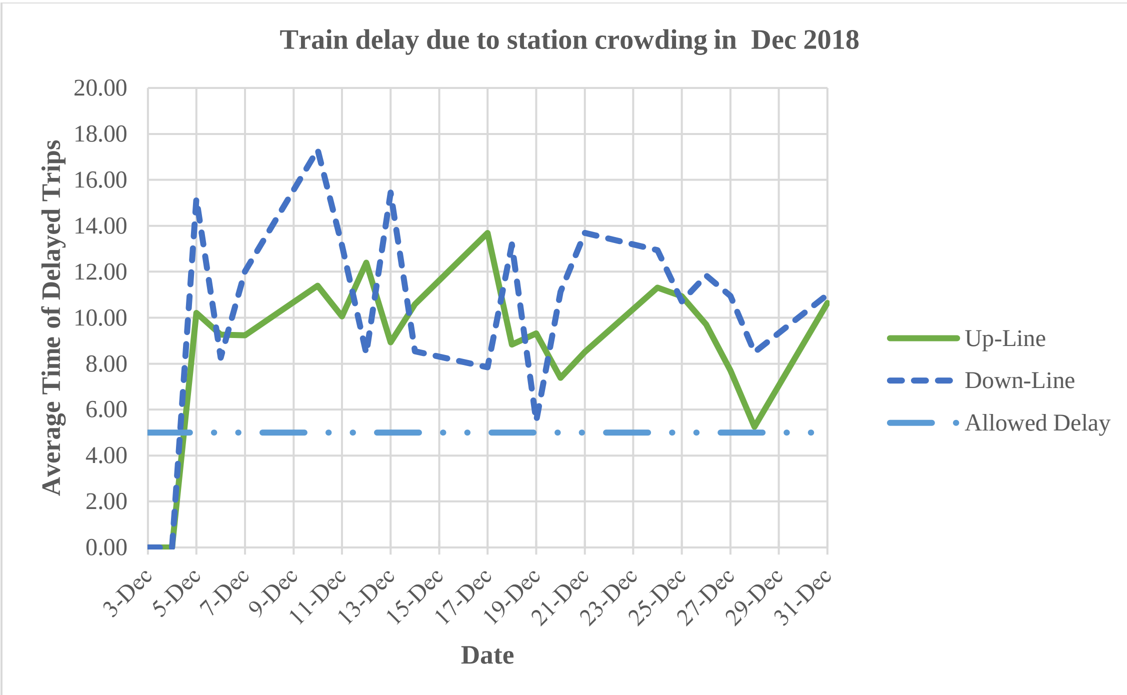
MECHANICAL FAULTS AFFECTING EVENING RUSH-HOUR OPERATIONS (OCT – DEC 2018)						
Oct-18						
Date	**Issue**	**Faulty Train**	**Replacement Train**	**Line Un-serviced Time (Min)**	**Observations made from OCC** [48] **reports**	**Failure Effect to Evening Peak hour Crowding**
16/10/2018	Brakes	109	-	12	Problem sorted out while on track	Headway interference
22/10/2018	Horn	119/120	-	53	Repaired and resumed operation	Train capacity reduction
23/10/2018	Electrics	101/102	-	21	Problem sorted out while on track	Headway interference
Total time of service disruption				86		
Nov-18						
1/11/2018	Door	119/102	-	180	Removed from operations since morning	Train capacity reduction
	Door	101/102	-	7	Problem sorted out while on track	Headway interference
7/11/2018	Door	101/102	111/110	49	-	Train capacity reduction
16/11/2018	Air – Con	114/118	106/121	74	-	Train capacity reduction
Total time of service disruption				310		
Dec-18						
4/12/2018	Air – Con	116/117	107/108	7	Problem occurred in the afternoon and spilled over to evening rush-hour	Headway interference
5/12/2018	Door	115	101	58	-	Headway interference
10/12/2018	Horn	110/111	101	35	Smaller replacement train used	Train capacity reduction
14/12/2018	Doors	107/108	-	15	Fault occurred in the last 15 min of peak hr	Train capacity reduction
27/12/2018	Electrics	103/101	115	15	Smaller replacement train used	Train capacity reduction
Total time of service disruption				130		

<table>
<tr><th colspan="7">POWER FAULTS AFFECTING EVENING RUSH-HOUR OPERATIONS (OCT – DEC 2018)</th></tr>
<tr><td colspan="7">Oct-18</td></tr>
<tr><th>Dates</th><th>Power Issue</th><th>Affected Section</th><th>Remedial Action</th><th>Fault Duration (Min)</th><th>Trips Cancelled</th><th>Other Effects</th></tr>
<tr><td>19/10/2018</td><td>EW 7,13,20 Substations off</td><td rowspan="3">EW 4 - EW 12</td><td rowspan="3">Telephone blocking method used with 6 trains</td><td>94</td><td>-</td><td rowspan="3">Part route train operation, Passengers forced to clear-off trains, 2 trains late by 75 minutes</td></tr>
<tr><td>30/10/2018</td><td>EW 7 Substation off</td><td>180</td><td>2</td></tr>
<tr><td>31/10/2018</td><td>EW 7,13,20 Substations off</td><td>95</td><td>13</td></tr>
<tr><td colspan="4">Total time of smooth service disruption & cancelled trips respectively</td><td>369</td><td>15</td><td>-</td></tr>
<tr><td colspan="7">Nov-18</td></tr>
<tr><td>1, 2,5,6,7,8 Nov 2018</td><td>EW 7 Substation off</td><td rowspan="2">EW 4 - EW 12</td><td rowspan="2">Telephone blocking method used with 6 trains</td><td>1080</td><td>358</td><td>-</td></tr>
<tr><td>14/11/2018</td><td>EW 2 & 7 Substations off</td><td>148</td><td>17</td><td>-</td></tr>
<tr><td>27/11/2018</td><td>EW 13 & 20 Substations off</td><td>Whole line</td><td>Trains stop at stations and wait for fault correction</td><td>35</td><td>0</td><td>Trains clear passengers, part route train operations at EW 1 - EW 16</td></tr>
<tr><td colspan="4">Total time of smooth service disruption & cancelled trips respectively</td><td>1263</td><td>375</td><td>-</td></tr>
<tr><td colspan="7">Dec-18</td></tr>
<tr><td>3/12/2018</td><td rowspan="2">EW 2 & 7 Substations off</td><td rowspan="2">EW 4 - EW 12</td><td rowspan="2">Telephone blocking method used with 6 trains</td><td>42</td><td>180</td><td>Trains clear passengers, Part route train operations</td></tr>
<tr><td>4/12/2018</td><td>35</td><td>50</td><td>-</td></tr>
<tr><td>19/12/2018</td><td>EW 20,22,16,13,10,7,2 Substations off</td><td>Whole line, then all sections except EW 8 - EW 22</td><td>Part route operation from EW 8 - EW 22</td><td>35</td><td>85</td><td>Complete stop to operations for 2 hrs 25 min, Part route operations for 35 min</td></tr>
<tr><td>25/12/2018</td><td>EW 13 & 20 Substations off</td><td>107/108</td><td>Trains stop at stations and wait for fault correction</td><td>19</td><td>0</td><td>Train delays</td></tr>
<tr><td colspan="4">Total time of smooth service disruption & cancelled trips respectively</td><td>131</td><td>315</td><td></td></tr>
</table>

