



**ADDIS ABABA UNIVERSITY SCHOOL OF GRADUATE STUDIES  
INSTITUTE OF TECHNOLOGY SCHOOL OF MECHANICAL AND  
INDUSTRIAL ENGINEERING**

**Integrating urban public bus with LRT:  
Case of Leghar station.**

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 stream)

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## DECLARATION

I hereby declare that the work which is being presented in this thesis entitled, **“INTEGRATING URBAN PUBLIC BUS WITH LRT: CASE OF LEGHAR STATION”**. is original work of my own, has not been presented for a 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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## **Abstract**

In the last two or three decades an outstanding large increase in traffic congestion, air pollution, pressure on the infrastructure and passengers volumes has occurred. Having a well-designed public transport network that works individually without any coordination with the other modes of public transport was found not to be sufficient. In such a situation providing a door to door trip between all pairs of origins and destinations is neither applicable nor cost-effective. On the other hand transfer time is the waiting time penalty encountered by passengers at a transfer stop or terminal while changing between modes of public transport lines. The higher the transfer time the higher the passengers inconvenience and the lower the ridership rates. The lack of properly planned urban transport in Addis Ababa is manifested through the low degree of efficiency of urban mobility that is now observed in almost all of the city's centre, sub-centers and other major traffic corridors. As case study Identifying transport problems and integration challenges of Addis Ababa transport is main concern. . Thus, as part of research methodology, this paper tries to explore integrated LRT transportation with Anbessa city bus. The objective of this research is to develop a scheduling model for operational integration of LRT services and ANBESSA buses in case of leghar station. Generally, the research I am going to carry out will clearly show the synchronized scheduling of Anbessa city bus and the newly built LRT with operational integration considering waiting time for the case of Leghar station.

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## Contents

CHAPTER ONE	1
1.1 INTRODUCTION	1
1.2 Statement of the Problem	3
1.3 RESEARCH QUESTIONS	4
<u>1.4</u> OBJECTIVE OF THE STUDY	4
1.4.1 General objective	4
1.4.2 Specific objective:	4
<u>1.5</u> SIGNIFICANCE OF THE STUDY	5
CHAPTER TWO	6
2.LITERATURE REVIEW	6
2.1 INTRODUCTION TO PUBLIC TRANSPORTATION.	6
2.2 Benefits and needs of improving Public Transportation	6
2.3. Public Transport Net work Design	8
2.3.1 A Transfer Coordination Approach	8
2.3.2 Public transport net work design problem	8
2. 4.PUBLIC TRANSPORT OPTIMIZATION PROBLEM DESCRIPTION.	10
2. 5 Intermodal - Main Concept	12
2.6 Decision variables	14
CHAPTER 3	16
METHODOLOGY	16
3.1 Methodological Approach	16
3.2 Case study as research strategy	16
3.3 Contextual setting of methodology	18
3.3.1 Definitions	19

3.3.2 Inputs Required	19
3.3.3 Assumptions	20
CHAPTER 4	21
Modeling for the problems	21
4.1 Details for modeling.	21
4.2 Creating the Model	22
4.3 Heuristic Approach	23
4.4 Model Inputs	26
4.5 Node Selection Procedure	26
4.5.1 PROCEDURE 1	27
4.5.2 PROCEDURE 2	29
4.5.3 PROCEDURE 3	30
4.6 Numerical Example	31
4.7: Numerical Example – 2	36
CHAPTER 5	40
APPLICATION FOR REAL LIFE PROBLEM AND DISCUSSION	40
CHAPTER 6	54
6.1 CONCLUSIONS AND RECOMMENDATION FOR FUTURE STUDY	54
6.2 FUTURE STUDY	55
REFERENCE:	56
Appendix	58

**List of Tables**

Table 1. Research Matrix.....	17
Table 2. Inputs for Routes in Example 1.....	31
Table 3. Inputs for Nodes in Example 1.....	32
Table 4. Departure Time For Example 1.....	34
Table 5. Arrival Time for Example 1.....	34
Table 6. Simultaneous Arrival Time For Example 1.....	35
Table 7. Inputs for the Routes in Numerical Example 2.....	36
Table 8. Inputs for Nodes in Example 2.....	36
Table 9. Departure Time for Example 2.....	38
Table 10. Arrival Times for Example 2.....	38
Table 11. Simultaneous Arrival for Example 2.....	39
Table 12. Inputs for Routes in Real Life Problem.....	41
Table 13. Inputs for Nodes in Real Life Problem.....	42
Table 14. Departure Time for Real Life Problem.....	51
Table 15. Arrival Times for Real Life Problem.....	51
Table 16. Simultaneous Arrival Times for Real Life Problem.....	52

**List of Figures**

Figure 3.1. Transportation Plan-LRT and BRT .....	16
Figure 3.2. Addis Ababa Revised Master Plan .....	16
Figure 3.3. Flow Chart of Algorithm .....	25
Figure 4.1. Numerical Example 1 .....	31
Figure 4.2. Numerical Example 2 .....	36
Figure 5.1. Modeling Routes for Real Life Problem .....	41

