INTEGRATING ANBESSA CITY BUS WITH ADDIS ABABA LIGHT RAIL TRANSIT:

CASE OF MERKATO TERMINAL

A Thesis submitted to School of Graduate Studies of Addis Ababa University, Addis Ababa Institute of Technology (AAiT), in the School of Mechanical and Industrial Engineering, for the partial fulfillment of the requirements of Degree of Master of Science in Mechanical Engineering (Railway Engineering Stream)

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DECLARATION

I hereby declare that the work which is being presented in this thesis entitled, “INTEGRATING ANBESSA CITY BUS WITH ADDIS ABABA LIGHT RAILTRANSIT: CASE OF MERKATO TERMINAL**”** is original work of my own, has not been presented for a Master’s degree of any other university and all the resource of materials used for this thesis have been properly acknowledged.

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This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

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TABLE OF CONTENTS **PAGE**

APPENDIX A: CASE STUDY

LIST OF TABLES

LIST OF FIGURE PAGE

ABBREVIATIONS

CBD=Central Business District

AACG= Addis Ababa city government

ERC=Ethiopian Railway Corporation

AALRT=Addis Ababa Light Rail Transit

AACRA = Addis Ababa City Road Authority

AATB = Addis Ababa Transport Branch

ABSTRACT

As a consequence of worsening traffic congestion in metropolitan areas, the shifting of travel between transportation modes is becoming a pressing need. Urban public transit systems are often seen as effective alternative modes to mitigate traffic congestion, so it is expected that such systems will see increasing ridership. Improving the quality of transit service and increasing the operational efficiency of transit systems are essential to attracting more passengers to public transit. In reality, the modal choice decisions are more sensitive to the amount of time that transit passengers spend in transferring between modes than the time they spend on board.

This research considers the problem of developing synchronized timetable for anbessa bus and addis ababa light rail transit for mercato station when waiting time limit exist at each transfer stops, for passengers making connections. The objective of this research is to have maximum number of simultaneous arrivals. Previous studies defined simultaneous arrival as an arrival buses and train of different routes at a transfer point such that the time between these arrivals did not exceed the passengers waiting time range associated with transfer stop.

A heuristic model is developed and applied for the case merkato terminal to evaluate the outcome. The total number of synchronization obtained by the model and passenger waiting time was compared for different headways of buses. Results show that as the headway of anbessa bus is reduced the number of simultaneous arrivals increases and waiting time of passengers reduced.

CHAPTER ONE: BACKGROUND OF THE RESEARCH

1.1 INTRODUCTION

Addis Ababa is the heart of social, political and economic activities of Ethiopia and is a seat of UN Economic Commission for Africa (UNECA) and African Union (AU), is currently facing rapid urbanization and high population growth leading to high transportation demand. Urbanization is a challenge which when coupled with congestion and automobile oriented- development practices intensifies the magnitude and dimension of urban problems across cities of the world, particularly in developing cities like Addis Abba. Addis is already in peak pressure of providing competent transportation infrastructure and service that can absorb the pressing demand of the ever growing population. Railway transportation and conventional public transportation in passenger transportation system can be supplemented to each other and develop together in order to promote the proportion of public transportation in passenger transportation system and confirm the dominant position of public transportation in city transportation system. The plan should display the joint mode of different transportation systems and the control of traffic equipment and land using for station area around the station, so that public transportation system can be formed step by step.

Integrating pre-existing transit services with new rail lines is a complex task. Clearly it involves many technical decisions ranging from the fare integration to network design and schedule coordination. As importantly, these decisions also affect transit employees, politicians, construction workers, riders, and other stakeholders in the transit system. Transportation providers are important stakeholders. It is fairly clear that operating a successful intermodal system requires the cooperation and dedication of front line employees. However, bus operators may feel threatened by a new rail line or other high-capacity transit improvements. Presumably the rail line the rail line will reduce demand for bus service along parallel corridors. Since trains can carry far more passengers per operator than buses, some drivers could potentially face unemployment if a transit agency decides to reduce bus service.

Given the symbiotic relationship between rail and bus, these modes can and should complement each other in an integrated multimodal network. Transit's overall effectiveness and efficiency depends in large part upon designing a coordinated system that utilizes the strength of each mode. Often the urban rail components form a system's symbolic backbone because of its service quality and visual presence. Compared to buses, trains generally operate more frequently and rapidly, carry greater passenger volumes, emit no visible pollution, and often run with full grade separation. Stations provide better passenger facilities than roadside bus stops and have potential to encourage transit-friendly development. However, the cost of building and operating rail transit severely constrains network extent and coverage. To expand its reach and broaden its customer base, a comprehensive transit system requires flexible, less expensive options such as bus to supplement rail service.

Opening or extending a rail line draws attention to a transit. It presents a company with rare and vital opportunity to improve a system's overall level-of-service, to create excitement about transit, and to realize large long-term ridership gains. While the rail line may attract the most attention, a company should take the advantage of this moment to showcase the complete system by designing and demonstrating how an integrated network of buses and trains can meet a variety of travel needs. Nevertheless, achieving transport and other goals with new rail investments is inherently a long-term effort. Systems may take decades to mature because individual travel behavior and land uses do not adapt to new transit systems overnight.

Clearly, a fundamental difference exists between long-term system design and short-term implementation issues. The transition to a new rail system can create uncertainty by disrupting established travel patterns and operating procedures. (The transition can be equally challenging when introducing bus rapid transit or other forms of high-quality, high-capacity transit). The rail line may speed the commutes for some current transit customers, but changes in bus routes may introduce transfers for others. Employees may fear that the rail line will bring bus service cutbacks and jeopardize jobs. Meanwhile, a rail line adds substantial new capacity to the transit system that people are unlikely to fully utilize immediately. Some shifts from buses or automobiles to rail may initially occur, but it probably will take years for travel patterns to stabilize and even longer for land use and lifestyle changes to occur. Transit agencies and elected officials often face tremendous pressure to demonstrate immediate results of rail projects to the general public and to the media. Consequently, it is tempting to pursue short-term strategies to boost rail ridership, such as reconfiguring the bus system to serve only the rail feeder market. In the worst-case scenario, such strategies may result in ridership losses, political embarrassment, and other unfavorable results.

The challenge facing transit agencies is to manage the transition to new rail systems effectively, minimizing short-term impacts while making progress to achieve long-range objectives. Given this context, this research aims to develop a framework and analytical methods to assist transit planners with the process of integrating new rail lines with existing transit systems.

1.2 STATEMENT OF THE PROBLEM

In cities like Addis Ababa, public buses are and light rail transit will be the most common public transport carriers. Commuter dissatisfaction toward public transport stems from increased travel time, poor levels of comfort, uneconomical operations, and higher out-of-vehicle time, especially at transfer points. These problems can be solved by appropriate coordination between major public transport modes. Successful coordination implies

- The traveller’s ability to transfer freely and conveniently between modes;
- Distinct service areas between each mode, thereby minimizing duplication of services;
- Adjustment and interrelationship of schedules; and

A poorly coordinated transfer can require long, irregular waiting for infrequent connecting services. The point of balance between travellers' demand for a direct service and the transit operator's need for economy often lies in the level of attention given to the details of the transfer. Thus, well-designed feeder routes satisfying maximum demand with acceptable travel times are of prime concern. To minimize transfer time, coordinated schedules have to be optimized. It seems more realistic to model the network with some minimum waiting time at transfer point for smooth transfer of passengers from one route to another. But the waiting time should not be too long which will make the system unreliable. The model developed in this research can be applied to transit networks with certain minimum waiting time involved in making transfers.

1.3 THESIS OBJECTIVE

1.3.1 GENERAL OBJECTIVE

The primary purpose of this research is to have maximum synchronizations at the transfer points for integrating existing transit service with new rail line and to apply the findings to merkato station. The general objectives are:

1. To create a synchronized timetable, this ensures that the time between different buses and train arriving at transfer points, does not exceed the allowed waiting time.
2. To present an appropriate heuristic model to solve this problem.
3. To apply the proposed model for the case of merkato station.

1.3.2 SPECIFIC OBJECTIVES

The specific objectives of the thesis are:

1. Identify existing anbessa bus and rail routes

2. Evaluate how these routes and schedules can be augmented to seamlessly integrate bus service with the new rail line;

3. Truncate bus lines which run parallel to the rail line to avoid unnecessary competition

4. To demonstrate the effect changing bs headway on the number of simultaneous arrival

1.4 SCOPE OF THE STUDY

The scope of the thesis is to build analytical approach to integrate anbessa city bus with the new light rail transit. The two routes of the Addis Ababa light rail transit are:

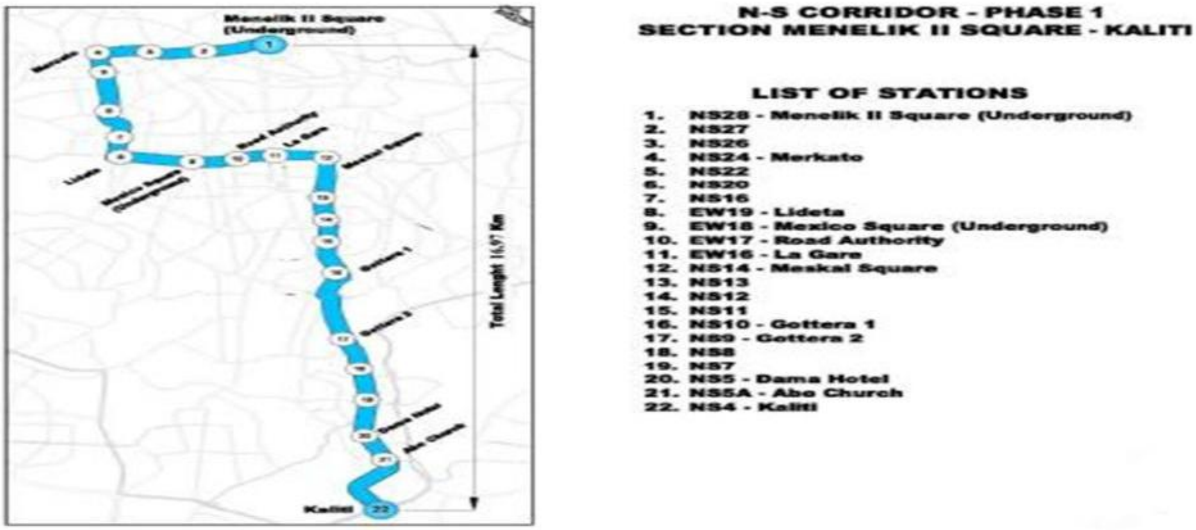
1. east-west line

Ayatt-Megenagna-Tor Hailoch-Ayertena

2. north –south line

Shiro meda-Merkato-La Gare-Kaliti

Our study focuses on the north-south line specifically on merkato station. Merkato station is found on the north-south line. Twenty-two LRT stations are placed along N-S route, five of which are shared with E-W route. 9 of which are elevated stations (5 elevated stations are shared with E-W route) , 2 of which is underground station. The rest 11 stations are ground stations. Average interval between two adjacent stations is 793 meters. The longest interval is 1370 meters and the shortest interval is 510 meters.