Appendix M : **Train delay analysis due to crowding.**







Train delay due to station crowding in Dec 2018
Average Time of Delayed Trips
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
3-Dec
5-Dec
7-Dec
9-Dec
11-Dec
13-Dec
15-Dec
17-Dec
19-Dec
21-Dec
23-Dec
25-Dec
27-Dec
29-Dec
31-Dec
Date
Up-Line
Down-Line
Allowed Delay

Appendix N: Direct economic loss calculation.

Evening peak designed passenger demand in 2018.

2018 – 121,500 passenger/day (CREC 2012 AALRT design)

Actual evening peak 2018 passenger demand.

$$\boldsymbol{Actual\ average\ daily\ passenger\ flow\ = \frac{Total\ number\ of\ passengers\ in\ 2018}{No.of\ operational\ days}}$$

$$= \frac{\mathbf{21,825,181}}{\mathbf{365}} = \mathbf{59,750}\ \boldsymbol{passengers/day}$$

Number of passengers lost due to AALRT's in-sufficient train supply during the PM peak.

2018 PM peak designed passenger flow estimate = 20.73% of total daily flow (CREC 2012 design)

$$Proporional\ PM\ designed\ \ passenger\ flow\ to\ actual\ flow = \frac{20.73*121,500}{59,750} = \ 42.15\%$$

$$Est. Passengers\ lost\ at\ PM\ peak\ on\ E-W\ line$$
$$=\ Designed\ PM\ passenger\ demand\ –\ Current\ PM\ Passenger\ numbers$$
$$Est. percentage\ Passengers\ lost\ \ =\ 42.15\%\ –\ 39.4\%$$
$$=\ 2.75\%\ of\ actual\ passenger\ flow$$

Average passenger flow/ working week: October – December 2018 = 66,640 passenger/ week 39.4% passengers flow/ working day = 26,257 commuters/ working day/ PM peak (2018).

$$Passengers\ lost\ at\ PM\ peak\ on\ E-W\ line = \frac{2.75}{100} * 26,257 = 723\ passengers$$

Average revenue accrued from a single passenger on the E-W line.

Average daily fare gate revenue (October – December 2018) = 13,080,482 birr (AALRT operator)

$$Average\ daily\ revenue\ \ = \frac{13,080,482}{65} = 201,239\ birr$$

Average daily passenger revenue for a typical day in a working week (October – December 2018)

$$Average\ daily\frac{revenue}{passenger} = \frac{201{,}239}{66{,}640} = 3.02\frac{birr}{passenger}/day$$

Evening rush hour revenues that would have been accrued on E-W line from passenger lost.

$$Evening\ rush\ hour\ revenue\ that\ would\ be\ accrued$$
$$= Est.passengers\ lost\ at\ PM\ Peak\ on\ E-W\ main\ line$$
$$*\ Average\ revenue\ from\ single\ passenger$$
$$723\ *3.02 = 2{,}183.46\ birr$$

Change in operational costs incurred due to running an extra train set over rush hour period.

Operational costs: specific to those expected to be incurred due to an additional train sets on E-W line. Infrastructure and management costs of existing line were not considered since these elements were already in place; 976 birr/train/evening rush hour (AALRT operator, 2018)

Distribution of passenger loss on E-W line per every hr:

TIME	% Distribution	Estimated Passenger Volume
4 -5 Pm	33.66	244
5 -6 Pm	37.59	271
6 -7 Pm	28.75	208
TOTALS		723

Additional rolling stock number required within each hour = At-least 2 trains; one train set per direction, thus change in operational cost = 976 ×2 = 1952 birr.

Revenue lost

$$\boldsymbol{Revenue\ lost = Possible\ revenue\ to\ be\ accrued - Operational\ Cost\ change}$$

$\mathbf{2183.46 - 1952 = 231.46}$ birr/ evening rush hour/ working day or
or 60,179.60 birr/year.

ADDIS ABABA INSTITUTE OF TECHNOLOGY (AAiT)

AFRICAN RAILWAY CENTER OF EXCELLENCE (ARCE)

AALRT PASSENGER QUESTIONNAIRE

You are invited to participate in this research because of your role as the passenger. Your input is essential in determining overcrowding solutions on the AALRT service.

PURPOSE OF QUESTIONNAIRE

Your input in this questionnaire will offer you a valuable opportunity to share your commuting experience and voice out your ideas for academic research on how AALRT's overcrowding problem can be solved.

Kindly Tick **one** answer accordingly

1. How long have you been using this rail line on a regular basis?

   Never/ First time ☐ **6-12 months** ☐ **More than 2 years** ☐

   1-6 months ☐ **1-2 years** ☐

2. How often do you use the train

   3 or more times a week ☐ **1 or 2 times a month** ☐

   Once or twice a week ☐ **Less often** ☐

3. How long do you have to wait for the train at the station? **……. Minutes.**
4. How would you describe a typical trip over the past month?

There are always seats available ☐ **I usually stand and it is crowded** ☐

There are usually seats available ☐ **I usually stand and it is very crowded** ☐

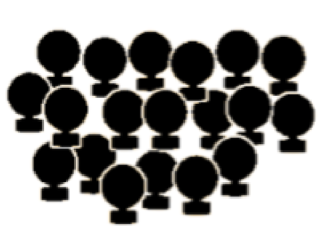
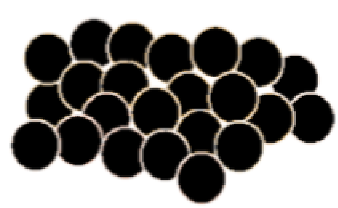
I usually stand but there is space for standing ☐ **It varies** ☐

5. How often do you encounter delays during your commute to work?

   Not at all ☐ **Often** ☐

   Sometimes ☐ **All the time** ☐

6. **How crowded is the train you were on today**? (Tick only one) in the next page

 1. All of body visible: **No crowd issues**	 2. Only body & head visible: **Slightly Crowded**
 3. Only shoulder & head visible: **Crowded**	 4. Only head visible: **Extremely crowded**