## CHAPTER ONE

### 1 INTRODUCTION

In big metropolitan cities and large urban areas the demand for public transit is often widely spread and significantly varies over space and time. In such a situation providing a door to door trip between all pairs of origins and destinations is neither applicable nor cost-effective. An attractive and efficient alternative is to serve the passengers by an efficient intermodal system. In such a system, passengers may need one or more transfers to complete the journey to their final destination. Consequently, coordinating transit schedules to reduce transfer time can contribute significantly in improving the transit service quality and increasing the passenger energy, ridership levels. Such coordination should be dealt with carefully to guarantee the satisfaction of the inherently conflicting objectives of the passengers and the transit system operator. In the present research the benefits of coordinating the schedules of LRT with secondary feeder buses at a transfer stop is assessed and evaluated through an optimization model. A total cost objective function that represents both the passengers and the operator objectives is formulated and optimized for each stage of the optimization model to determine the optimal coordination status among the coordinated bus route at the selected transfer stop. In the first stage the operating headways of both the LRT and the feeder buses are optimized under uncoordinated service, the corresponding total waiting time is also obtained and compared with the total waiting under the current existing situation. In the second stage all possible combinations of stage-feeder bus coordination at the stop are tested and corresponding waiting time of each combination is also obtained. The results of the second stage are compared with the existing situation results as well as the first stage results and the coordinated combination resulting in the minimum waiting time is identified. In the third and last stage the optimal loose time added to the schedule of the coordinated buses to increase the probability of a successful connection and overcome the stochastic arrivals conditions. The concluded study is that coordinated transfers between the LRT and feeder buses under a common headway is beneficial when the increase the in-vehicle and

waiting time costs can be compensated by the saving in the transfer time. Also the desirability of coordinated transfers is highly dependent on the transfer passenger's volume, the standard deviation of vehicle arrivals to the stop.

The efficiency of an entire public transport system can be enhanced by overall coordination among its modes. Coordination among different modes can be achieved by system integration, which occurs at three levels: institutional, operational and physical [3]. The literature review has revealed that many studies are carried out for optimization of services of a single mode specially bus or train but the effort is inadequate as far as coordination of two modes are concerned. However, routing and scheduling problems for coordinated operations were attempted using analytical models [7]. They had made an attempt to describe complex transit system by approximate analytical models. Thus most of the studies on coordination of modes are limited to analytical modeling without considering a real life network [6]. Likewise, the research I am going to carry out will clearly show the scheduling Anbessa bus that will benefit both the railway corporation/organization and passengers with application of waiting time minimization. The current bus routing and scheduling plan for Anbessa is fully controlled internally by member of staff of Anbessa bus enterprise, and not externally by any regulatory or planning authority [15]. As result, there is no centralized bus routing and scheduling plan. Their route network has developed over time to link the fixed terminals on a basis as demand has been identified for the potential service offer. However these routes are then broken down into smaller sections, apparently so as to provide route interchange opportunities. Drivers then often exploit these interchanges, particular at peak hours, so as to maximize their effective fee rate within the approved tariffs. No routes are operated to schedule, but rather are responsive to passenger demand from their originating terminal [5]. As passengers arrive at the terminal they are allocated to the first vehicle waiting to serve their intended route, which then begin service once it has been filled. Even on the same routes, there is no set maximum headway between services. This may cause severe delays to waiting passengers, both at the terminals and along the routes. The efficiency of the public transport system in any city depends on integration of its major public transport modes. Therefore, non coordination of Anbessa bus has great impact on effective performance on the Addis Ababa LRT. It has been observed that most of the metropolitan cities of developed and developing countries are facing problems due to lack of coordination among public transport facilities. Each public transport facility is planned and designed without

considering its impact on other public transport services [1]. In fact in most of the cases these facilities try to win each other instead of balancing. This unhealthy competition leads to duplication of services to many areas and hence shifts time due to lack of integration among public transport modes.

## 2. Statement of the Problem

The efficiency of the public transport system in any city depends on integration of its major public transport modes. Urban railway and public buses are the modes normally used by the majority of population in metropolitan cities of developed and developing countries. Integration of these two services reduces overall journey time of an individual. As a case study the Addis Ababa Leghar station is selected. Now days, large numbers of people are living in Addis-Ababa and most of them are relying heavily on public transport to meet their mobility needs. Unbalanced assignment of buses to routes is also another problem; which means some routes have buses which are relatively idle while others are highly busy. This means the customer demand at routes are not properly addressed to assign buses to them. The same number of buses is assigned to routes throughout the days without considering peak and off-peak hours. This reduces bus utilization during off-peak hours and decreases service quality during peak hours. On the other hand, Anbessa city bus loses considerable amount of money for not delivering the service to these customers and incur idle cost to those assigned at low demanded area. The lack of properly planned urban transport in Addis Ababa is manifested through the low degree of efficiency of urban mobility that is now observed in almost all of the city's centre, sub-centers and other major traffic corridors. Urban mobility, which is increasingly becoming inefficient in Addis Ababa and resulting in congestion, can be viewed as a function of various components of the urban transport system. These elements are Transport system, Traffic Management, and Transport Infrastructure. [1] Overcrowding is becoming a common experience in all the different parts of the city due to the lack of consistent combined efforts from the various stakeholders. Furthermore the demand for public transport services in Addis Ababa is growing at a rapid rate due to the continued rise in population. This is apparent from the mismatch between the estimated growth of need and the reality. Thus, efficient and effective public transport operations have become critical to sustainable economic and social development. Since Leghar station is center for the city, the flow of Anbessa city bus higher relative to the other stations selected. Therefore the delay of Anbessa

bus has direct effect on the efficiency of LRT. Without efficient integration of Anbessa city bus, obviously the efficient working capacity of Addis Ababa LRT will be not viable.

### 3. RESEARCH QUESTIONS

This Research study is going to answer the following questions. Which are?

1. How integration will be made between urban bus and LRT?
2. What are different approaches to ingrate urban transport system?
3. What matters the scheduling of urban bus to integrate with railway system (LRT)?
4. What should be done to reduce competitive spirit and enhance complementary environment between the companies?
5. How public bus utilization and LRT can be improved so that the empty travelling cost is minimized?

### 4. OBJECTIVE OF THE STUDY

**4.1. General objective.** The objective of the research is to develop a scheduling model for operational integration of LRT services and ANBESSA buses in case of leghar station.