N-S CORRIDOR - PHASE 1
SECTION MENELIK II SQUARE - KALITI

LIST OF STATIONS

1. NS28 - Menelik II Square (Underground)
2. NS27
3. NS26
4. NS24 - Merkato
5. NS22
6. NS20
7. NS16
8. EW19 - Lideta
9. EW18 - Mexico Square (Underground)
10. EW17 - Road Authority
11. EW16 - La Gare
12. NS14 - Meskal Square
13. NS13
14. NS12
15. NS11
16. NS10 - Gottera 1
17. NS9 - Gottera 2
18. NS8
19. NS7
20. NS5 - Dama Hotel
21. NS5A - Abo Church
22. NS4 - Kaliti

Fig 1.3. N-S corridor of AALRT (source ERC)

Around 36 bus routes originate from merkato terminal. The routes with their direction and origin- destination are shown in fig 1.4.

1.5 LIMITATION OF THE STUDY

In this research only the interface between city bus and rail network will be analyzed, the interconnection with other transport mode like mini and midi buses, collective taxis, taxis will not be considered. Luck of real time transfer data of bus to rail not available since the operation didn’t start.

Fig1. 4 origin destination of anbessa buses originating from mercato terminal

route	origin	direction	destination
2	mercato	Through lideta>mexico>mekanisa	kore
4	mercato	Through mexico>kera>gotera>saris	kaliti
8	mercato	Through yohenes church>kechene school	kechene
12	mercato	Through atekilet tera>afencho ber> 6 kilo	Feransay
13	mercato	Through cinema Ethiopia>4 kilo> 6 kilo	Bela(Italy
15	mercato	Through teklehaymanot >piassa>4 kilo>aware	megenagna
16	mercato	Through giorgis church> afencho ber>shiro meda	Kidane mihret
17	mercato	Through piassa>kidist mariyam church>6 kilo	qusqam
18	mercato	Through kolfe bridge>18 mazoreya>holland embassy	keraneyo
20	mercato	Through chew berenda>enkulal faberika>rufael church	Dil ber
21	mercato	Through kolfe bridge>18 mazoreya>lukaneda	filidoro
23	mercato	Through giorgis church>afencho ber>4 kilo>megenagna	lameberet
24	mercato	Through kas meda>st.paul hospital>wingate>asko	Dire soleya
26	mercato	Through coca>tor hailoch>ayer tena>amem gena	sabeta
28	mercato	Through mesalemeya> abebe bikilastadeum > wingate	sansuzi
29	mercato	Through tekle haymanot>senga tera>legehar>gotera	Addis sefer
30	mercato	Through giorgis church>semien gebeya	sululta
34	mercato	Through lideta>mexico> kera>GOFA	German
35	mercato	Through berbere berenda>tegbared>kirkos>lafto>mebrat hail	Lebu school
39	mercato	Through piassa>4 kilo>kazanchis>urael church	Bole
40	mercato	Through piassa>4 kilo>megenagna	karalo
41	mercato	Through piassa>4 kilo>6 kilo	eyesus
43	mercato	Through meselameya>abebe bikila stadium>asko	menagesha
44	mercato	Through piassa>4 kilo>megenagna>kara	legedadi
47	mercato	Through awutobus tera>Michael>paulos	Shegole yenege
51	mercato	Through cocacola>tor hailoch>zenebe werk hospital	Betel hospital
52	mercato	Through tekle haymanot>tikur anbessa>legehar>bole	Gerji mebrat
63	mercato	Through kolfe deldey>atena tera>wingate	mickeleland
65	mercato	Through cocacola>tor hailoch>ayer tena	Alem bank
66	mercato	Through cocacola>tor hailoch>ayer tena	Kara kore
69	mercato	Through mesalemeya>18 mazoreya>	Lomi meda
74	mercato	Through teklehaymanot>tikur anbessa>ghion urael	Gurd shola
85	mercato	Through kolfe deldey>18 mazoreya>filidor	holeta
88	mercato	Through paisa >semien gebeya>sululta	chancho
89	mercato	Through piassa>4 kilo>megenagna>kara >legedadi	sendafa
95	mercato	Through kolfe deldey>filidor>holeta	Addis alem

1.6 SIGNIFICANCE AND BENEFICIARIES OF THE RESEARCH

Different organizations can benefit directly or indirectly from the results of this research. To mention some

Anbessa city Bus Company can develop better awareness about the spatial distribution, strength and weakness of their services. Besides they can get ideas on how and where to improve the service

ERC will have awareness about Anbessa city bus service in particular and can identify where feeder services are required the problems of spatial equity.

It gives opportunity for further research by individuals and organization.

CHAPTER TWO: LITERATURE REVIEW

This chapter reviews previous literatures and how this thesis builds upon previous research. Various techniques to create user-friendly timetables are discussed, and finally, the importance of synchronizing timetables is discussed. This study will provide a better understanding of the ways to model a public transit system.

2.1 PREVIOUS RESEARCH

Intermodal integration involves many complex issues ranging from transfers, network design, and fare coordination, to the political implications of associated service changes. To date, extensive research has covered many of these topics individually, but often not in a multimodal context.in addition, relatively few papers address the transition from bus-only systems to integrated bus and rail systems. This section highlights some of the most relevant research covering one or more aspects of intermodal integration, but is by no means exhaustive.

One of the primary objectives of this paper is to identify ways to integrate Addis Ababa light rail transit and Anbessa city bus service public network. Several papers and studies discuss strategies to improve private buses like the public system. Takyi (1990) discusses the conditions under which private buses can sustain economic viability, namely in cities with cheap labor, inadequate conventional transit services, and low expectations for service, comfort, and safety. His paper also identifies potential roles jitneys can fill in a larger transportation system (e.g. supplemental peak hour service, service on narrow streets). Takyi contends that buses and private sector buses provide different types of services and therefore can and should complement rather than compete with each other. A primary limitation of his analysis is that private buses (jitneys) become less attractive as income and automobile ownership rise.

Lau (1997) builds upon previous research by identifying role markets for private sector buses as well as government intervention strategies to rescue failing jitney system. Lau develops an analytical framework to evaluate potential intervention strategies. Applying the framework to SAN JUAN'S public, Lau recommends a set of "experimental strategies" on poorly performing public routes, routes that would directly compete with rail. Possibilities include contracting service to established carriers in corridors with poor public service, government assistance with vehicle procurement, fare integration, and contracting operations on short-run basis with public drivers on routes that compete with rail.

Kaysi et al. (1999) investigate the role that the private sector (particularly jitneys) may play in public transportation operations. Their paper identifies the challenges facing these services and develops potential external intervention strategies to assist the private sector. These include regulation, financial assistance with capital expenditures, and moving to other market arrangements such as contracted operations. The private sector can also supplement instead of compete with conventional transit modes (e.g. providing Para transit services or additional peak hour runs on overcrowded routes). The paper also outlines specific strategies to improve the situation in San Juan. These include imposing new regulation that require public drivers to improve their vehicles and provide scheduled service ,encouraging operators to penetrate the new train urban feeder market , and developing new market arrangements such as contracting out services to private carriers.

Extensive research has also been conducted into other integration issues such as fare integration. Barr (1997) develops a methodology for evaluating intermodal fare coordination decisions. His research primarily focuses on technology (e.g. smart cards, magnetic stripe cards) and pricing policy. While improved technology can improve revenue collection and rider convenience, Barr argues that favorable pricing policies can produce clear benefits for users but may have positive or negative impacts on revenue. The purpose of Barr's work is access the impacts of fare integration through an analytical framework based on usage, financial, system, and external criteria. Another objective is to apply this framework to the specific case of urban train.

Hirsch et al. (2000) recount how New York City transit's recent fare integration improvements have translated into double digit ridership growth on both its subways and buses. The authority has implemented automatic fare collection (AFC) system throughout the network featuring a stored value ticket for a specified time period. Hirsch et al. analyze metro card's impacts on various ridership markets and system utilization.

Besides fare coordination, research efforts have also focused on developing theoretical to optimize transit networks.Baba (1995) formulate a theoretical and computationally intensive model for generic bus route network. To provide transit agencies with a framework for bus restructuring, his work develops a methodology for solving the bus network design problem (BNDP): determining the best bus route configuration and frequencies given bus transit demand, the street network, available resources, and operational constraints.it adopts a heuristic approach, focusing on route generation and frequency determination/vehicle allocation, encompassed in a single automated design procedure. Baba's methodology improves previous BNDP heuristic approaches by (a) incorporating fleet size constraints, (b) identifying major trip patterns and demands to guide route design, and (c) solving the BNDP using either a general or transit center network design. This work develops a detailed route generation and vehicle allocation procedure. The thesis then applies the proposed methodology and automated design procedure to San Juan, Puerto Rico.

Lee and Vuchic (2000) present an iterative approach to handle the bus network design problem, which they call more generally the transit network design problem (TRNP).three general objectives for an optimized network include (1) user travel time minimization, (2) the transit agency's profit maximization (or net cost minimization),(3) social benefit maximization or social cost minimization. For simplicity, they focus on user travel time (including waiting, transfer, and in-vehicle travel times) minimization as the primary criterion for their analysis. The algorithm used to determine an optimal network consists of three major steps. First, an initial network is generated with a minimum number of routes using shortest path algorithm. Second, travel flow is assigned to specific routes. Finally, the alignments of certain transit routes are modified to reduce passenger travel times. This iterative approach also addresses the dynamic characteristics between variable transit trip demand and optimal transit network design. More specifically, the algorithm contains feedback mechanism that recognizes the dependent relationship between transit demand, transit supply, automobile usage, and in-vehicle travel times.

Other work has analyzed multimodal transit systems, also from a theoretical perspective. Wirashenghe (1979) develops an analytical model to describe a generalized rail line and its feeder bus network. This model presents a nearly an "optimal solution" to feeder bus route design and rail station placement.to keep the model tractable, however, wirashenge makes some key assumptions that limit its applicability; for example , the model assumes a regular grid street network as well as ignores travel time variability and schedule coordination needs. Nevertheless, it roughly approximates the relationships between transit demand volumes, waiting times, walking distance, and operating costs. Kuah and Perl (1988) build upon wirashenghe's work by presenting an analytical model for the design an optimal feeder bus network for rail line. Unlike wirashenghe's work(and many other bus network design problem approaches), it includes bus stop spacing as a parameter ,since stop spacing affects walking time and in vehicle travel time.it also assumes that rail station already exist, removing one decision variable from the analysis.