7. How crowded is the train that you are on today? Please tick **one** answer on each of the category.

A	5	Extremely Dense	B	5	Extremely Confining	C	5	Extremely Chaotic	D	5	Extremely Unpleasant
	4	Very Dense		4	Very Confining		4	Very Chaotic		4	Very Unpleasant
	3	Dense		3	Confining		3	Chaotic		3	Unpleasant
	2	Slightly Dense		2	Slightly Confining		2	Slightly Chaotic		2	Slightly Unpleasant
	1	Not Dense		1	Not Confining		1	Not Chaotic		1	Not Unpleasant

8. How is the **physical environment inside the train** that you commute on today? **Please tick one answer in A,B,C,D.**

A	5	Extremely Hot	B	5	Extremely Stuffy	C	5	Extremely Smelly	D	5	Extremely noisy
	4	Very Hot		4	Very Stuffy		4	Very Smelly		4	Very noisy
	3	Hot		3	Stuffy		3	Smelly		3	Noisy
	2	Slightly Hot		2	Slightly Stuffy		2	Slightly Smelly		2	Slightly Noisy
	1	Not Hot		1	Not Stuffy		1	Not Smelly		1	Not Noisy

9. **How do you feel inside the train** you are commuting on today? **Please tick one answer.**

A	5	Extremely Restricted	B	5	Extremely Uncomfortable	C	5	Extremely Frustrated	D	5	Extremely Stressful
	4	Very Restricted		4	Very Uncomfortable		4	Very Frustrated		4	Very Stressful
	3	Restricted		3	Uncomfortable		3	Frustrated		3	Stressful
	2	Slightly Restricted		2	Slightly Uncomfortable		2	Slightly Frustrated		2	Slightly Stressful
	1	Not Restricted		1	Not Uncomfortable		1	Not Frustrated		1	Not Stressful

10. In your opinion, **what three areas should the train company address** to overcome passenger overcrowding? Give a brief answer

1. ....
2. ....
3. ....

አዲስ አበባ የቴክኖሎጂ ኢንስቲቲዩት

የአፍሪካ የባቡር የልቀት ማዕከል

የአዲስ አበባ ቀላል የባቡር መንገድ የተሳፋሪዎች መጠይቅ

በዚህ ጥናት ላይ ተሳፋሪ በመሆኖ እንዲሳተፉ ተጋብዘዋል፡፡ እርስዎን በተሻለ ለማገልገል የአዲስ አበባ ቀላል ባቡር መንገድ መጨናነቅን መፍትሄ ለመስጠት እርስዎ የሚሰጡት ግባት ወሳኝነት አለው፡፡

የመጠይቁ አላማ

የአዲስ አበበ ቀላል ባቡር መንገድ አገልግሎቱ እንዲሻሻል ለመጠይቁ የሚያበረክቱት ግብአት ለትምህርታዊ ጥናቱ ልምድዎን እና ሀሳብዎን እንዲገልጹ እድል ይሰጥዎታል፡፡

<u>አንድኛው ላይ ምልክት እባክዎን ያድርጉ</u>

1. በመደበኛነት ለምን ያህል ጊዜ የባቡር መስመርን ሲጠቀሙ ነበር?

   በጭራሽ/ለመጀመሪያ ጊዜዛሬ ☐ 1-6 ወራት ☐ ከ1-2ዓመት ☐

   ከ6-12 ወራት ☐ ከ2 ዓመት በላይ ☐

2. ምን ያህል ባቡር ይጠቀማሉ?

   በሳምንት ሦስትወይም ከዚያ በላይ ጊዜ ☐ በወር አንድ ወይም ሁለት ጊዜ ☐

   በሳምንት አንድ ወይም ሁለት ጊዜ ☐ በጣም ጥቂት ጊዜ ☐

3. በባቡር ጣቢያ ባቡር ለመጠበቅ ምን ያህል ጊዜ ይቆያሉ? …………… ደቂቃ

4. ያለፈው ወር ኣይነተኛ ጉዞዎን እንዴት ይገልጹታል ?

ሁል ጊዜ ወንበር አገኝ ነበር ☐ ብዙ ጊዜ የምቆም ሲሆን የተጨናነቀ ነው ☐

በአብዛኛው ጊዜ ወንንበር ይገኝ ነበር ☐ ብዙ ጊዜ የሚቆም ሲሆን እጅግ የተጨናነቀ ነው ☐

ብዙ ጊዜ የምቆም ቢሆንም የመቆመኒያ ቦታ ነበር ☐ ይለያያል ☐

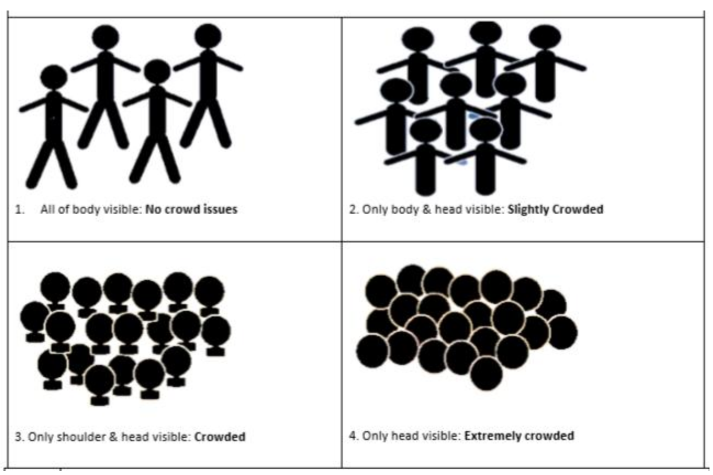
5. ወደ ስራ ሲሄዱ ምን ያህል ያረፍዳሉ ?

   በጭራሽ ☐ ብዙ ጊዜ ☐

   አንድ አንዴ ☐ ሁል ጊዜ ☐

6. ምን ያህል ጊዜ ይሆናል በባቡሩ ተጨናንቀህ ስትሄድ? (ከታች ያለውን ምስል ተመልክተው ይምረጡ)

   1. *ሁሉም የሰውነት አካል ይታያሉ፣ አልተጨናነቀም*
   2. *አካል እና ጭንቅላት ብቻ ይታያል፣ በመጠኑ ተጨናንቋል*
   3. *ትከሻ እና ጭንቅላት ብቻ ይታያል፣ ተጨናንቋል*
   4. *ጭንቅላት ብቻ ይታያል፣ እጅግ ተጨናንቋል*



7. ዛሬ እርስዎ ያሉበት ባቡር ምን ያህል ተጨናንቋል? በሳጥኑ ውስጥ እባክዎን ከኤ፣ ቢ፣ ሲ እና ዲ አንዱ ላይ ምልክት ያድርጉ፡፡