**4.2. Specific objective:** In achieving the general objective stated above there will be the following specific objectives as well. These are;

1. to schedule the number of passenger trip in study area specifically in leghar station.
2. To study the trip distribution and schedule among each feeding route.
3. To develop means of bus assignment to a predetermined route at optimal operating cost and to develop demand oriented bus assignment model considering LRT schedule.
4. To determine the optimum number of buses required for a given route during different time periods.
5. To reduce the overloading of buses by balancing the assignment of buses between highly busy routes and relatively idle routes.
6. To reduce the cost customers incurred due to waiting time and increase customer satisfaction on Anbessa City Bus and LRT system.

7. To optimize the transfer coordination between the selected bus routes in the study area.
8. To create a synchronized timetable, this ensures that the time between different Buses arrive at transfer points, does not exceed the allowed waiting time.

## **5. SIGNIFICANCE OF THE STUDY**

It has been observed that most of the metropolitan cities of developed and developing countries are facing problems due to lack of coordination among public transport facilities. Each public transport facility is planned and designed without considering its impact on other public transport services. Therefore, the schedule coordination of feeder Anbessa buses for the existing schedules of LRT is the main significance of this research paper. Finally the outcome of the research is to generate feeder route network and synchronized services of feeder buses with the LRT station, leghar. The benefits of the results are of wide range and can be viewed from different directions. The most important benefits from the research are it provides optimal schedule and optimal number of buses for the bus routes that are operated by Anbessa City Bus. The research intends to solve the waiting problem and save the time customer would waste by waiting for the bus at bus stations and enable them to be available at work and earning money for using their precious time for work. This improves the income of their family and improves the working environment and relations with colleagues and bosses due to timely presence at working places. Also, Anbessa City Bus Service Enterprise will increase the income it collects from the improved number of customers gained by making its service available for more customers and by saving high maintenance cost due to overloading of buses. Finally LRT which is newly constructing corporation will highly benefit having passengers whom timely uses the mode of transport.

## CHAPTER TWO

### 2. LITERATURE REVIEW

#### 2.1 INTRODUCTION TO PUBLIC TRANSPORTATION.

Public transportation is a particularly attractive method of travel in urban areas. Travelers choose public transportation for a variety of reasons including: reduced cost, environmental concerns and convenience. Transportation services and facilities are essential for the future well-being of the individuals. Public transport can offer significant advantages in areas with higher population densities, due to its smaller physical and environmental footprint per rider and the problems associated with mass private car ownership and use (high parking area and high levels of traffic congestion). A balanced public transportation system utilizes all available means of travel cooperatively and in a mutually balancing manner to provide comprehensive service for the needs of the community. The global problem of how to offer a good quality service to the passengers, while respecting certain constraints (e.g. design and operating cost, compliance to standards, eventual revenues, intermodal net work etc.) is complicated and requires tradeoffs at various stages of the process. [12] In urban areas the demand for buses is unevenly distributed over space and time. It is usually impractical to directly connect all origin-destination pairs with bus routes due to limited economic and social resources. In such cases a bus transit network with limited accessibility and mobility is effective in serving the demand and formed from several bus routes and transfer centers integrating with other transport system, i.e. with LRT system.

#### 2.2 Benefits and needs of improving Public Transportation

The integration of public transportation options can help a community expand business opportunities, reduce spread out, and create a sense of community through transit oriented development. For these reasons, areas with good public transit systems are economically successful communities. And in times of emergency, public transportation is critical to safe and efficient evacuation. Public transportation also helps to reduce road congestion, travel times, air pollution, energy, and oil consumption. Some of the important benefits by

integrating public transportation as explained by the American Public Transportation Association discussed as follows [10, 14, and 2].

**Creates jobs:** increasing public transport creates thousands of jobs in the related areas like Engineering, manufacturing, construction, retail... etc

It also helps in getting more people to work who does not own cars.

**Decreases traffic congestion:** Public transport helps to alleviate a nation's crowded network of roads by providing more options for commuting.

**Encourage more habitable communities and increase real assets values:**

Public transportation facilities are focal points for economic and social activities. These activities help create strong neighborhood centers that are economically more stable, productive and safe.

**Improves air quality and reduce energy consumption:**

Public transportation helps to promote cleaner air by reducing automobile use. Also it can significantly reduce dependency on gasoline, reducing auto fuel consumption. There are many reasons to improve public transportations. Current transportation assessment practices tend to overlook and undervalue many transit benefit categories. Since transit service and automobile travel both impose significant costs (including indirect costs such as congestion, road wear and pollution emissions), improvements and incentives that increase transit load factors and attract travelers who would otherwise drive tend to provide large benefits. There are four general categories of transit improvement [17, 2]:

- 1. Increased service** (more bus vehicle-*kms*)
- 2. Improved service** (more comfortable, convenient, reliable, etc.).
- 3. Incentives to use transit** (lower fares, customer financial incentives, marketing, etc.).
- 4. Transit oriented development** (land use patterns designed to support transit, including more compact, walk able, mixed development around transit stations and corridors).

## **2.3. Public Transport Net work Design**

### **2.3.1 A Transfer Coordination Approach**

This chapter provides an insight into the different aspects of the transfer coordination problem as one of the problems of the intermodal public transport network design. It starts with a definition of the public transport network design problem and the identification of stakeholders involved in it, their main interests, concerns, and its effect on the network design objectives. Then an overview of the transfer problem and all its related aspects is given with a specific emphasis on transfer coordination being the main element of concern in present research. The transfer coordination problem basic elements and variables are also discussed with available solution techniques. A review of previous models developed on the transfer coordination problem is then conducted with their advantages and the shortcomings.