Chowdhury and Chien (2000) develop a method to optimize coordination in a general intermodal network featuring a rail (or major bus) trunk line supplemented by intersecting buses. The goal is to minimize an objective function – first among individual routes and then the entire network- that include both supplier (the transit agency) and user (passenger) costs associated with transferring . Supplier costs are captured by the operating costs of the trunk and secondary routes; user costs are represented by wait, transfer, and in-vehicle travel times. The major decision variables include route headways and slack times, or the extra time built into the schedule to increase the probability of making a connection. With this objective function, Chowdhury and Chien propose a four-step procedure to develop a coordinated schedule. Their models assumes that the rail line operates maintains a deterministic headway, which keeps the problem tractable but is not always realistic, while bus arrival at transfer stations are stochastic with approximately a normal distribution. The model also assumes fixed demand, which could limit its applicability since service frequency and ridership are clearly interrelated.

As a prime component of transit networks in general and particularly intermodal systems , transfer have received considerable attention. Matoff (1994) and Hickey (1992) argue that providing everybody “one-seat” , transfer free rides is logistically impossible given that the spatial layout of most north American metropolitan areas. Schumann (1997) describes how a hierarchy of integrated transit services (e.g. regional, trunk bus routes, circulator and shuttles) can be effective in allowing transit to serve low-density areas and non-radial trips. They suggest that multimodal systems that feature network connectivity (i.e. many points where passengers can switch between intersecting routes) allow transit systems to become more responsive to multiple travel patterns. This thesis builds upon their work by providing case study evidence to support these concepts and developing incremental strategies for implementation.

Although it is beyond the scope of this thesis, the physical design of transfer facilities at rail station is a key component of an intermodal system. The transportation research board’s “transit capacity and quality of service manual” (kittleson & associates, 1999) define some generic objectives for evaluating the design of transfer facilities.

Other research has also investigated ways to mitigate the negative impacts of transferring in order to achieve the full benefits of network connectivity. Vuchic and Musso (1992) present a systematic classification and analysis of transfers based on the headways of passenger’s initial and connecting routes. Part of their paper addresses station layout and scheduling between frequent, intersecting rail lines which exchange large volumes of passengers.at the other extreme, they also focus on developing a “timed transfer system” (TTS)to improve transfer convenience between two or more long headway transit routes, a strategy commonly employed to increase customer convenience in systems covering dispersed activity centers with infrequent service Becker and Spielberg (1998)elaborate on the timed-transfer issue. They describe the conditions under which it may be feasible to establish timed transfer centers in a network, and develop a procedure for system scheduling. They also found that in the case of Norfolk, Virginia, the introduction of timed transfer network increased ridership slightly despite a cutback in service hours and improved customer perceptions of the system.

Hall (1999) investigates holding strategies to improve the probability of making a successful transfer when an initial vehicle is delayed. Of course, holding also lengthens waiting times for passengers on the connecting vehicle. The objective of the holding strategy hall develops is to minimize total passenger delay. He models the waiting process in two steps, first optimizing holding times for known vehicle arrival time, and then expanding the analysis to stochastic case, it is difficult to find the optimal dispatch time. Hall identifies a point at which it makes sense to dispatch a connecting vehicle based upon the distribution of arrival time (s) of the initial vehicle(S). The topic of real-time strategies is beyond the scope of this thesis; for further information, Hall’s paper provides references on this subject.

Clearly, transfers can impact travel time, customer perceptions, and ridership. A study by the central transportation planning staff (CTPS)(1997) in Boston attempts to quantify this so called “transfer penalty.” empirical data were collected and analyzed for metropolitan Boston, a region with an extensive multimodal network that relies heavily on transfers. The study concludes the “transfer penalty” is more onerous than initial waiting time and over twice as onerous as in- vehicle time. Liu et al. (1997, 1998) reach similar findings using a methodology that involves both stated preference data and simulation. They also find that the “penalty” is greater for intermodal transfers (e.g. between bus and rail) than for intermodal (e.g. bus-bus or rail-rail) ones. These studies are based on the premise that a transfer-free bus ride may be better than a trip that involves both bus and rail. This is an important consideration when deciding whether to discontinue express buses that parallel a new rail line.

Other research has also attempted to investigate the holistic effects of bus-rail integration on transit systems that have introduced new rail systems. However, most of the existing literature that examines intermodal systems questions the appropriateness of rail investment from revisionist perspective, usually emphasizing economic factors over other criteria. In contrast, this thesis looks at ways to coordinate existing bus service with a new rail line at the time rail is being constructed.

Richmond (1998) attempts to explore this issue by comparing north American cities with new light rail systems with those that have pursued bus “solutions”. He concludes that in virtually all cases, new rail lines have disrupted existing bus systems by diverting financial resources from buses to rail construction and operations. He also accuses transit agencies of reconfiguring bus networks to force passengers (particularly from express buses) onto trains, resulting in additional transfers and artificially higher rail ridership. In contrast, Richmond contends that express bus systems in Ottawa, Pittsburgh, and Houston have been as more successful than rail systems, but at much higher capital costs.

Higgins (1981) examines the experiences of the San Francisco Bay area’s BART system about seven years after the system’s opening. Higgins’s paper focuses on two major points. First, he asserts that in retrospect an all-bus system would have been more cost-effective for the Bay Area than a coordinated rail and bus feeder network. Secondly, he suggests that it might be better to maintain existing parallel bus services instead of rerouting buses to new rail lines. He posits that automobile may be more attractive than a combination of bus and rail trip. Citing that the operating and capital costs per passenger trip were higher on rail than on local buses, he concludes that express buses should operate on BART corridors instead of trains.

Denant-Boemont and mills (1999) also approach intermodal integration from an economic perspective. Citing systems in the United States, Canada, and Europe, they conjecture that many rail many new rail lines do not produce enough benefits to outweigh financial assistance. In the cases were rail systems do make economic sense, Denant-Boemont and Mills argue that citiesmay want to pursue intermodal competition instead of coordination because coordinated multimodal operations “may well incur excessive costs.” Citing free market economic principles, they posit that on-street competition between bus and rail might be beneficial to passengers, even though they acknowledge that the level-of-service on each mode may decline as a result of market saturation.

2.2 Synchronization

According to Ceder et al. (2001), the importance of transfers in public transport service is motivated by several operational reasons as shown in Figure 4. In a large public transport network, all the origins and destinations are connected not connected by a single route and have a number of transfer points. In this case passengers who want to travel between different routes have to change routes at transfer points. If there are a large numbers of such transfer points a “perfect” timetable can be achieved only if the waiting time between the transfer points is minimized.

In large networks it is extremely difficult to completely eliminate these transfers. Transfers improve the transit network service characteristics by: increasing the possible number of travel paths, improving transit network operational flexibility and efficiency, making the system cost effective, and improving transportation infrastructure which guarantee high service quality and efficient resource utilization.

Unfortunately, transfers involve certain inconveniences connected with discomfort of boarding a new vehicle (necessity of passenger orientation and walking between vehicles on feeder and receiving lines), negative perception of waiting for arrival of a vehicle and existence of some delay during a trip. The elimination of these inconveniences by schedule synchronization to provide an attractive service level with easy access and transfer possibilities is continuously a challenging problem in timetable construction.

Bookbinder and Désilets (1992) proposed transfer optimization in a transit network to minimize the overall inconvenience to passengers. Bus trips are scheduled to depart from their terminal so as to minimize some objective function measuring that inconvenience. A mean disutility function is defined here which is used to evaluate the inconvenience under random bus travel times of a transfer connection. This disutility function $g(w)$ is some function of waiting time, which gives the desirability of a waiting time w, as perceived by the user. To obtain a heuristic solution, an iterative improvement procedure is used. This procedure starts with an initial solution and looks for improvements by changing the departure times for each route from a set of possible starting times, until no further improvement can be obtained.

This method is from the perspective of the user's that reduces the inconvenience caused to the user of the transit system. Ceder et al. (2001) proposed a method for synchronization from the perspective of the scheduler creating a useful synchronization tool for schedulers. They attempted to maximize the total number of synchronizations of bus arrivals at bus stops by formulating a model for the maximum synchronization of arrivals as a mixed-integer problem (MIP). Also, a heuristic algorithm that would solve this problem in a reasonable time was proposed. In each step of the algorithm, a node is selected based on some criteria, provided that at this node not all the departure times have yet been determined. Once the departure time is resolved, all its corresponding arrival times are also set. The algorithm has been constructed to handle one time period *T*.

A heuristic model based on node-oriented approach is developed. Each iteration attempts to optimize transfers taking place at a selected node. Quak (2003) in his work "Bus line planning", have discussed in detail the first two phases (i.e., designing routes and setting timetables) of bus transit planning. He adjusted the objective function of Ceder et al. and constructed a different heuristic to set the departure times. This is based on Line-Oriented Departures Setting Method (LODSM), i.e., to synchronize departures from the point of view of routes instead of the nodes.

Ceder et al. (2001) defined simultaneous arrivals as the arrival of two buses at the transfer node at the same time. This seems to be applicable to only peak period. For non-peak period transit operation, the frequency of buses in generally low and the system is characterized with a certain waiting time. Our research creates timetables for off- period operations by incorporating the waiting times at each transfer point.

It is evident from the review that there are various techniques to create timetables, each employing different objective suitable to a specific situation. In transit planning the method employed to create user-friendly timetables by the planners depends on the need of the public and the characteristics of that particular transit network. Our research creates timetables for a transit by incorporating different headways at a transfer point.

2.3 BENEFITS OF INTEGRATED BUS AND RAIL SERVICES

For customers:

-More attractive system with the vision "one network, one timetable, one ticket, one fare-from door to door".

-Reduced travel time

-Save money and time

For operators:

-authorities and the public benefits will be felt over the medium and long term. Making public transport more attractive and reducing access barriers (more regular use by existing customers plus new customers):

-Higher revenue

-Better for environment

-Less congestion

-Community benefits-social space

-Cost effective (reduction of parallel services)

2.4 PUBLIC TRANSPORT IN ADDIS ABABA

The current public transport service in Addis Ababa is provided by mini and midi buses, collective taxis, taxis, as well as 12 meter and articulated city buses operated by Anbessa. Minibuses move the majority of the daily passengers, though Anbessa bus has a significant modal share and a network of routes that provide good coverage of the city.Anbessa City Bus Service Enterprise runs the conventional bus system. Currently, it operates 650 buses, 100 articulated buses and manages four terminals (Merkato, La Gare, Menelik Square and Megenagna).The total network is composed of 104 routes and the most important one operates 13 trips per day in each direction. The fare is based on distance and ranges from 1 Birr (city centre) to 7 Birr (suburb) and there is a 45-cent public subsidy per ticket. Currently, Anbessa carries 400,000 passengers per day.