A	5	በእጅጉ በጣም ተጣቧል	B	5	እጅግ በጣም ተጨናንቋል	C	5	እጅግ በጣም ደስ አይልም	D	5	እጅግ በጣም ይረብሻል
	4	በጣም ተጣቧል		4	በጣም ተጨናንቋል		4	በጣም ደስ አይልም		4	በጣም ይረብሻል
	3	ተጣቧል		3	ተጨናንቋል		3	ደስ አይልም		3	ይረብሻል
	2	በመጠኑም ተጣቧል		2	በመጠኑ ተጨናንቋል		2	በመጠኑ ደስ አይልም		2	በመጠኑ ይረብሻል
	1	ልተጣበበም		1	አልተጨናንቋል		1	ደስ አይልም		1	አይረብሽም

8. ዛሬ እርስዎ የነበሩበት ባቡር ውስጥ ያለው የአየር ሁኔታ ምን ይመስላል? እባክዎን ከኤ፣ ቢ፣ ሲ እና ዲ አንዱ ላይ ምልክት ያድርጉ፡፡

A	5	እጅግ በጣም ይሞቃል	**B**	**5**	እጅግ በጣም የታፍኗል	**C**	**5**	እጅግ በጣም ይሸታል	**D**	**5**	እጅግ በጣም ጫጫታ አለ
	4	በጣም ይሞቃል		**4**	በጣም ታፍኗል		**4**	በጣም ይሸታል		**4**	በጣም ጫጫታ አለ
	3	ይሞቃል		**3**	ታፍኗል		**3**	ይሸታል		**3**	ጫጫታ አለ
	2	በመጠኑ ይሞቃል		**2**	በመጠኑ የታፍኗል		**2**	በመጠኑ ይሸታል		**2**	በመጠኑ ጫጫታ አለ
	1	አይሞቅም		**1**	አልታፈነም		**1**	አይሸትም		**1**	ጫጫታ የለም

9. በባቡር እየተጓዙ የተሰማዎት /የሚሰማዎት ስሜት ምን ይመስላል? እባክዎን ከሀ፣ለ፣ሐ እና መ ውስጥ አንዱ ላይ ምልክት ያድርጉ፡፡

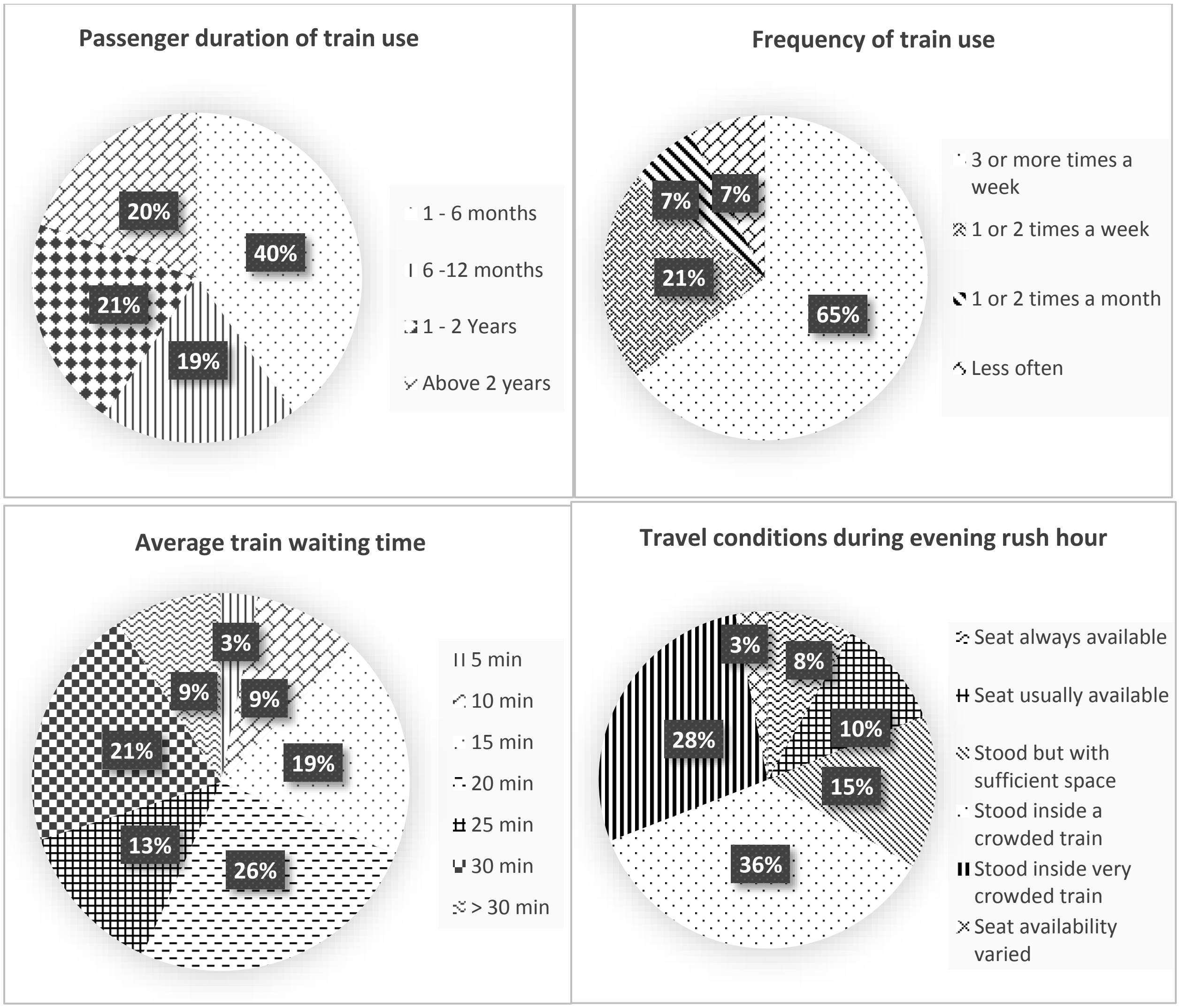
ሀ	5	እጅግ በጣም ለመንቀሳቀስ የሚያዳግት	ለ	5	እጅግ በጣም ምቾት ይነሳል	ሐ	5	እጅግ በጣም ያናድዳል	መ	5	እጅግ በጣም ይጫጫናል
	4	በጣምለመንቀሳቀስ የሚያዳግት		4	በጣም ምቾት ይነሳል		4	በጣም ያናድዳል		4	በጣም ይጫጫናል
	3	ለመንቀሳቀስ የሚያዳግት		3	ምቾት ይነሳል		3	ያናድዳል		3	ይጫጫናል
	2	በመጠኑ ለመንቀሳቀስ የሚያዳግት		2	በመጠኑ ምቾት ይነሳል		2	በመጠኑ ያናድዳል		2	በመጠኑ ይጫጫናል
	1	ለመንቀሳቀስ አያዳግትም		1	ይመቻል		1	አያናድድም		1	አይጫጫንመ