### **2.3.2 Public transport net work design problem**

#### ***2.3.2.1 Main characteristics***

The main characteristic of public transport network design is the balance between opposing objectives. A design that is optimal with respect to one objective is not optimal for the other objective, and vice versa [19]. While passengers are interested in a fully connected network between all origins and destinations with minimum travel times, fees and maximum comfort the operator or the service provider is interested on having the smallest network possible with the highest revenue and the lowest operational costs. Accordingly, Attention should be paid while selecting the network design objectives so that they satisfy, represent and consider the conflicting views and the opposing interests of the stakeholder's identification.

#### **2.3.2.2 Stake holder's identification**

In public transport network design there are three parties involved, each of them having their own point of view on the objective that has to be used are traveler, operator, and authority. The passenger judge or value the public transport services by three main components: travel time, costs, and comfort. The major and the most crucial component to the passenger is the perceived door- to door travel time. The door-to door travel time consists of various time elements namely access time, waiting time, transfer time, in-vehicle time and way out time. Each of these travel time elements is perceived, weighted and appreciated differently for each

passenger. A suitable network design objective for the passenger might to be to minimize one of these time elements or to minimize the weighted total travel time. Using this objective for the network design will result in fully connected networks with very high public transport frequencies. This is obviously not a suitable design for the operators since the operational costs will be huge when compared to the revenue or the profit coming from operating the public transport system.

The operator view of the system is very different; his main concern is the continuity and the profitability business. A suitable network design objective for the operator might be to maximize the profit, which is the revenue minus the operational cost or to minimize the operational costs. Obviously using this objective for design will result in poorly connected network with very long travel times and very low frequency public transport services. Ultimately, if such an objective is used in network design the ridership levels will decrease and as a result, the system profitability will decrease as well [19]. The third and the last stakeholder involved have their own different agenda. A suitable objective for the network design from the authority point of view might be minimizing the total costs of the system including both the passenger and the operator costs. The authorities might also be interested on minimizing the subsidy given to the operator. Apart from defining design objectives, the authorities might play another role in public transport network design, namely setting constraints such as a maximum access distance or a minimum frequency. In that case the operator can use their own objective in the public transport network design as long as those constraints are fulfilled and satisfied [19].

In conclusion, it can be clearly seen that the stakeholder's objectives are mainly opposing and conflicting with respect to each other. An optimum design of public transport network should be close to the operator optimum but with introducing transfer stops or hubs in intermediate locations where large passenger's volumes are generated. At those hubs various routes coming from different origins and going to different destination should be connecting. Providing transfer passengers at those centers with faultless mobility by coordinating the services of the connecting buses to minimize the time spent in transfers is a good alternative to the unrealistic door to door trip. A suitable analytical approach to reach this optimum design is mathematical optimization. The objective of optimization is to select the best

possible decision for a given set of circumstances without having to enumerate all of the possibilities [11].

## **2. 4.PUBLIC TRANSPORT OPTIMIZATION PROBLEM DESCRIPTION.**

The goal of an optimization problem can be defined as follows: find the combination of parameters (independent variables) which optimize a given quantity, possibly subject to some restrictions on the allowed parameters range. The quantity to be optimized (maximized or minimized) is termed the objective function ; the parameters , which may be changed in the search for the optimum are called control or decision variables ; the restrictions on allowed parameters values are known as constraints[11]. With respect to goal of the optimization problem will be to find the optimal value of the design variables such as stop spacing, stop location and service headway that best satisfies the operators , the passengers and the authorities objectives [19] formulated an optimization based analytical approach that can be used for public transport network design. In his approach, he used the following terminology:

**Objective:** The criterion or set of criteria to be optimized, for instance minimizing travel time.

**Objective function:** Mathematical formulation of the objective using the decision variables.  
Design variables or Decision variables: Endogenous variables for which optimal relationships or optimal values have to be determined, in his case design variables are stop spacing and line spacing.

**Design parameters:** exogenously given parameters used in the mathematical formulation those are not determined by public transport system itself, for instance, the weights of different time elements;

**System Parameters:** exogenously given parameters used in the mathematical formulation are determined by public transport system itself, for instance the costs of operating a bus.

**Output:** results of analytical model, for instance, the value of the objective function;

**Outcome:** the total set of criteria used to judge a network design, such as travel time, In his study, the mathematical descriptions of these relationships were formulated and used as building blocks to define objective functions, which are mathematical representations of the formulated objectives. Those objective functions were then optimized with respect to the decision variables stop spacing and line spacing yielding the optimal relationships for these decision variables under certain fixed parameters and a set of constraints. General Structure. Based on [19] the general structure of the problem description for such an analytical model is as follows: 1) The Decision variables 2) Objective Function: The main objective function used in literature is minimizing the total costs, either the sum of travel costs and operating costs, or the sum of travel costs , operating costs and capital costs that is investment costs and fleet costs. 3) Problem constraints (optional): The use of constraints in analytical models is limited. Capacity and budget constraints are the most commonly used constraints. Solution Techniques [19] Furthers explains that there are two solution techniques for the optimization problems, the analytical approach and the numerical approach (enumeration). [19] Method Advantages Disadvantages Analytical Approach For each decision variable the optimal relationships with parameters and other decision variables are defined explicitly. The objective function must be formulated in such a way that is suitable for mathematical analysis Numerical Approach (enumeration) can deal with mathematically less good objective functions Provides less insight into the main relationships of the decision variables.

Based on[19],the main characteristics found in nearly all studies is that optimal relationships for the decision variables can be described using a square root or cubic route functions. This finding implies that the optimal values have a limited sensitivity with respect to the parameters and the variables used. Doubling the value of decision variables or of a system parameter, results in an increase of the decision variable of 41 % (square root relationship) or 26 % (cubic root relationship) at most. Also the objective functions were found to be shallow around the optimum which allows for varying or rounding the values in planning practice, for instance to account for typical characteristics of an urban area, without serious consequences on the design objectives . However, for it was found that due to the square and cubic root relationships, lower values of the decision variables would have more impact on the value of the objective function than higher values.