Alternative public transport is also an important feature of the system. There are about 10,000 private-owned taxis and mini buses. This type of transportation is decreasing because of the priority given to AACG public transportation. The current transport plan includes the construction of seven BRT (Bus Rapid Transit) and two LRT (Light Rail Transport) corridors, as well as improvements in pedestrian facilities, non-motorized transport and parking management. Currently the Addis Ababa light rail transit is under completion on the east-west axis (from Ayat to Tor Hailoch) and on the north-south axis (from Menelik II Square to Kality). The LRT will have 10 main hubs (Ayat, Megenagna, La Gare, Lideta, Tor Hailoch, Menilik Square, Mercato, Gotera, Dama Hotel, and Kality) out of a total of 32 stations.

The hubs will be close to important public areas or service centers, such as the stadium, university, hospitals, CBD, markets and shopping malls. They will also provide important connections with other modes of transport such as anbessa bus, BRT (Bus Rapid transit), taxis, mini- buses etc. Predicted peak hour passenger capacity should be 15,000 per direction and will increase later.

The network of the AALRT is shown in fig1.1 below:

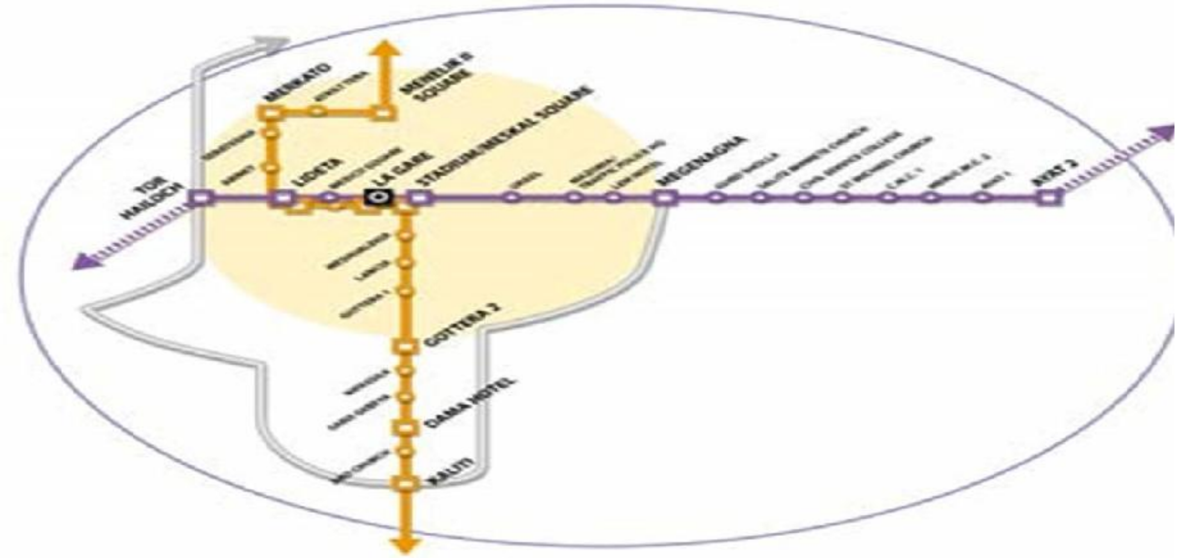


Fig 1.1 AALRT network (source ERC)

Car ownership is still significantly low in addis ababa, though rapidly increasing mainly due to economic growth and the introduction of low cost private vehicles into the local market. non- motorised transport, and particularly walking, still dominates the modal split for daily trips in addis ababa, whereas public transport service is not adequate to accommodate the respective demand.in 2006, the city’s modal share was about 45% pedestrian, 46% public transport and 9% private modes.

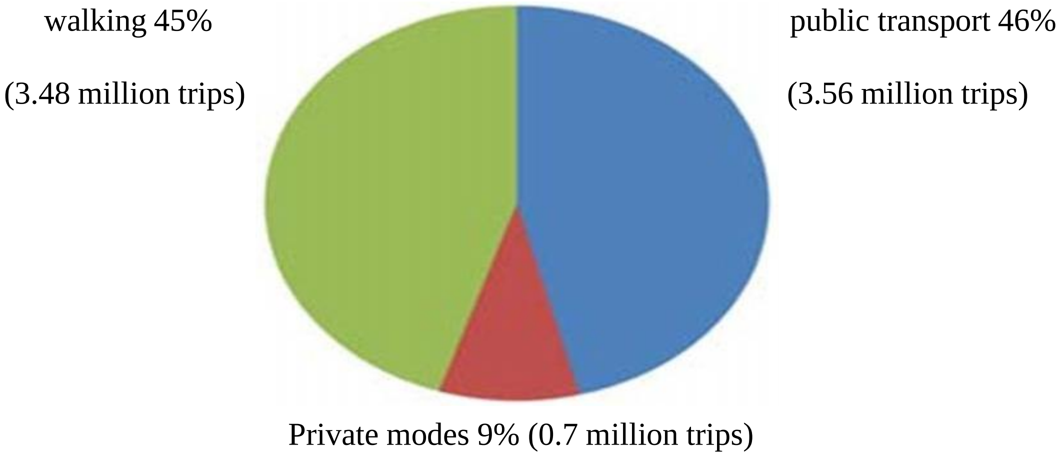


Fig 1.2 Addis Ababa modal share 2006 e.c

CHAPTER THREE: METHODOLOGY

This thesis adopts a heuristic approach to solve the bus to rail synchronization problem and also presents the effect of headways on the number of simultaneous arrival and passenger waiting time for the case of merkato station.

The data inputs required for the accomplishment of the thesis are origin and destinations, number of buses available to be scheduled to routes, working hours (peak hours and normal hours), the current dispatching rules of buses, current daily schedule, overall length of routes, bus capacity etc , and also train's capacity, headway, schedules, travel distance, travel time etc.

3.1 LITERATURE SURVEY

Literature survey is done to analyze and deeply understand what is previously done on the topic and also to find out important techniques for problem formulation and modeling. This helps to identify the gaps of the previous works and provide improvement. Literature survey is done through browsing internet, books, thesis, articles and journals.

3.2 INTERVIEW

The beginning step in the research methodology followed in this paper is verifying the existing networks of Anbessa City Buses and routes of Addis Ababa light rail transit. Interviews made to the different staffs of Anbessa City Bus service enterprise and also interviews made with concerned bodies of addis ababa light rail transit project office. Informal interview is made with the bodies that are responsible for the scheduling operation, market research and planning department, on the city bus and have enough experience in that area to identify the major difficulties they face while scheduling and what they currently consider to allocate buses to a given route.

3.3 DATA COLLECTION THROUGH RECORDING AND OBSERVATION

Merkato bus terminal is one of the four major terminals of the anbessa city bus. There are around 36 routes originating from merkato. Merkato railway station is also one of the prominent stations of AALRT on its north-south line. Merkato was decided as a study area due to its considerable movement of passenger take place towards many areas from the station since it is a central business district. Data collection involves the review of previously recorded data and works done related to the topic. These data are collected from Anbessa City Bus Enterprise and Addis Ababa light rail project office. Some of these data are the number of passengers served by ACBE per month or per day, route performance, number of trips made per month or per day and the resources available for providing service (buses) etc. and number of rail stations on the two corridors ,their routes ,predicted passenger at the stations etc.

3.4 MODEL DEVELOPMENT

This part discusses the methodology that is implemented in this research to create synchronized timetables. This includes formulating the problem as a Mixed Integer programming problem.

3.4.1 Notations

The following are the notation used in defining the problem and are used in the entire thesis.

N – Total number of nodes k present in the network.

M – Total number of bus routes present in the network.

T – Planning horizon during which the departure times are constructed.

$H\ min_i$ – Minimum required headway for route i.

$H\ max_i$ – Maximum required headway for route i.

t_{ik} – Travel time from the starting point (origin) on route i to node k.

$WT\ min_k$ – Minimum allowed waiting time at node k.

$WT\ max_k$ – Maximum allowed waiting time at node k.

X_{ip} – Departure time of p^{th} bus on route i.

T^{k}_{ip} – Arrival time of p bus on route on route i at node k.

X_{jq}- departure time of q^{th} train on route j

T_{jq}- arrival time q^{th} train on route j at node k.

B_i – Set of nodes contained on route i.

$B_{i,j}$ – Set of common nodes contained on route i and route j.

f_i – Frequency (number of buses departing in a given time period) on each route.

3.4.2 Formulating the Model

The decision variable Y_{ijkpq} is defined as,

$Y_{ijkpq} = 1$, if the arrivals of p^{th} train on route i and q bus on route j at node k are separated by a time that is within the required waiting time limit.

$Y_{ijkpq} = 0$, otherwise.

The arrival time of bus and train at a node is calculated by adding the departure time and the time taken to travel to that node, i.e. $T_{ip}^{K}=X_{ip}+t_{ik}$

The objective function of the model presented is to maximize the number of simultaneous arrivals.

$$\text{Max} \sum_{i=1}^{M-1} \sum_{j=i+1}^{M} \sum_{k \in b} \sum_{p=1}^{f_i} \sum_{q=1}^{f_j} \{Y_{ijkkpq}\}$$

The constraints are given by the following equations

$$X_{i1} \leq H\,\max_i;\ 1 \leq i \leq M \qquad (1)$$

$$X_{if_i} \leq T;\ 1 \leq i \leq M \qquad (2)$$

$$H\,\min_i \leq X_{i(p+1)} - X_{ip} \leq H\,\max_i;\ 1 \leq i \leq M; 1 \leq p \leq f_i - 1 \qquad (3)$$

$$Y_{ijkpq} = 1 \text{ if } WT\min \leq \left|(X_{ip} + t_{ik}) - (X_{jq} + t_{jk})\right| \leq WT\max_k,\ k \in B_{i,j} \qquad (4)$$

$$Y_{ijkpq} = 0;$$

$$\text{If } \left|(X_{ip}+t_{ik}) - (X_{iq}+t_{ik})\right| < WTmin_k \text{ or } \left|(X_{ip}+t_{ik}) - (X_{jq}+t_{jk})\right| > WTmax_k, \qquad (5)$$

Constraint (1) ensures that the first departure time of each route will not be beyond maximum headway from the start of time horizon and

Constraint (2) ensures that the last departure is within the planning horizon.

Constraint (3) indicates the headway limits.

Constraint (4) shows that the decision variable takes a value of 1 if the arrivals at the node are within the waiting limits and

Constraint (5) ensures that Y_{ijkpq} takes the value 0 otherwise.

3.4.3 HEURISTIC APPROACH

This section will present the algorithm developed to solve our problem of setting departure times. The basic outline of the algorithm is based on the algorithm developed by Ceder et al. (2001). The incorporated change in the definition of simultaneous arrival is applied in the different procedures used to set the departure times. The algorithm is based on the selection of nodes. There are three possible states for a node. A node can be ‘new’, ‘possible’ or ‘not possible’.