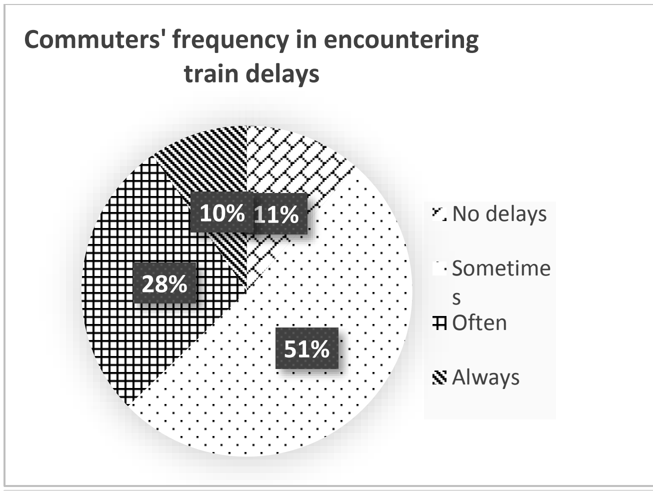
10. እንደ እርስዎ ሀሳብ ባቡሩ የተጓዦችን መጨናነቅ ማስቀረት መተግበር ያለበት ሦስት ነገሮች ምን ምንድናቸው ብለው ያስባሉ ?እባክዎ አጭር መልስ ይስጡ፡፡

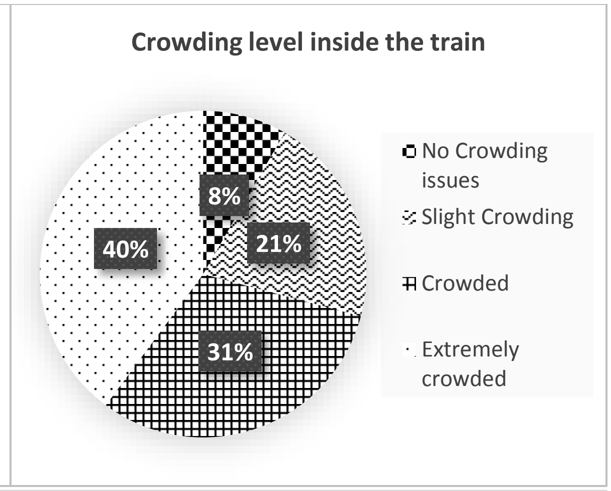
1...

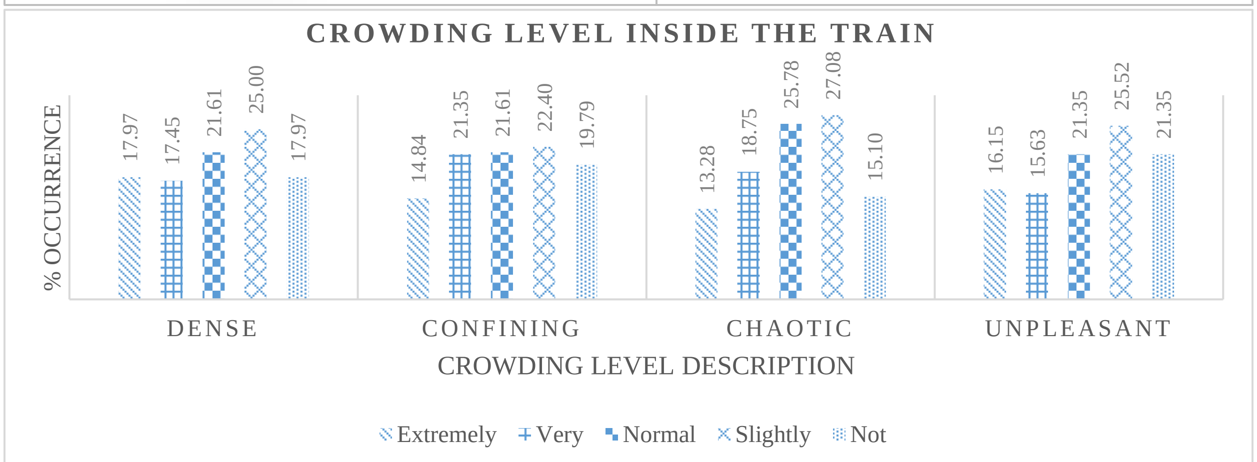
2...