## 2.5 Intermodal - Main Concept

In the last two or three decades an outstanding large increase in traffic congestion, air pollution, pressure on the infrastructure and passengers volumes has occurred. Having a well-designed public transport network that works individually without any coordination with the other modes of public transport was found not to be sufficient. As a result, the concept of inter-modals emerged. Inter-modals refers to a transportation system in which individual modes work together or within their own place to provide the user with the best choices of service , and in which the consequences on all modes of polices for a single mode are considered[18]. There are many advantages of having an intermodal public transport system in place such as reducing fuel consumption , air pollution, pressure on the infrastructure and traffic congestion ; increasing the accessibility to the infrastructure through better coordination of the scheduling process within the same public transport mode as well as between different modes . An efficient intermodal public transport system should be able to achieve all these benefits and at the same time maintain the attractiveness of the public transport network to all the stakeholders involved.

The research is limited to the transfer coordination problem as one of the intermodal public transport network design problems. The same optimization based analytical approach can be followed in the present research. The following sections provide a detailed description of the transfer coordination problem, main decision variables involved, objective functions, and constraints. A review of previous models in transfer coordination is also conducted with its advantages and shortcomings.

Transfers play significant role in daily transit operations in terms of ridership, cost-effectiveness and customer satisfaction. Rider usually have a negative perception of transfers because of their inconvenience, which can be thought of as a transfer penalty understanding what affects transfer penalty can have significant implications for the transit authority. It can help in identifying which type of improvement to the system can most effectively improve transfers, thus attracting new customers [12]. There are many factors affecting the transfer penalty such as the transfer time, the total trip time, the number of transfer, the comfort of transfers (i.e Landscape, weather . . .) and the financial costs of transfers. The level of service of an intermodal transit system is dependent significantly on transfer times [9]. Indeed the

transfer time between public transport modes or within the same mode is the most weighted and appreciated element for passengers when assessing the quality of transfers.

Transfer time is the waiting time penalty encountered by passengers at a transfer stop or terminal while changing between public transport lines. The higher the transfer time the higher the passengers inconvenience and the lower the ridership rates. As mentioned in the previous chapter the transfer time can be reduced by increasing the service frequency or in other words decreasing the service headway. The service headway is the difference in time between two subsequent vehicles operating at the same line. Decreasing the service headway might be a suitable design objective from the passenger's point of view but not always cost effective from the operator's point of view. Low operating headway, which can substantially reduce transfer time, is not always cost effective due to variations of demand among transit routes over space and time [9]. Aside from decreasing the service headway considerable user waiting time may be saved at transfer terminals if the arrivals of vehicles from different routes can be synchronized or otherwise coordinated [16]. The synchronization of vehicle arrivals can be achieved through the implementation of common operating headways for the connecting routes. Schedule synchronization is a suitable approach for rural areas and uncongested public transport networks. The traffic conditions in such case are stable and schedule delays are least relatively. In large cities and congested urban areas, the schedule synchronization alone might not be a suitable approach to minimize passengers transfer time because of unreliable traffic conditions that might cause vehicles to deviate from schedule. Vehicle breakdowns and accident are also frequent under those traffic conditions. In that case, transfer coordination is a better approach. Holding times (slack times) added into the schedule of coordinated routes may be required to increase the probability of successful connections [9]. The slack time is an additional time added to the schedule of a vehicle to wait for other connecting vehicles at a transfer stop in case of delay. The feasibility and desirability of such coordination depends on the variability of traffic conditions and stopping times, service frequencies, fractions of users involved on the transfers and relative costs of vehicle delays and user times [16]. Accordingly, not all connecting routes are suitable for schedule synchronization or transfer coordination and all those measures should be tested first to ensure the feasibility of coordination. The feasibility of coordination is assessed and evaluated based on the objectives of the three stakeholders involved. Still and even if

connecting routes are suitable for coordination the optimal values of the problem variables should be obtained in such a way that fulfils the three stakeholders objectives.

## 2.6 Decision variables

An efficient alternative is to have a well designed intermodal transit network with acceptable transfer time for passengers. An intermodal network can be defined as an integrated transportation system consisting of two or more modes. In contrast to multimodal networks, modes on intermodal networks are connected through facilities which allow travelers and or freight to transfer from one mode to another during a trip from an origin to a destination. Intermodal networks aim to provide efficient, seamless transport of people and goods from one place to another [4]. 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 new vehicle and existence of some delay during a trip [2]. A well designed intermodal transit network should be able to facilitate the passenger's transfers between transit modes in order to reach their final destination. When facilitating passengers transfers there are more than one element to be considered such as transfer time, total trip time, number of transfers, comfort of transfers, and the fare of transfer.

From the previous discussion, it should be clear that the transfer coordination problem is a function of two decision variables namely the common headway of the connecting vehicles and the slack times added to their schedule to increase the probability of a successful connection. An increase in the common headway, for instance will result in longer waiting times for non-transfer passengers waiting at the stop and higher passengers volumes and consequently longer stoppage time and longer overall travel time. If the common headway is decreased, the waiting times will be reduced but the operational costs for the operators will increase due to the increase in the operational fleet size. For the slack times, an increase in the slack time will increase the probability of a successful connection and will minimize the transfer time but at the same time will increase the stoppage time and the overall travel time of the in-vehicle passengers and will also increase the operator's costs. The effect of increasing or decreasing any of the decision variables on the travel time components (waiting time, transfer time, stoppage time “) and on the operators, costs should be measured and

analyzed. To do so, the travel time components and the operator costs should be defined and formulated as a function the decision variables and other fixed system parameters. Then optimal values of the decision variables can be obtained based on the used design objective.