1. A node is ‘new’ if none of the departure times of routes passing through the node are set.
2. A node is defined as ‘possible’ if:
    - There is at least one route passing through it and not all the departure times for that route are set.
    - There is a possibility to create more synchronized arrivals at the node.

3. A node is ‘not possible’ if all the departures of the routes passing through it are set and no more simultaneous arrivals are possible.

Details about input values, node selection process and procedures are discussed in the following sub-sections. The following are the steps in the algorithm:

1. Take the input values and initialize all the nodes as ‘new’;

2. Identify the node 'SELECTED NODE' by following the Node Selection Procedure in section 3.4.3.2;

3. If 'SELECTED NODE' is new perform PROCEDURE 1, otherwise perform PROCEDURE 2;
4. Are there any 'new' or 'possible' nodes? If yes, go to Step 2. Otherwise continue;
5. Are there any routes with unassigned departures? If yes, perform PROCEDURE 3, otherwise stop.
6. Are there any possible nodes? If yes, go to Step 2. Otherwise stop.

3.4.3.1 MODEL INPUTS

The following are the assumptions made on the input data for each route i:

1. $Hmax_i \geq Hmin_i$
2. $T \geq (f_i - 1) . Hmin_i$
3. The maximum possible limit on the planning horizon is the maximum value given by $(f_i \cdot H \max_i)$ among all routes.

4. The minimum possible waiting time at each node is some value greater than zero.

5. The maximum waiting time at each node is a value that does not exceeds the maximum headway of routes passing through it.

3.4.3.2 NODE SELECTION PROCEDURE

In each iterative step of the algorithm, a node is selected from among all the 'new' and possible' nodes. There are three steps for selecting a node. They are:

1. Among the 'new' and 'possible' nodes find the node that has maximum number of already set arrival times. If no arrival times are set or if ties exist go to Step 2. If only one 'new' or 'possible' node is identified, label this node as 'SELECTED NODE' (k^*) and exit.

2. Identify the node with the maximum number of routes passing through it. If ties exist go to Step 3. If only one node is identified, label this node as 'SELECTED NODE' (k^*) and exit.

3. Calculate the maximum travel time from the origin of each route to these nodes.
Select the node with the minimum value and label it as 'SELECTED NODE' (k^*). If a tie exists break it arbitrarily.

3.4.3.3 PROCEDURE 1

This procedure assigns departure times for routes meeting at the 'SELECTED NODE' if it is 'new'. Suppose that two routes meet at the node, then this procedure assigns the departure time of the route that takes maximum time to arrive to that node. It assigns a departure time of 0 (i.e., the starting time of the planning horizon) to the 1st bus on this route that takes maximum travel time. For the other route it assigns the departure time such that the arrival times of these two routes at the selected node is within the specified waiting time limits.

The procedure first checks if it is possible to have the minimum allowed waiting time and if it is possible, departure times are assigned accordingly. If it is not satisfied it increases the time by one (discrete time) and verifies for the next possible waiting time from the limit and so on till the maximum limit is reached. The subsequent departures for these routes are fixed after a time d from the last departure. The procedure finds the minimum possible d that is given by:

$$d = \min_{i=1,2...M} \left[\max_{i=1,2...M} (H\min_i),\ \min_{i=1,2...M} (H\max_i) \right] \ \forall\ \text{i, passing through the selected node.}$$

This procedure performs the following steps:

Step 1: At the SELECTED NODE (k^*),

- For all routes i, passing through it calculate minimum possible d satisfying,

$$d = \min_{i=1,2...M} \left[\max_{i=1,2...M} (H\min_i),\ \min_{i=1,2...M} (H\max_i) \right] \ \forall\ \text{i passing through } k\ .$$

This procedure performs the following steps:

Step 1: At the SELECTED NODE (k^*),

- For all routes i, passing through it calculate minimum possible d satisfying,

$$d = \min_{i=1,2...M} \left[\max_{i=1,2...M} (H\min_i),\ \min_{i=1,2...M} (H\max_i) \right] \ \forall\ \text{i passing through } k^*\ .$$

- Set maxtime= maximum travel time to reach k* and identify the route associated with maxtime to reach k* and label it as i*.

Step 2: For the route i^* set the first departure (p = 1) as $X_{i^*1} = 0$

Step 3: For the other routes i, passing through this node:

- If (maxtime-WTmin$_{k*}$ - t$_{ik*}$ > 0)

  Set X_{i1}=(maxtime-WTmin$_{k*}$-t_{ik*}) and go to step 5

  Otherwise, set w = WT min $_{*}$

STEP 4: If (maxtime + w) ≥ t_{ik^*} and if (maxtime + w - t_{ik^*}) ≤ H max$_i$

- Set X_{i1} = (maxtime + w - t_{ik^*}) and go to Step 5.

Else, set w = w +1. If w ≤WT max$_{K^*}$ Repeat step 4, else exit.

Step 5: For these routes i and i^*, if the procedure is able to find the value of d in Step 1, Then the subsequent departures i.e interval of d from ∀p = 2… min (f_i,f_j) are assigned after the previous departure. That is:

Set X_{ip}= $X_{i(p-1)}$ + d

Set X_{i*p} =$X_{i*(p-1)}$ + d

Else go to Step 6.

Step 6: For these routes i and i^* compute the arrival times of all the set departures (p =1, 2,…,min(f_i,f_i) to each possible and new nodes on the route as

- T^k_{ip}=X_{ip}+ t_{ik} ∀ k = 1,…., N present on i.

- T^K_{i*p} =X_{i*p} + t_{i*k} ∀ k = 1,…., N present on i*.

Step 7: Label all the other nodes on these routes, as ‘possible’ and label k^* as ‘not possible’ and exit.

3.4.3.4 PROCEDURE 2

This method sets the departure times when the selected node is ‘possible’. For a selected ‘possible’ node there will be some routes whose starting times are already set using PROCEDURE 1. Hence the departure times of the routes that are not set are assigned to have a simultaneous arrival with the set arrivals at the node. If no more assignments are possible the node is marked as ‘not possible’. The following steps are performed by this procedure:

Step 1: At the SELECTED NODE, k^* that is ‘possible’,

- Set i^* as the route passing through k^* and all the departure times are already set using PROCEDURE 1. Set arrival times of i^* from the origin to k^* as:

  $T_{i^*p}^{k^*} = X_{i^*p} + t_{ik^*} \quad \forall p = 1....f_{i^*}$

Step 2: For the other routes i, passing through k^*, set p as the minimum un-assigned frequency where $p \in (1....f_i)$.

For each $T_{i^*p}^{k^*}$ that is, $T_{i^*1}^{k^*}, T_{i^*2}^{k^*}, \ldots\ldots, T_{i^*f_{i^*}}^{k^*}$ set $w = WT\min_{k^*}$

Step 3: For route i, if $0 \le (T_{i^*p}^{k^*} - w - t_{ik^*}) \le H\max_i + X_{i(p-1)}$

For p = 1, set $X_{ip} = (T^{k^*}_{i^*p} - w - t_{ik^*})$ and go to Step 4

For p > 1, if $(T^{k^*}_{i^*p} - w - t_{ik^*}) - X_{i(p-1)} \geq H\min_i$, set $X_{ip} = (T^{k^*}_{i^*p} - w - t_{ik^*})$ and go to Step 4.

Else if $0 < (T^{k^*}_{ip} + w - t_{ik}) < H_{max} + Y_{i(p-1)}$

For p = 1, set $X_{ip} = (T^{k^*}_{i^*p} + w - t_{ik^*})$ and go to Step 4

For p > 1, if $(T^{k^*}_{i^*p} + w - t_{ik^*}) - X_{i(p-1)} \geq H\min_i$, set $X_{ip} = (T^{k^*}_{i^*p} + w - t_{ik^*})$ and go to Step 4.

Other wise set w = w + 1 and, if $w \leq WT\max_{g^*}$ repeat Step 3. Otherwise set

$T^{k^*}_{i^*p} = T^{k^*}_{i^*p+1}$ and set w = $WT\min_{g^*}$ And go to Step 3. Else exit.

Step 4: For route i if p < f_i – go to Step 2, Otherwise label k^* as ‘not possible’.

Step 5: For routes i passing through k^* and for the departure times that are set in Step 3, compute the arrival time to each ‘possible’ and ‘new’ nodes present on the route as, $T^k_{ip} = X_{ip} + t_{ik}$ ∀ k = 1,….., N on route i.

Step 6: Label all the other ‘new’ nodes on these routes, as ‘possible’.

3.4.3.5 PROCEDURE 3

This procedure checks if there are any un-assigned departures that are not created by the first two procedures.

1. If there is only one unassigned departure on route i, and set p as the minimum unassigned frequency where $p \in (1.... f_i)$,
    - Set this departure time using the minimum headway from the last departure as $X_{ip} = X_{i(p-1)} + H\min_i$ and exit.
2. If there are more than one unassigned departures on different routes,
    - Identify the route i, passing through the maximum number of nodes, break ties arbitrarily.
    - Assigns its next departure by using minimum headway from the last departure. i.e.
      $X_{ip}=X_{i(p-1)} + H\min_i$

CHAPTER FOUR: MODEL ANALYSIS AND DISCUSION

4.1 MODEL ANALYSIS FOR MERKATO STATION

In this chapter, the heuristic developed is applied to merkato terminal which uses the realistic data on number of routes, nodes and headways and waiting times. The model is tested for different headways and compares the total number of simultaneous arrival. In mercato area there are 36 routes originating from the bus station, composing one-third of the city's total anbessa city bus service as shown in the table 4.1, 16 of them run parallel to the AALRT so we considered those which do not run parallel to the rail for our model.

Table 4.1 data of AALRT and anbessa bus at merkato terminal

Routes i	Minimum headway, $H\min_i$	Maximum Headway, $H\max_i$	Frequency, f_i	travel time
1(train)	6	12	6	5
8	20	25	3	35
18	6	15	8	43
20	20	25	3	31
21	10	15	4	39
24	10	15	4	60
26	20	25	3	60
28	10	15	4	46
35	20	25	3	50
43	40	50	2	90
47	20	25	3	35
51	20	25	3	50
52	6	15	8	68
63	20	25	3	45
65	20	25	3	45
66	10	15	4	52
69	20	25	3	45
74	6	10	6	58
85	40	50	2	90
95	40	50	2	105

Taking into account route 1(train) and route 8 of anbessa bus and node of merkato anbessa bus station i have tried to explain the heuristic approach presented in chapter three. The inputs for this network are given in Table 4.2 and Table 4.3. The planning horizon is [0, 140] minutes.