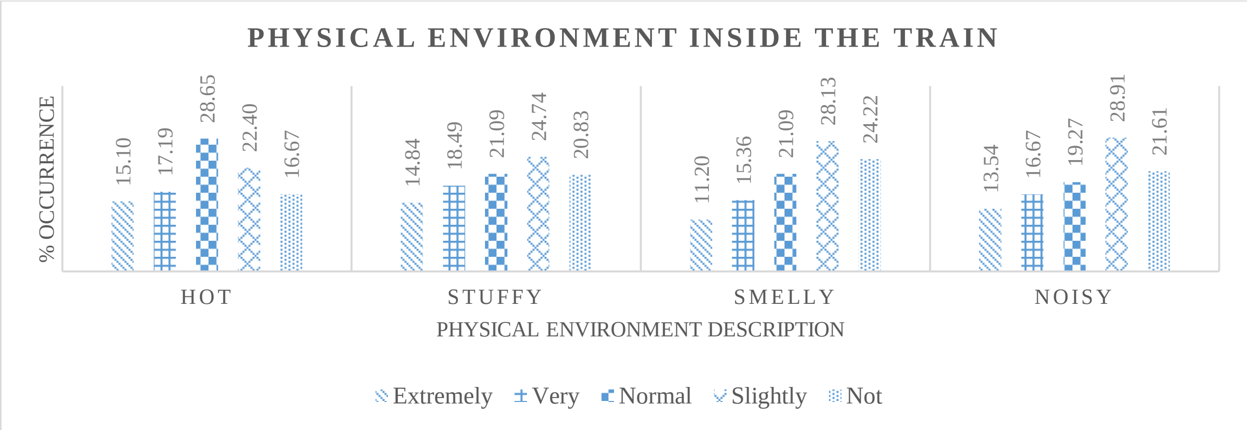
3..አመሰግናለሁ፡፡

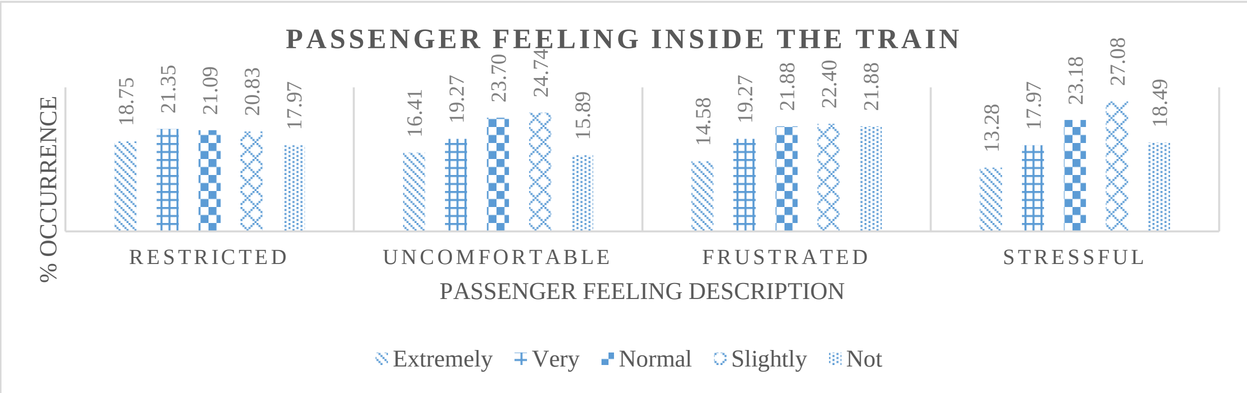

Passenger duration of train use
20%
40%
21%
19%
1 - 6 months
6 -12 months
1 - 2 Years
Above 2 years
Frequency of train use
7%
7%
21%
65%
3 or more times a week
1 or 2 times a week
1 or 2 times a month
Less often
Average train waiting time
3%
9%
9%
19%
21%
13%
26%
5 min
10 min
15 min
20 min
25 min
30 min
> 30 min
Travel conditions during evening rush hour
3%
8%
28%
10%
15%
36%
Seat always available
Seat usually available
Stood but with sufficient space
Stood inside a crowded train
Stood inside very crowded train
Seat availability varied

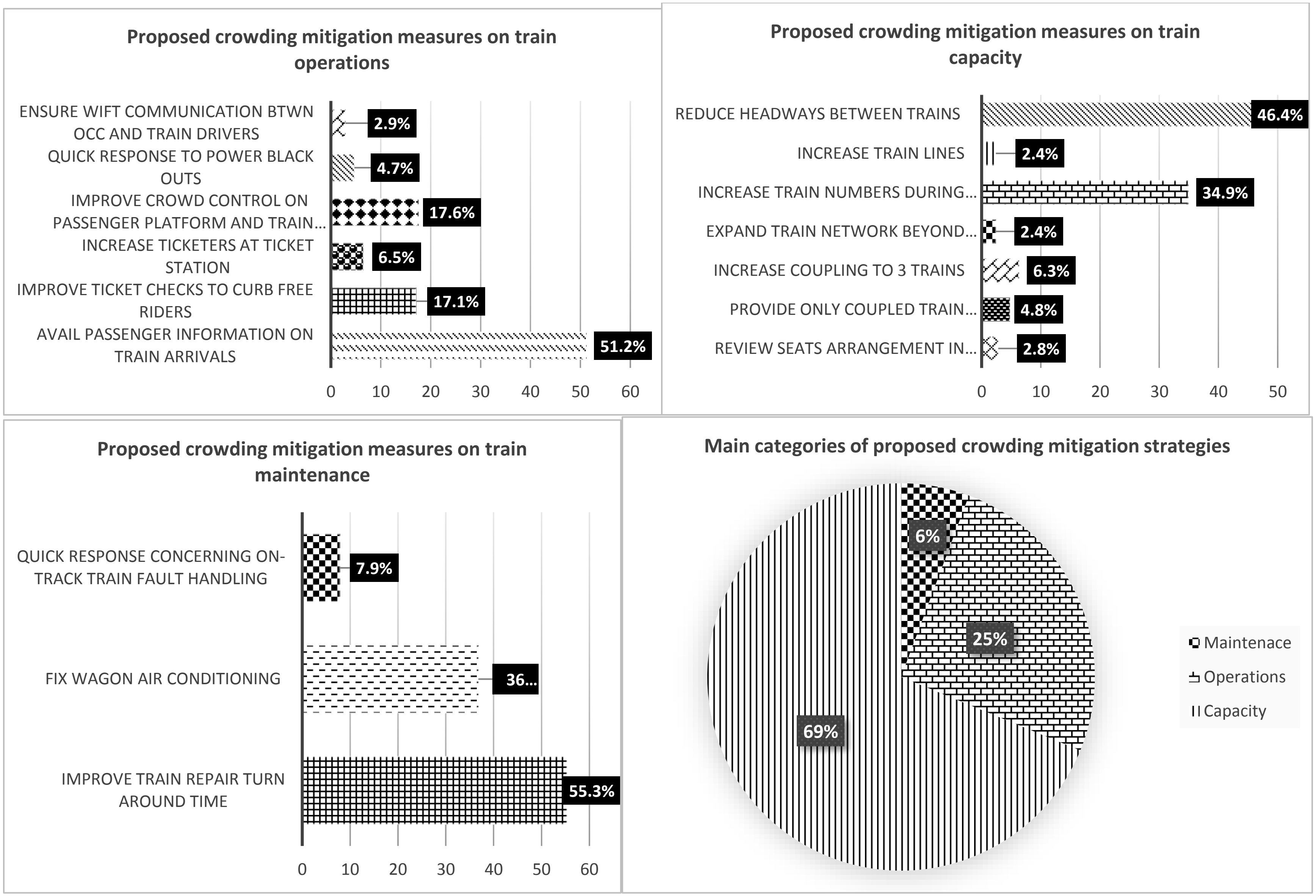

Commuters' frequency in encountering train delays
10%
11%
28%
51%
No delays
Sometimes
Often
Always


Crowding level inside the train
8%
21%
31%
40%
No Crowding issues
Slight Crowding
Crowded
Extremely crowded


CROWDING LEVEL INSIDE THE TRAIN
% OCCURRENCE
17.97
17.45
21.61
25.00
17.97
14.84
21.35
21.61
22.40
19.79
13.28
18.75
25.78
27.08
15.10
16.15
15.63
21.35
25.52
21.35
DENSE
CONFINING
CHAOTIC
UNPLEASANT
CROWDING LEVEL DESCRIPTION
Extremely
Very
Normal
Slightly
Not


PHYSICAL ENVIRONMENT INSIDE THE TRAIN
% OCCURRENCE
15.10
17.19
28.65
22.40
16.67
14.84
18.49
21.09
24.74
20.83
11.20
15.36
21.09
28.13
24.22
13.54
16.67
19.27
28.91
21.61
HOT
STUFFY
SMELLY
NOISY
PHYSICAL ENVIRONMENT DESCRIPTION
Extremely
Very
Normal
Slightly
Not