## **2.7 Summary of Literature Review**

As can be seen in the literature review public transport optimization is a well studied optimization problems and different author's uses and proposes different approaches to solving the problem. The main objective function of most of the authors is minimizing the operating cost while some are minimizing the customer waiting time and the fleet size. Since the public transport optimization is highly interrelated, the above objective function can be achieved indirectly by solving one of them. This means that when the objective function of the optimization problem is minimizing the operating cost of the transportation company, the waiting time of the customer is one of the constraints and vice versa. But in the optimization problem always what is to be optimized is the objective function and the constraints are the predetermined values or the desired service level. Generally, the approaches discussed above have their own strength and weakness based on the assumptions they used in solving the problem and their application to the real world problems. Most of the approach follows complex optimization problem which is difficult to apply and are more of theoretical than solving the real integrating problems of public Transportation. Thus this research aimed at solving the synchronization problem by relaxing some of the assumptions used by different authors in related topics. Also this research is aimed at developing new model that can be easily figure to solve the real problem of public transport optimization integrating with LRT system by considering different constraints and assumptions. Thus, the model is developed in such a way that it can easily determine the number of buses of different capacity that arrive simultaneously at the selected station for most favorable public transportation at given routes especially in the case of Legehar station to ingrate with newly built LRT system.

## CHAPTER 3

### METHODOLOGY

#### 3.1 Methodological Approach

This chapter discusses the methodology that is implemented in this research to create synchronized timetables. Thus, as part of research methodology, this paper tries to explore integrated LRT transportation with Anbessa city bus. The concern of accessibility, mobility and the need for improving the quality of public transport networks and service provision in the city of Addis Ababa is fundamental part of the thesis.

#### 3.2 Case study as research strategy

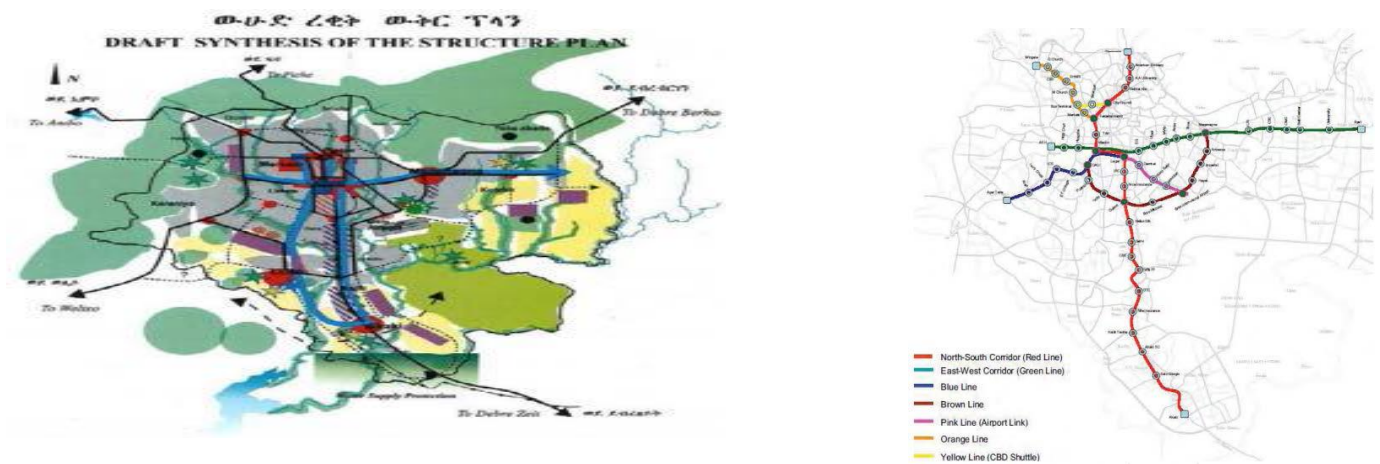


Figure 3-1 Transportation Master Plan (2005)-LRT and BRT networks. Figure 3-2 Addis Ababa's Revised Master Plan (2002)

Source: Lyon Town Planning Agency (2010)

**Table 1 research matrix.**

Specific research	methodology	Case study	Data source
Identifying transport problems and integration challenges of Addis Ababa transport.	Case studies	AA-LRT and Anbessa city bus leghar station	Primary and secondary sources AATB and ERWC.
Defining indicators of integrated public transport.	Literature review Case studies Building theoretical framework	LRT –Based integration of Anbessa city bus	Primary and secondary sources (books, scientific articles, Internet) Field observation
Improving transport integration	Time table development modeling	Leghar station	Primary and secondary sources, design and using software.

### 3.3 Contextual setting of methodology

A waiting time of zero is considered to be optimal. But in practice the passengers do not appreciate a transfer waiting time of zero. Due to the uncertainties involved in the public transit system, passengers generally prefer a certain minimum transfer waiting time rather than zero. Creating timetables with this minimum possible waiting time makes the transit system healthier. Moreover, during non-peak period, transit management is more likely to operate buses with a decreased frequency than would be required purely on capacity grounds during off-peak hour and to reduce operating cost. Because of this decreased frequency the transit system is characterized by waiting time for the passengers at the transfer points. This waiting time is the time the passengers wait at the transfer points and depends on different operating characteristics like passenger arrival distribution at various points in the network, headways, frequency, time of operation, congestion, etc. It also depends on various physical characteristics associated with each transfer point like its location and surroundings. Apart from this, 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. In this research, it is assumed that at each transfer node there is a minimum and maximum waiting time limit for passengers. The challenge of this research is to set the departure times of the routes as good as possible inside the respective periods so that their arrival times at a transfer node are close to each other, in order to have minimum possible waiting time for the passengers. In this model ‘simultaneous arrivals’ are defined in a different way. It is defined as the arrival of two buses at transfer points such that the time gap between the arrivals does not exceed the required waiting time. The objective of this research is to have maximum number of simultaneous arrivals.