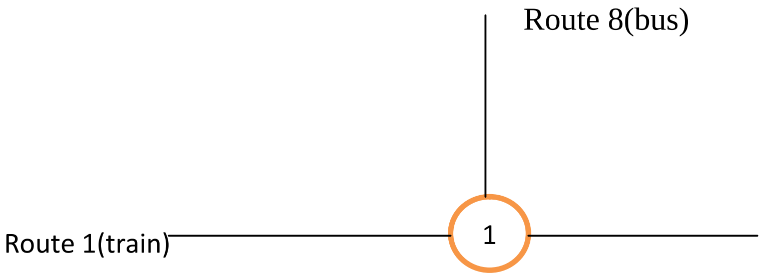


Figure 4.1 diagram of our case study

Table 4.2 Inputs for the merkato bus routes

Routes i	Minimum headway, H min_i	Maximum Headway, H max_i	Frequency, f_i	travel time
1(train)	6	12	10	20
8	20	25	3	35

Table 4.3 Inputs for the node (merkato station)

Nodes, k	Number of routes	Minimum waiting time, WT min_k	Maximum waiting time, WT max_k
1	2	4	6

Step 1: Initialize Node 1 as 'new'.

Step 2: Identify the node 'SELECTED NODE' k^*

1. No arrival times are set.
2. The number of routes crossing Node 1 = 2,
3. Maximum travel time for node 1: maximum (5, 35) =35.

4. k^* = Node 1

Step 3: As node 1 is ‘new’ perform Procedure 1.

1. The d value obtained is, d = min [20,12] = 12

   maxtime = 35 and the route i^* is route 8.

2. For route 8, set the first departure (X_{81}) at zero minutes.

3. For route 1, (maxtime - WT $\min_1$ - t_{11}) = 35 - 4 - 20 = 11 which is greater than zero,

   Hence set the first departure time of route 1 (X_{11}) = maxtime - WT $\min_1$ - t_{11} =1 1.

4. For routes 1 and 8 the number of subsequent departures set by this procedure are

p = 2… min (f_1 , f_8) = min (10,3) = 3. These are set after a time d from the previous departures, i.e

For route i, (i = 1):

$X_{12} = X_{11} + d = 11+12 = 23$

$X_{13} = X_{12} + d = 23+12 = 35$

Similarly for route i^* (i^* = 8):

$X_{82} = X_{81} + d = 0+12 = 12$

$X_{83} = X_{82} + d = 12+12 = 24$

6. The arrival times of routes 1and 8 buses to node 1 are:

$T^1_{11}=11+20=31$ $T^1_{12}=23+20=43$ $T^1_{13}=35+20=55$

Similarly, the arrival times of route 8 buses at node 1 are

$T^1_{81}=0+35=35$ $T^1_{82}=12+35=47$ $T^1_{83}=24+35=59$

7. The results of this procedure are summarized in Table 4.4.

Table 4.4 Procedure 1 results for merkato station I

Departures	Route1	Route 8	Arrival time at Node 1	
			Route 1	Route 8
1	11	0	31	35
2	23	12	43	47
3	35	24	55	59
4	Not yet assigned	-	Not yet assigned	Not yet assigned
5	Not yet assigned	-		
6	Not yet assigned	-		
7	Not yet assigned	-		
8	Not yet assigned	-		
9	Not yet assigned	-		
10	Not yet assigned	-		

Step 4 labeling node 1 is “possible” - go to step 2

1. The “selected node”, k^*= node 1

Step 3: route i^* is 8 and T^1_{81}, T^1_{82} , T^1_{83} are 35,47 and 59 respectively

2. Route 1 has an un-assigned frequency which is p = 4, 5,6,7,8,9,10. For each T^1_{8P} = 35, 47 and 59 set w = 20

3. For T^1_{81}=35 and w= 4… 25 the procedure fails to set departure time .when w is 26 all conditions are satisfied and the departure time is set as,

$X_{14}=T^1_{81}+w-t_{11}=35+26-20=4$

$X_{15}=41+12=52$, $X_{16}=52+12=64$, $X_{17}=64+12=76$, $X_{18}=76+12=88$, $X_{19}=88+12=100$,

$X_{1\,10}=100+12=112$

4. The arrival times of route 1 are:

$T^1_{14}=41+20=61$, $T^1_{15}=52+20=72$, $T^1_{16}=64+20=84$, $T^1_{17}=76+20=96$, $T^1_{18}=96+20=116$ $T^1_{19}=100+20=120$, $T^1_{110}=112+20=132$

5. No more departures of route 1 are un-assigned. Hence stop the procedure and label node 1 as ‘not possible’.

Step 4: There are no more ‘new’ or ‘possible’ nodes.

Step 5: No more unset departures on any routes, stop.

The final results are shown in Table 4 and the seven simultaneous arrivals obtained are four as shown in Table 4.5. For example, $Y_{I,II,2,1,1}$ = 1 shows that the first departure on route 1 and first departure of route 8 arrive simultaneously at node 1.

Table 4.5: Final Timetables for merkato station I

Departures	Route1	Route 8	Arrival time at Node 1	
			Route 1	Route 8
1	11	0	31	35
2	23	12	43	47
3	35	24	55	59
4	41	-	61	-
5	52	-	72	-
6	64	-	84	-
7	76	-	96	-
8	88	-	116	-
9	100	-	120	-
10	112	-	132	-

Table 4.6 Table showing simultaneous arrivals for merkato station I

Simultaneous Arrivals At Node 1
$Y_{1,8,1,1,1} = 1$
$Y_{1,8,1,2,2} = 1$
$Y_{1,8,1,3,3} = 1$
$Y_{1,8,1,4,3} = 1$

Next we will see the effect of reducing the headway of the bus and rail on the simultaneous arrival of the public transport. Input data for the reduced headway are shown in table 4.7.

Table 4.7 Input data for the reduced headway of the merkato bus routes

Routes i	Minimum headway, H $\min_i$	Maximum Headway, H $\max_i$	Frequency, f_i	travel time
1(train)	4	8	10	20
8	15	20	3	35

Step 1: Initialize Node 1 as ‘new’.

Step 2: Identify the node ‘SELECTED NODE’ k^*

1. No arrival times are set.
2. The number of routes crossing Node 1 = 2,
3. Maximum travel time for node 1: maximum (5, 35) =35.
4. k^* = Node 1

Step 3: As node 1 is ‘new’ perform Procedure 1.

1. The d value obtained is, d = min [15,8] = 8

   maxtime = 35 and the route i^* is route 8.

2. For route 8, set the first departure (X_{81}) at zero minutes.

3. For route 1, (maxtime - WT $\min_1$ - t_{11}) = 35 - 4 - 20 = 11 which is greater than zero,

   Hence set the first departure time of route 1 (X_{11}) = maxtime - WT $\min_1$ - t_{11} =1 1.

4. For routes 1 and 8 the number of subsequent departures set by this procedure are $p = 2\ldots \min(f_1, f_8) = \min(10,3) = 3$.

These are set after a time d from the previous departures, i.e

For route i, (i = 1):

$X_{12} = x_{11} + d = 11+8 = 19$

$X_{13} = x_{12} + d = 19 + 8 = 27$

Similarly for route i^* ($i^* = 8$)

$X_{82} = x_{81} + d = 0+8 = 8$

6. The arrival times of routes 1train and 8 bus to node 1 are:

$T^1_{11} = 11+20 = 31$ $T^1_{12} = 19+20 = 39$ $T^1_{13} = 27+20 = 47$

Similarly, the arrival times of route 8 buses at node 1 are

$T^1_{81} = 0+35 = 35$ $T^1_{82} = 8+35 = 43$ $T^1_{83} = 16+3$

7. The results of this procedure are summarized in Table 4.8.

Step 4 labeling node 1 is "possible" - go to step 2

1. The "selected node", $k^* =$ node 1

route i^* is route 8 and T^1_{81}, T^1_{82} , T^1_{83} are 35,43 and 51 respectively

2. Route 1 has an un-assigned frequency which is p = 4, 5,6,7,8,9,10. For each $T^1_{8P} = 35$, 43 and 51 set w = 20

3. For $T^1_{8P} = 35$ and w= 4… 17 the procedure fails to set departure time .when w is 16 all conditions are satisfied and the departure time is set as,

Table 4.8 Procedure 1 results for merkato station II

Departures	Route1	Route 8	Arrival time at Node 1	
			Route 1	Route 8
1	11	0	31	35
2	19	8	39	43
3	27	16	47	51
4	Not yet assigned	-	Not yet assigned	Not yet assigned
5	Not yet assigned	-		
6	Not yet assigned	-		
7	Not yet assigned	-		
8	Not yet assigned	-		
9	Not yet assigned	-		
10	Not yet assigned	-		

$X_{14}=T^{1}_{81} + w-t_{11}=35+16-20=31$

$X_{15}=31+8=39$, $X_{16}=39+8= 47$, $X_{17}=47+8=55$, $X_{18}=55+8=63$, $X_{19}=63+8=71$,

$X_{1\ 10}=71+8=79$

4. The arrival times of route 1 are:

$T^{1}_{14}=31+20=51$,$T^{1}_{15}=39+20=59$,$T^{1}_{16}=47+20=67$,$T^{1}_{17}=55+20=75$,$T^{1}_{18}=63+20=83$

$T^{1}_{19}=71+20=91$, $T^{1}_{110}=79+20=99$

5. No more departures of route 1 are un-assigned. Hence stop the procedure and label node 1 as ‘not possible’.

Step 4: There are no more ‘new’ or ‘possible’ nodes.

Step 5: No more unset departures on any routes, stop.

The final results are shown in Table 8 and the seven simultaneous arrivals obtained are six as shown in Table 9. For example, $Y_{1,8,1,1,1} = 1$ shows that the first departure on route 1 and first departure of route 8 arrive simultaneously at node 1.

Table 4.9: Final Timetables for mercato station II

Departures	Route1	Route 8	Arrival time at Node 1	
			Route 1	Route 8
1	11	0	31	35
2	19	12	39	43
3	27	24	47	51
4	31	-	51	-
5	39	-	59	-
6	47	-	67	-
7	55	-	75	-
8	63	-	83	-
9	71	-	91	-
10	79	-	99	-

Table 4.10 Table showing simultaneous arrivals for merkato station II

Simultaneous Arrivals At Node 1
$Y_{1,8,1,1,1} = 1$
$Y_{1,8,1,2,1} = 1$
$Y_{1,8,1,2,2} = 1$
$Y_{1,8,1,3,2} = 1$
$Y_{1,8,1,3,3} = 1$
$Y_{1,8,1,4,3} = 1$

As the results on table 4.6 and table 4.10 show the number of simultaneous arrivals increases from 4 to 6 as the headway of the bus is reduced.The timetable for the whole anbessa buses running in the merkato route and considering the node of mercato anbessa bus terminal have been presented in the appendix a. the morning peak from 12:00 to 3:00 local times have been used in the case study. The time table presents the train pickup points of passengers and their waiting time considering the current headway of buses and using the reduced headways. From the results shown in table 5.2 and 5.3 we can see that by reducing the headways the passengers can take train more frequently and also they will face a reduced waiting time. This will lead to a more synchronized bus to train time table.