PASSENGER FEELING INSIDE THE TRAIN
% OCCURRENCE
18.75
21.35
21.09
20.83
17.97
16.41
19.27
23.70
24.74
15.89
14.58
19.27
21.88
22.40
21.88
13.28
17.97
23.18
27.08
18.49
RESTRICTED
UNCOMFORTABLE
FRUSTRATED
STRESSFUL
PASSENGER FEELING DESCRIPTION
Extremely
Very
Normal
Slightly
Not



Proposed crowding mitigation measures on train operations
ENSURE WIFT COMMUNICATION BTWN OCC AND TRAIN DRIVERS
2.9%
QUICK RESPONSE TO POWER BLACK OUTS
4.7%
IMPROVE CROWD CONTROL ON PASSENGER PLATFORM AND TRAIN...
17.6%
INCREASE TICKETERS AT TICKET STATION
6.5%
IMPROVE TICKET CHECKS TO CURB FREE RIDERS
17.1%
AVAIL PASSENGER INFORMATION ON TRAIN ARRIVALS
51.2%
0 10 20 30 40 50 60
Proposed crowding mitigation measures on train capacity
REDUCE HEADWAYS BETWEEN TRAINS
46.4%
INCREASE TRAIN LINES
2.4%
INCREASE TRAIN NUMBERS DURING...
34.9%
EXPAND TRAIN NETWORK BEYOND...
2.4%
INCREASE COUPLING TO 3 TRAINS
6.3%
PROVIDE ONLY COUPLED TRAIN...
4.8%
REVIEW SEATS ARRANGEMENT IN...
2.8%
0 10 20 30 40 50
Proposed crowding mitigation measures on train maintenance
QUICK RESPONSE CONCERNING ON-TRACK TRAIN FAULT HANDLING
7.9%
FIX WAGON AIR CONDITIONING
36...
IMPROVE TRAIN REPAIR TURN AROUND TIME
55.3%
0 10 20 30 40 50 60
Main categories of proposed crowding mitigation strategies
6%
25%
69%
Maintenace
Operations
Capacity

```
[DataSet1] C:\Users\Duncan1\Desktop\SPSS Analysis.sav
```

Variable Information

Variable	Position	Label	Measurement Level	Role	Column Width	Alignment	Print Format	Write Format
Q_1	1	<none>	Nominal	Input	8	Right	F8.2	F8.2
Q_2	2	<none>	Nominal	Input	8	Right	F8.2	F8.2
Q_3	3	<none>	Nominal	Input	8	Right	F8.2	F8.2
Q_4	4	<none>	Nominal	Input	8	Right	F8.2	F8.2
Q_5	5	<none>	Nominal	Input	8	Right	F8.2	F8.2
Q_6	6	<none>	Nominal	Input	8	Right	F8.2	F8.2
Q_7_A	7	<none>	Nominal	Input	8	Right	F8.2	F8.2
Q_7_B	8	<none>	Nominal	Input	8	Right	F8.2	F8.2
Q_7_C	9	<none>	Nominal	Input	8	Right	F8.2	F8.2
Q_7_D	10	<none>	Nominal	Input	8	Right	F8.2	F8.2
Q_8_A	11	<none>	Nominal	Input	8	Right	F8.2	F8.2
Q_8_B	12	<none>	Nominal	Input	8	Right	F8.2	F8.2
Q_8_C	13	<none>	Nominal	Input	8	Right	F8.2	F8.2
Q_8_D	14	<none>	Nominal	Input	8	Right	F8.2	F8.2
Q_9_A	15	<none>	Nominal	Input	8	Right	F8.2	F8.2
Q_9_B	16	<none>	Nominal	Input	8	Right	F8.2	F8.2
Q_9_C	17	<none>	Nominal	Input	8	Right	F8.2	F8.2
Q_9_D	18	<none>	Nominal	Input	8	Right	F8.2	F8.2
VAR00001	19	<none>	Nominal	Input	8	Right	F8.2	F8.2
VAR00002	20	<none>	Nominal	Input	8	Right	F8.2	F8.2

Variables in the working file

Variable Values

Value		Label
Q_1	1.00	1-6 Months
	2.00	6-12 Months
	3.00	1-2 Years
	4.00	> 2 Years
Q_2	1.00	3 or more times a week
	2.00	once or twice a week
	3.00	1 or 2 times a month
	4.00	less often
Q_3	1.00	5 Min
	2.00	10 Min
	3.00	15 Min
	4.00	20 Min
	5.00	25 Min
	6.00	30 Min
	7.00	> 30 Min
Q_4	1.00	ASA
	2.00	USA
	3.00	USSS
	4.00	USC
	5.00	USVC
	6.00	V
Q_5	1.00	NOT AT ALL
	2.00	SOMETIMES
	3.00	OFTEN
	4.00	ALL THE TIME
Q_6	1.00	A
	2.00	B
	3.00	C
	4.00	D
Q_7_A	1.00	ND
	2.00	SD
	3.00	D
	4.00	VD
	5.00	ED
Q_7_B	1.00	NC
	2.00	SC

	3.00	C
	4.00	VC
	5.00	EC
	1.00	NCH
	2.00	SCH
Q_7_C	3.00	CH
	4.00	VCH
	5.00	ECH
	1.00	NU
	2.00	SU
Q_7_D	3.00	U
	4.00	VU
	5.00	EU
	1.00	NH
	2.00	SH
Q_8_A	3.00	H
	4.00	VH
	5.00	EH
	1.00	NS
	2.00	SS
Q_8_B	3.00	S
	4.00	VS
	5.00	ES
	1.00	NSM
	2.00	SSM
Q_8_C	3.00	SM
	4.00	VSM
	5.00	ESM
	1.00	NN
	2.00	SN
Q_8_D	3.00	N
	4.00	VN
	5.00	EN
	1.00	NR
	2.00	SR
Q_9_A	3.00	R
	4.00	VR
	5.00	ER
Q_9_B	1.00	NUn
	2.00	SUn

	3.00	Un
	4.00	VUn
	5.00	EUn
	1.00	NF
	2.00	SF
Q_9_C	3.00	F
	4.00	VF
	5.00	EF
	1.00	NSt
	2.00	SSt
Q_9_D	3.00	St
	4.00	VSt
	5.00	ESt

Q_7_A * Q_8_A Cross-tabulation

Count

		Q_8_A					Total
		NH	SH	H	VH	EH	
Q_7_A	ND	32	20	10	3	2	67
	SD	13	35	33	9	7	97
	D	7	14	38	23	1	83
	VD	3	9	21	22	13	68
	ED	3	6	12	12	36	69
Total		58	84	114	69	59	384