### 3.3.1 Definitions

#### 1. Route

A route contains ordered sequence of bus stops. This sequence consists of at least two elements. The starting stop represents the origin of the trip and the final stop is the destination.

#### 2. Node

A node is a location where the buses stop to either to pick up or to deliver one or more passengers.

#### 3. Headway

Headway is defined as the time between successive departures on each route.

#### 4. Frequency

Frequency is defined as the possible number of departures on each route in a specified time interval.

In this research timetables are created for a given bus transit network. The network is represented by a set of bus-routes (arcs) and bus-stops (nodes). According to this figure certain routes meet at bus-stops and passengers might transfers between routes at these stops. Each route is characterized by a certain minimum frequency (number of buses per hour) and headway (time between successive departures). Each stop is associated with the different routes passing through it and waiting time for the passengers making a transfer between these routes.

Appropriate departure times have been assigned so that simultaneous arrivals at the transfer nodes are maximized.

### 3.3.2 Inputs Required

The following are the inputs required for the problem described in this research.

1. Details of existing bus network like origin-destination of various routes and the nodes present on these routes. The given network is presented by a directed graph,  $G(O, C)$  where  $O$  is a set of arcs representing the traveling path of the bus routes and  $C$  is a set of transfer nodes in the network.

2. Period during which the departure times of buses can be set. This is called planning horizon represented by  $[0, H]$
3. Number of bus routes in the network,  $L$ .
4. Maximum and minimum headway (time between each successive departures) for each route  $i$ ,  $1 \leq i \leq L$  represented by  $[Hmin, Hmax_i]$ .
5. Minimum required frequency,  $f_i$  (number of buses to be scheduled for a particular time period) on each route.
6. Traveling time,  $t_{ik}$  from starting point of route  $i$   $1 \leq i \leq L$  to node  $k$   $1 \leq K \leq C$
7. Permissible waiting time limits for passengers making transfers at each node  $k$ ,  $1 \leq K \leq C$   $[WTmin_k, WTmin_k]$

### 3.3.3 Assumptions

The following are the assumptions made for the problem presented in this research.

1. The planning horizon in which the departure times are set is a discrete interval and also large enough so that all the departures can be set.
2. for each route  $i$ .  $Hmin_i \geq Hmax_i]$
3. Traveling times and the waiting times are considered deterministic.
4. The waiting time limits for the passengers at each node are assumed to be predetermined by the transit planners.
5. The first departure of each route  $i$  must take place in the interval  $[0, Hmax_i]$
6. The travel on all routes is in one particular direction.
7. The buses leave the terminal (nodes) as soon as they arrive.

## CHAPTER 4

### Modeling for the problems

#### 4.1 Details for modeling.

The following are the details used in defining the problem and are used in the entire research.

$C$  – Total number of nodes  $k$  present in the network.

$L$  – Total number of bus routes present in the network.

$H$  – Planning horizon during which the departure times are constructed.

$Hmin_i$  – Minimum required headway for route  $i$ .

$Hmax_i$  – Maximum required headway for route  $i$ .

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

$WTmin_k$  – Minimum allowed waiting time at node  $k$ .

$WTmax_k$  – Maximum allowed waiting time at node  $k$ .

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

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

$A_i$  – Set of nodes contained on route  $i$ .

$A_{ij}$  – 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.

### 4.2 Creating the Model

The decision variable  $S_{ijkpq}$  is defined as,  $S_{ijkpq} = 1$  if the arrivals of bus on route  $i$  and bus on route  $j$  at node  $k$  are separated by a time that is within the required waiting time limit.  $S_{ijkpq} = 0$  Otherwise.

The arrival time of buses at a node is calculated by adding the departure time and the Time taken to travel to that node, i.e.:  $T^k_{ip} = D_{ip} + t_{ik}$

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

$$Max \sum_{i=1}^{P-1} \sum_{j=i+1}^L \sum_{k \in A_{ij}} \sum_{p=1}^{f_i} \sum_{q=1}^{f_j} \{S_{ijkpq}\}$$

The constraints are given by the following equations

$$D_{i1} \leq Hmax_i \quad 1 \leq i \leq L \dots\dots\dots (1)$$

$$D_{if1} \leq H \quad ; \quad 1 \leq i \leq L \quad \dots\dots\dots (2)$$

$$Hmin_i \leq D_{i(p+1)} - D_{ip} \leq Hmax_i \quad 1 \leq i \leq L; 1 \leq p \leq f - 1 \dots\dots\dots (3)$$

$$S_{ijkpq} = 1 \text{ if } Wmin_k \leq |(D_{ip} + t_{ik}) - (D_{jq} + t_{jq})| \leq Wmax_k \quad K \in A_{ij} \dots\dots\dots (4)$$

$$S_{ijkpq} = 0 \text{ if } |(D_{ip} + t_{ik}) - (D_{jq} + t_{jq})| < Wmin_k \text{ Or } |(D_{ip} + t_{ik}) - (D_{jq} + t_{jq})| > Wmax_k \dots\dots\dots (5)$$

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  $S_{ijkpq}$  takes the value 0 otherwise.

### 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 [7]. The incorporated change in the definition of simultaneous arrival is applied in the different procedures used to set the departure times. The flow chart of the algorithm is shown in Figure 6. 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. The flow chart of the algorithm is presented in Figure 6. Details about input values, node selection process and procedures are discussed in the following sub-sections 4.4.1 and 4.4.2. 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**.
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.