4.2 CONCLUSION

From the results shown on table 4.6 and 4.10 one can conclude that as we decrease the headway of anbessa buses by 5 minutes, the number of simultaneous arrivals has increased from 4 to 6. Results shown on the appendix a show that frequency of passengers to catch-up train has increased and also the waiting time of passengers has reduced as we decrease the headway of buses. For example, if we consider the train and route 8 of anbessa bus , for the current headway the bus can catch every 4th train where us by the reduced headway the bus can catchup every 3rd train. And also the waiting time of passengers for the 3rd bus has reduced from 9 minutes to 3 minutes. This shows the effect of headway of buses on the transfer synchronization

CHAPTER FIVE: CONCLUSION

5.1 SUMMARY

A new rail line has the potential to strengthen a transit system by introducing a quick, reliable, comfortable, and frequent transportation that attracts new riders and generates public support. A bus network that supplements the rail line can extend transit's reach and make the system more responsive to a variety of travel patterns. Although a new rail system can bring about long-term gains for transit, in the short term it introduces many changes that may result in uncertainty for both passengers and operators. At the same time, external pressures to demonstrate "success" (often measured in terms of rail ridership) may cause agencies to divert their attention away from the equally important bus system. As both bus and rail are critical components of a successful intermodal system, agencies should focus on how both modes can work together.

This thesis studied the integration of Anbessa city bus and Addis Ababa light rail transit. The merkato Terminal was used as case study. Since the area is the business heart of the city significant amount of public transportation services and passenger flow exists.

After introduction presented in chapter 1, chapter 2 presented a literature review on bus and rail integration. The objective of this review was to determine the practices available to improve integration between transit systems and the strategies that could facilitate the implementation of such practices in context of different transit operators.

In chapter 3 the methodology of the researched has been presented. The mathematical model was formulated as a Mixed Integer problem. A heuristic approach is used to solve the problem. The heuristic is based on a node-oriented approach, which creates timetables of route passing through some selected node. The proposed model reduces waiting time by decreasing headways to achieve synchronization.

In chapter 4 the analysis for the proposed model was performed for the case of merkato terminal. In this chapter we used the heuristic approach to calculate the total number synchronization obtained using the current headway of anbessa bus and compared it with the total number of synchronization obtained if the headway of anbessa bus is reduced by 5 minutes. as the results show the total number of synchronization has increased as headway of anbessa is reduced and also the waiting time of passengers has decreased.

5.2 CONCLUSION AND RECOMMENDATION

In this thesis the effect of headway on simultaneous arrival of bus and train is shown by reducing the current headway of Anbessa bus on Merkato route. Considering the current headway of AALRT as 6 minutes we developed a timetable and pickup points of train for passengers traveling from bus to rail. And also calculate waiting time of passengers on each route. We have used walking time of 3 minutes and boarding time of 2 minutes and the results are shown on table 6.2.Then we developed a similar timetable to the one shown on table 6.2 by decreasing the current headway of anbessa bus by 5 min and by relocating the anbessa bus station at merkato in close proximity to LRT station so that we can decrease the walking distance to 1 min and results are shown in table 6.3 in appendix section.

Therefore as can be seen in timetables developed on table 6.2 and 6.3 there is significant change in the simultaneous arrival of bus and train and passengers waiting time. For instance if we see anbessa bus route 8 and AALRT , in the first scenario shown in table 6.2 passengers boarding from the consecutive buses arriving at merkato can pick the fourth train but for the second scenario passengers can take the third train which reduces their waiting time. We can also see the reduction of waiting time of the third bus from 0.09 minutes in the first scenario to 0.03 in the second scenario. For other routes the effect is similar, the tables have shown the reduction in the total and average waiting time.

Generally from the results obtained we can conclude:

1. The number of simultaneous arrivals obtained depends on the headway of buses,
2. Synchronizations are inversely proportional to headway of buses. That is, when the headway is reduced the number of simultaneous arrival is larger. The waiting time of passengers at the transfer station has been reduced by decreasing the headway of buses.

So it is recommended for anbessa bus to reduce its headway so that passengers can pick their train at minimum waiting time possible. And also anbessa bus station at merkato terminal is far from the train terminal at merkato station this creates longer walking distance for passengers transferring from bus to train and vise versa.so it is recommended to relocate anbessa bus station to a nearer proximity of a rail station or assign a bus which can run from bus station to the rail station

5.3 FUTURE WORK

In the area of integration between bus and rail services, studied in this thesis, there is still room for further research. Perhaps the most important opportunities for research in this area would be

1. Revenue and ridership impacts of integrated fare structures for transit services in merkato terminal.

The availability of detailed data on transfers between rail and bus services can be used to propose and evaluate different combined fare structures for bus and rail services in merkato.

2. Integration of light rail transit with BRT(bus rapid transit)

This thesis examines coordination of anbessa bus with AALRT only so integration with the planned bus rapid transit of Addis Ababa will be an important issue.

3. Extensions

After phase I of AALRT are complete, there are proposals to extend rail services. Work is needed to determine how to integrate bus and public services with these extensions

4. Other modes

Other ways of accessing train station include taxis and automobile drop-offs (“kiss-and- ride”).these modes can supplement bus feeder services, particularly during off-peak hours and in remote areas. Better accessibility to train can allow family members to share cars (instead of leaving a car idle at a park-and-ride lot), creating a more transit-dependent culture. Additional research can help identify ways to encourage alternative modes (for example, neighborhood taxis).

REFERENCES

1. C. L. Martins and M. V. Pato, “Search strategies for the feeder bus network design problem,” European Journal of Operational Research, vol. 106, no. 2-3, pp. 425–440, 1998.

2. Shrivastava P, Dhingra SL. Development of feeder routes for Suburban railway stations using heuristic approach.Journal of Transportation Engineering. 2001; 127(4):334–341.

3. Shrivastava P, O'mahony M. Modeling an Integrated Public Transportation System a Case Study in Dublin. Ireland, 2009.

4. Wirasinghe S. Assignment of buses in a coordinated rail and bus transit system. Proceedings of the 7th International Symposium on Transportation and Traffic Flow Theory; 1977; pp. 673–696.

5. Wirasinghe SC. Nearly optimal parameters for a rail/feeder-bus system on a rectangular grid. Transportation Research A. 1980; 14(1):33–40.

6. Hu Y, Zhang Q, Wang W. A model layout region optimization for feeder buses of rail transit. Procedia.2012; 43:773–780.

7. Chien and Schonfeld, 1998S. Chien, P. Schonfeld. Joint optimization of a rail transit line and its feeder bus system.Journal of Advanced Transportation, 32 (3) (1998), pp. 253–284.

8. Moorthy, 1997 N.V.R. Moorthy .Planning of integrated transit network for bus and LRT. Journal of Advanced Transportation, 31 (3) (1997), pp. 283–309.

9. Gebeyehu, M. and Takano, S. (2007) Diagnostic Evaluation of Public Transportation Mode Choice in Addis Ababa. Japan Journal of Public Transportation, Vol. 10, No. 4, 2007.

10. Abate Demelash Analyzing Public Transportation Performance Using Efficiency measures and

Spatial Analysis. The case of Addis Ababa. [Report].-[s.l.]: International Institute for Geo-Information Science and Earth Observation. 2007.

11. Eranki Anitha A Model to Create Bus Timetables to Attain Maximum Synchronization Considering Waiting Times at Transfer Stops. [Report].-[s.l.]: University of South Florida. 2004.

12. Song Lijing, Chen Feng Xian Kai, Sun Mingzheng. (2012). Research on a Scientific Approach for Bus and Metro Networks Integration. 8th International Conference on Traffic and Transportation Studies. Changsha, China, August 1-3, 2012.

13. Jansen, L.N., Nielsen, O.A., (2002),"Minimizing passenger transfer times in public transport timetable." In: Proceedings of the 7th Conference of the Hong Kong Society for Transportation Studies, Transportation in the Information Age, Hong Kong. pp. 229 – 239.

14. A, Ceder, B, Golany. (2001)."Creating but timetables with maximal synchronization." Transportation Research Part A 35(2001) 913-928.

15. Abate Demelash Analyzing Public Transportation Performance Using Efficiency measures and Spatial Analysis. The case of Addis Ababa. [Report]. - [s.l.] : International Institute for Geo-Information Science and Earth Observation., 2007.

16. Ethiopian Railway Corporation (ERC). (2012). Addis Ababa Light Rail Transit (AA-LRT) Project. Addis Ababa.

17. Lyon Town Planning Agency. (2010). Addis Ababa Bus Rapid Transit Line Feasibility study.

18. Hickey,T.R.(1992) coordination of intermodal transfers at LRT stations. Transportation research record 1361. Transportation research board, Washington D.C. pp. 136-140.

19. Shrivastava P, O'mahony M. Modeling an Integrated Public Transportation System a Case Study in

Dublin. Ireland, 2009.

20. Wirasinghe S. Assignment of buses in a coordinated rail and bus transit system. Proceedings of the 7th International Symposium on Transportation and Traffic Flow Theory; 1977; pp. 673–696.

21. Hu Y, Zhang Q, Wang W. A model layout region optimization for feeder buses of rail transit. Procedia.2012; 43:773–780.

22. Hurdle VF, Wirasinghe SC. Location of rail stations for many to one travel demand and several feeder modes.Journal of Advanced Transportation. 1980;14(1):29–45.

23. Shrivastav P, Dhingra SL. Development of feeder routes for Suburban railway stations using heuristic approach.Journal of Transportation Engineering. 2001;127(4):334–341.

24. Xiong J, Guan W, Song L, Huang A, Shao C. Optimal routing design of community shuttle joint for metro stations. Journal of Transportation Engineering. 2013;139(12):1211–1223.

APPENDIX A: CASE STUDY

The following case study provides a timetable for anbessa bus and Addis Ababa light transit at merkato station. There are 20 anbessa bus routes that are destined at merkato station. Using the heuristic model developed in chapter 3 time table is developed for the morning peak between 12:00 to 3:00 local time for the bus and train. In this thesis the effect of headway on simultaneous arrival of bus and train is shown by reducing the current headway of anbessa bus on merkato route.