Q_8_A * Q_9_B Cross-tabulation

Count

		Q_9_B					Total
		NUn	SUn	Un	VUn	EUn	
Q_8_A	NH	37	16	8	0	3	64
	SH	13	34	19	11	10	87
	H	5	35	39	21	10	110
	VH	4	6	21	22	13	66
	EH	2	4	4	13	34	57
Total		61	95	91	67	70	384

Q_7_C * Q_9_C Cross-tabulation

Count

		Q_9_C					Total
		NF	SF	F	VF	EF	
Q_7_C	NCH	37	10	6	5	1	59
	SCH	32	35	16	13	8	104
	CH	6	17	38	28	9	98
	VCH	5	16	20	19	12	72
	ECH	7	7	3	9	25	51
Total		87	85	83	74	55	384

Q_7_B * Q_9_B Cross-tabulation

Count

		Q_9_B					Total
		NUn	SUn	Un	VUn	EUn	
Q_7_B	NC	45	21	7	2	2	77
	SC	6	35	22	12	10	85
	C	4	24	31	16	8	83
	VC	3	11	25	24	20	83
	EC	3	4	6	13	30	56
Total		61	95	91	67	70	384

Q_8_D * Q_9_D Cross-tabulation

Count

		Q_9_D					Total
		NSt	SSt	St	VSt	ESt	
Q_8_D	NN	49	15	7	9	2	82
	SN	15	48	22	16	11	112
	N	3	18	35	12	6	74
	VN	3	20	18	17	6	64
	EN	2	4	6	13	27	52
Total		72	105	88	67	52	384

Q_7_A * Q_9_C Cross-tabulation

Count

		Q_9_C					Total
		NF	SF	F	VF	EF	
Q_7_A	ND	46	10	7	2	2	67
	SD	21	32	16	16	12	97
	D	5	23	28	22	5	83
	VD	9	13	21	15	10	68
	ED	5	7	11	19	27	69
Total		86	85	83	74	56	384

Appendix R : Vehicle capacity for various seat arrangements.

Option 1	Sections	Seating arrangement (N)	Seating type	Seating number	Number of standing passengers	Total number of passengers
Car 1	Section 11	4	Transverse	16	21	37
	Section 12	2	Longitudinal	10	69	79
Car 2	Section 2	4	Transverse	16	22	38
Car 3	Section 31	2	Longitudinal	10	76	86
	Section 32	4	Transverse	16	19	35
Articulation				0	17	17
	Reduced number of seats			-3		
	Total number of passengers			65	221	286

Option 2	Sections	Seating arrangement (N)	Seating type	Seating number	Number of standing passengers	Total number of passengers
Car 1	Section 11	2	Longitudinal	18	13	31
	Section 12	2	Longitudinal	10	59	69
Car 2	Section 2	2	Longitudinal	20	10	30
Car 3	Section 31	2	Longitudinal	10	62	72
	Section 32	2	Longitudinal	18	10	28
Articulation				0	17	17
	Reduced number of seats			-3		
	Total number of passengers			73	171	244

Option 3	Sections	Seating arrangement (N)	Seating type	Seating number	Number of standing passengers	Total number of passengers
Car 1	Section 11	4	Transverse	16	17	33
	Section 12	4	Transverse	8	63	71
Car 2	Section 2	4	Transverse	16	18	34
Car 3	Section 31	4	Transverse	8	66	74
	Section 32	4	Transverse	16	19	35
Articulation				0	17	17
	Total number of passengers			64	200	264

Option 4	Sections	Seating arrangement (N)	Seating type	Seating number	Number of standing passengers	Total number of passengers
Car 1	Section 11	2	Longitudinal	18	13	31
	Section 12	4	Transverse	8	63	71
Car 2	Section 2	2	Longitudinal	20	10	30
Car 3	Section 31	4	Transverse	8	66	74

Continuation ...

	Section 32	2	Longitudinal	18	10	28
Articulation				0	17	17
	Total number of passengers			72	179	251

Option 5	Sections	Seating arrangement (N)	Seating type	Seating number	Number of standing passengers	Total number of passengers
Car 1	Section 11	4	Transverse	16	17	33
	Section 12	2	Longitudinal	10	59	69
Car 2	Section 2	2	Longitudinal	20	10	30
Car 3	Section 31	2	Longitudinal	10	62	72
	Section 32	4	Transverse	16	19	35
Articulation				0	17	17
	Reduced number of seats			-3		
	Total number of passengers			69	184	253

Option 6	Sections	Seating arrangement (N)	Seating type	Seating number	Number of standing passengers	Total number of passengers
Car 1	Section 11	2	Longitudinal	18	13	31
	Section 12	2	Longitudinal	10	59	69
Car 2	Section 2	2	Longitudinal	20	10	30
Car 3	Section 31	2	Longitudinal	10	62	72
	Section 32	4	Transverse	16	19	35
Articulation				0	17	17
	Reduced number of seats			-3		
	Total number of passengers			71	180	251

Option 7	Sections	Seating arrangement (N)	Seating type	Seating number	Number of standing passengers	Total number of passengers
Car 1	Section 11	4	Transverse	16	17	33
	Section 12	4	Transverse	8	63	71
Car 2	Section 2	2	Longitudinal	20	10	30
Car 3	Section 31	2	Longitudinal	10	62	72
	Section 32	2	Longitudinal	18	10	28
Articulation				0	17	17
	Reduced number of seats			-3		
	Total number of passengers			69	179	248

Option 8	Sections	Seating arrangement (N)	Seating type	Seating number	Number of standing passengers	Total number of passengers
Car 1	Section 11	4	Transverse	16	21	37
	Section 12	0		0	81	81

Continuation...						
Car 2	Section 2	4	Transverse	16	22	38
Car 3	Section 31	0		0	83	83
	Section 32	4	Transverse	16	19	35
Articulation				0	17	17
	Total number of passengers			48	243	291

Option 9	Sections	Seating arrangement (N)	Seating type	Seating number	Number of standing passengers	Total number of passengers
Car 1	Section 11	4	Transverse	16	21	37
	Section 12	2	Longitudinal	10	69	79
Car 2	Section 2	0		0	53	53
Car 3	Section 31	2	Longitudinal	10	76	86
	Section 32	4	Transverse	16	19	35
Articulation				0	17	17
	Reduced number of seats			-3		
	Total number of seats			49	255	304

Option 10	Sections	Seating arrangement (N)	Seating type	Seating number	Number of standing passengers	Total number of passengers
Car 1	Section 11	0		0	52	52
	Section 12	0		0	81	81
Car 2	Section 2	0		0	53	53
Car 3	Section 31	0		0	83	83
	Section 32	0		0	49	49
Articulation				0	17	17
	Total number of passengers			0	335	335