The input data required for the timetable are details of existing bus network like origin-destination of various routes, travel time from the origin to merkato station, departure time at the origin, arrival time at mercato station, number of buses and trains on each route, current headway of each route etc. All are shown in table 6.1

Table 6.1 Input data of anbessa bus on merkato route

Route No.	Origin - Destination	No. Of buses	KM	Travel Time trip(min)	Daily trip/route	headway		
8	Semen gebya-merkato	3	9.4	35	26	25	1st bus	12:00
							2ndbus	12:25
							3rdbus	12:50
18	Keraniyo-merkato	8	7.3	43	152	10	1st bus	12:00
							2ndbus	12:10
							3rdbus	12:20
							4thbus	12:30
							5th bus	12:40
							6th bus	12:50
							7thbus	1:00
							8th bus	1:10
20	Dilber-merkato	3	8.6	31	32	25	1st bus	12:00
							2ndbus	12:25
							3rdbus	12:50
21	Filidor-merkato	4	8.6	39	63	15	1st bus	12:00
							2ndbus	12:15
							3rdbus	12:30
							4thbus	12:45
24	Dire soleya-merkato	4	17.7	60	42	15	1st bus	12:00
							2ndbus	12:15
							3rdbus	12:30
							4thbus	12:45
26	Sebeta-merkato	3	25.5	60	39	25	1st bus	12:00
							2ndbus	12:25

								3rd bus	12:50
28	Asko sansune-merkato	4	11.1	46	72	15		1st bus	12:00
								2nd bus	12:15
								3rd bus	12:30
								4th bus	12:45
35	Cherkose-merkato	3	10	50	32	25		1st bus	12:00
								2nd bus	12:25
								3rd bus	12:50
43	Menagesha-Merkato	2	30.2	90	18	40		1st bus	12:00
								2nd bus	12:40
47	Yinegew fire school-Merkato	3	6	35	48	25		1st bus	12:00
								2nd bus	12:25
								3rd bus	12:50
51	Biheratsige-Balcha/betel-merkato	3	10.9	50	36	25		1st bus	12:00
								2nd bus	12:25
								3rd bus	12:50
52	Gerji-Merkato	8	14.1	68	96	10		1st bus	12:00
								2nd bus	12:10
								3rd bus	12:20
								4th bus	12:30
								5th bus	12:40
								6th bus	12:50
								7th bus	1:00
								8th bus	1:10
63	Mikelleland bulding-merkato	3	9.1	45	26	25		1st bus	12:00
								2nd bus	12:25
								3rd bus	12:50
65	World bank-merkato	3	11	45	36	25		1st bus	12:00
								2nd bus	12:25
								3rd bus	12:50
66	Kara kore-merkato	4	10.5	52	68	15		1st bus	12:00
								2nd bus	12:15
								3rd bus	12:30
								4th bus	12:45
69	Lomimeda -merkato	3	12.4	45	16	25		1st bus	12:00
								2nd bus	12:25
								3rd bus	12:50
74	Gurd shola-mikael-merkato	6	13.3	58	84	10		1st bus	12:00
								2nd bus	12:10
								3rd bus	12:20
								4th bus	12:30
								5th bus	12:40
								6th bus	12:50
85	Holeta-mercato	2	45	90	20	40		1st bus	12:00
								2nd bus	12:40
95	Addis alem-merkato	2	50	105	20	40		1st bus	12:00
								2nd bus	12:40

And also considering the current headway of AALRT as 6 minutes we developed a timetable and pickup points of train for passengers traveling from bus to rail. And also calculate waiting time of passengers on each route. We have used walking time of 3 minutes and boarding time of 2 minutes. The results are shown on table 5.2 as follows:

`																				Waiting time	Bus route		
12:32	12:40	12:48	12:56	1:04	1:12	1:20	1:28	1:36	1:44	1:52	2:00	2:08	2:16	2:24	2:32	2:40	2:48	2:56	3:04				Arrival time at merkato
	√																			0:05	1st bus	8	12:35
					√															0:07	2nd bus		1:05
									√											0:09	3rd bus		1:35
		√																		0:05	1st bus	18	12:43
				√																0:06	2nd bus		12:58
						√														0:07	3rd bus		1:13
							√													0:00	4th bus		1:28
										√										0:09	5th bus		1:43
												√								0:10	6th bus		1:58
													√							0:03	7th bus		2:13
															√					0:04	8th bus		2:28
	√																			0:09	1st bus	20	12:31

	√																			0:09	1st bus	20	12:31
				√																0:03	2nd bus		1:01
								√												0:05	3rd bus		1:31
		√																		0:09	1st bus	21	12:39
				√																0:05	2nd bus		12:59
							√													0:09	3rd bus		1:19
									√											0:05	4th bus		1:39
				√																0:04	1st bus	24	1:00
							√													0:08	2nd bus		1:20
									√											0:04	3rd bus		1:40
												√								0:08	4th bus		2:00
				√																0:04	1st bus	26	1:00
								√												0:06	2nd bus		1:30
												√								0:08	3rd bus		2:00
			√																	0:10	1st bus	28	12:46

			√																	0:10	1st bus	28	12:46
					√															0:06	2nd bus		1:06
								√												0:10	3rd bus		1:26
										√										0:06	4th bus		1:46
			√																	0:06	1st bus	35	12:50
							√													0:08	2nd bus		1:20
											√									0:10	3rd bus		1:50
								√												0:06	1st bus	43	1:30
														√						0:09	2nd bus		2:15
	√																			0:05	1st bus	47	12:35
					√															0:07	2nd bus		1:05
									√											0:09	3rd bus		1:35
			√																	0:06	1st bus	51	12:50
							√													0:08	2nd bus		1:20
											√									0:10	3rd bus		1:50

											√									0:10	3rd bus		1:50
					√															0:04	1st bus	52	1:08
							√													0:05	2nd bus		1:23
									√											0:06	3rd bus		1:38
											√									0:07	4th bus		1:53
													√							0:08	5th bus		2:08
															√					0:09	6th bus		2:23
																	√			0:10	7th bus		2:38
																		√		0:03	8th bus		2:53
		√																		0:03	1st bus	63	12:45
						√														0:05	2nd bus		1:15
										√										0:07	3rd bus		1:45
		√																		0:03	1st bus	65	12:45
						√														0:05	2nd bus		1:15
										√										0:07	3rd bus		1:45

			√																	0:04	1st bus	66	12:52
							√													0:16	2nd bus		1:12
										√										0:20	3rd bus		1:32
												√								0:16	4th bus		1:52
		√																		0:03	1st bus	69	12:45
						√														0:05	2nd bus		1:15
										√										0:07	3rd bus		1:45
				√																0:06	1st bus	74	12:58
						√														0:07	2nd bus		1:13
								√												0:08	3rd bus		1:28
										√										0:09	4th bus		1:43
												√								0:10	5th bus		1:58
													√							0:03	6th bus		2:13
								√												0:06	1st bus	85	1:30
														√						0:09	2nd bus		2:15

														√						0:09	2nd bus		2:15
										√										0:07	1st bus	95	1:45
																√				0:10	2nd bus		2:30
																				8.16	Total waiting time		
																				0.06	Average waiting time		

Table 6.2 Timetable according to the current headway

Next we will develop a similar timetable to the one shown on table 6.2 by decreasing the current headway of anbessa bus by 5 min and by relocating the anbessa bus station at merkato in close proximity to LRT station so that we can decrease the walking distance to 1 min. The results are shown in table 6.3 as follows:

Train departure time at merkato station and catch-up points of passenger																				Waiting time	Bus route		Arrival time at merkato
12:32	12:40	12:48	12:56	1:04	1:12	1:20	1:28	1:36	1:44	1:52	2:00	2:08	2:16	2:24	2:32	2:40	2:48	2:56	3:04				
	√																			0:05	1st bus	8	12:35
				√																0:04	2nd bus		1:00
							√													0:03	3rd bus		1:25
		√																		0:05	1st bus	18	12:43
			√																	0:03	2nd bus		12:53
				√																0:01	3rd bus		1:03
						√														0:07	4th bus		1:13
							√													0:05	5th bus		1:23
								√												0:03	6th bus		1:33
									√											0:01	7th bus		1:43
											√									0:07	8th bus		1:53
√																				0:01	1st bus	20	12:31
				√																0:08	2nd bus		12:56

							√													0:07	3rd bus		1:21
	√																			0:01	1st bus	21	12:39
			√																	0:02	2nd bus		12:54
					√															0:03	3rd bus		1:09
							√													0:04	4th bus		1:24
				√																0:04	1st bus	24	1:00
						√														0:05	2nd bus		1:15
								√												0:06	3rd bus		1:30
										√										0:07	4th bus		1:45
				√																0:04	1st bus	26	1:00
							√													0:03	2nd bus		1:25
										√										0:02	3rd bus		1:50
										√										0:06	1st bus	28	12:46
				√																0:03	2nd bus		1:01

						√														0:04	3rd bus		1:16
								√												0:05	4th bus		1:31
			√																	0:06	1st bus	35	12:50
						√														0:05	2nd bus		1:15
									√											0:04	3rd bus		1:40
								√												0:06	1st bus	43	1:30
													√							0:06	2nd bus		2:10
			√																	0:08	1st bus	47	12:48
						√														0:07	2nd bus		1:13
									√											0:06	3rd bus		1:38
			√																	0:06	1st bus	51	12:50
						√														0:05	2nd bus		1:15
									√											0:04	3rd bus		1:40
					√															0:04	1st bus	52	1:08
						√														0:02	2nd bus		1:18

						√														0:02	2nd bus		1:18
								√												0:08	3rd bus		1:28
									√											0:06	4th bus		1:38
										√										0:04	5th bus		1:48
											√									0:02	6th bus		1:58
													√							0:08	7th bus		2:08
														√						0:06	8th bus		2:18
		√																		0:03	1st bus	63	12:45
					√															0:02	2nd bus		1:10
								√												0:01	3rd bus		1:35
		√																		0:03	1st bus	65	12:45
					√															0:02	2nd bus		1:10
								√												0:01	3rd bus		1:35
											√									0.08	1st bus	66	12:52
					√															0:05	2nd bus		1:07

							√													0:06	3rd bus		1:22
									√											0:07	4th bus		1:37
		√																		0:03	1st bus	69	12:45
					√															0:02	2nd bus		1:10
								√												0:01	3rd bus		1:35
				√																0.06	1st bus	74	12:58
					√															0:04	2nd bus		1:08
						√														0:02	3rd bus		1:18
								√												0:08	4th bus		1:28
									√											0:06	5th bus		1:38
										√										0:04	6th bus		1:48
								√												0:06	1st bus	85	1:30
													√							0:06	2nd bus		2:10
										√										0:07	1st bus	95	1:45
															√					0:07	2nd bus		2:25

															√					0:07	2nd bus		2:25
																				6:56	Total waiting time		
																				0:04	Average Waiting time		

Table 6.3 Timetable by reducing current headway by 5 min

CONCLUSION AND DISCUSION

Therefore as can be seen in timetables developed on table 6.2 and 6.3 there is significant change in the simultaneous arrival of bus and train and passengers waiting time. For instance if we see anbessa bus route 8 and AALRT , in the first scenario shown in table 6.2 passengers boarding from the consecutive buses arriving at merkato can pick the fourth train but for the second scenario passengers can take the third train which reduces their waiting time. We can also see the reduction of waiting time of the third bus from 0.09 minutes in the first scenario to 0.03 in the second scenario. For other routes the effect is similar, the tables have shown the reduction in the total and average waiting time.