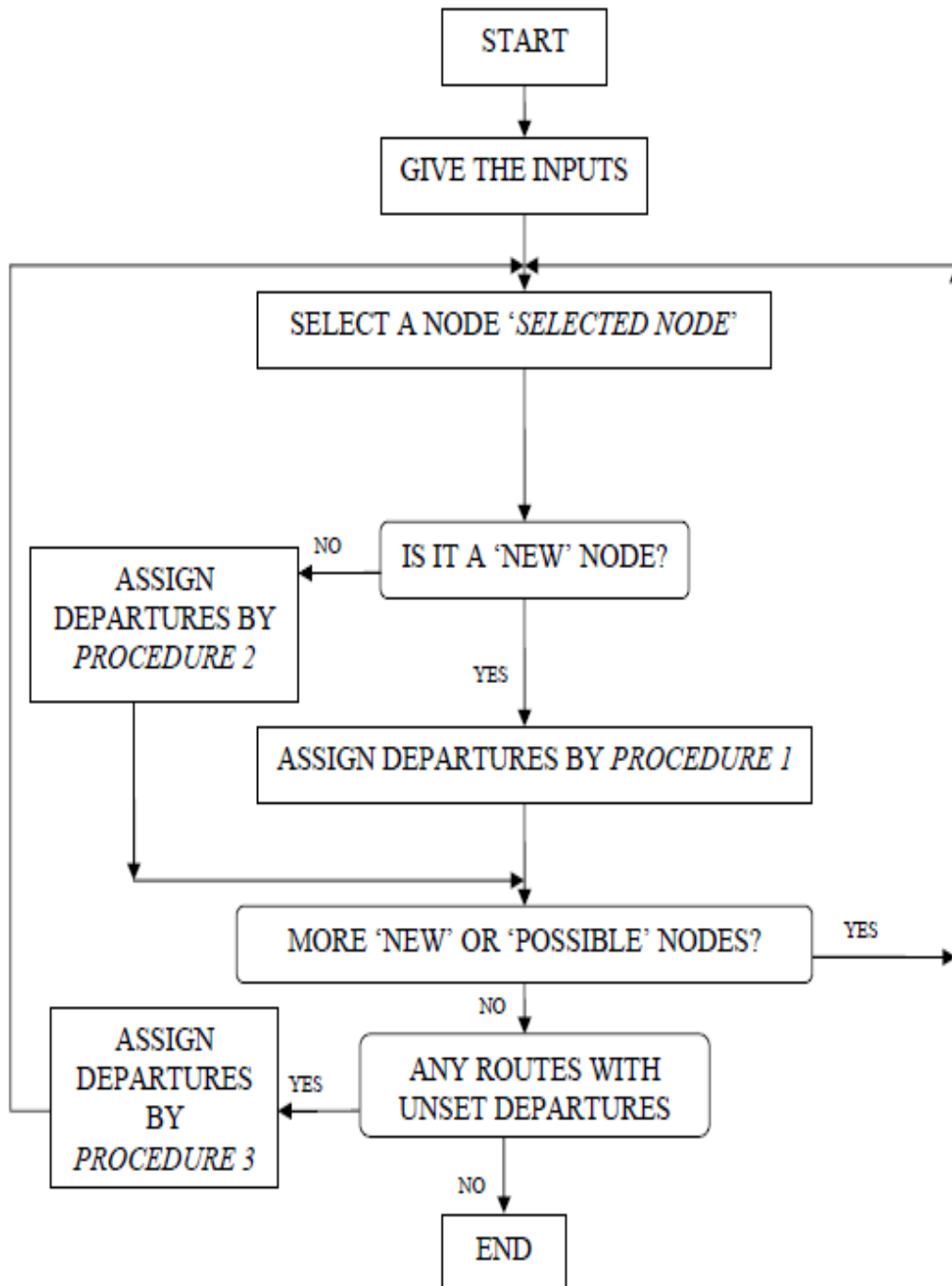


Figure:3.3 Flow chart of Algorithm

#### 4.4 Model Inputs

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

1.  $H_{max\ i} \geq H_{min\ i}$
2.  $H \geq (f_i - 1) \cdot H_{min\ i}$
3. The maximum possible limit on the planning horizon is the maximum value given by  $(f_i, H_{max\ i})$  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.

#### 4.5 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**' and ( $k^*$ ) 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 NOD** ( $k^*$ )' if a tie exists breaks it arbitrarily.

### 4.5.1 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 1<sup>st</sup> 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:

$$d = \text{Min}_{i=1,2..M} [\text{Max}_{i=1,2..M} (Hmin_i), \text{Min}_{i=1,2..M} (Hmax_i)] \quad \forall i$$

Routes 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

$$d = \text{Min}_{i=1,2..M} [\text{Max}_{i=1,2..M} (Hmin_i), \text{Min}_{i=1,2..M} (Hmax_i) \quad \forall i \text{ Passing through } k^*.$$

**Set max time = maximum** travel time to reach ( $k^*$ ) and identify the route associated with *max time* to reach ( $k^*$ ) and label it as.  $i^*$

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

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

$$\text{if} (maxtime - WTmin_{k^*} - t_{ik^*}) > 0$$

**Set  $D_{i1} = (maxtime - WTmin_{k^*} - t_{ik^*})$**  and go to Step 5.

Otherwise, set  $w = WTmin_{k^*}$

**Step 4:**  $(maxtime + w) \geq t_{ik^*}$  and if  $maxtime + w - t_{ik^*} \leq Hmax_i$

**Set  $D_{i1} = (maxtime - WTmin_{k^*} + t_{ik^*})$**  and go to Step 5.

Else; Set  $w = w + 1$  if  $w \leq WTmax_i$  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  $i.e \forall p = 2,3 \dots \min(f_i, f_{i^*})$  are assigned after an interval of  $d$  from the previous departure. That is:

$$\text{set } D_{ip} = D_{i(p-1)} + d$$

$$\text{set } D_{i^*p} = D_{i^*(p-1)} + d$$

Else go to Step 6.

**Step 6:** For these routes  $i$  and  $i^*$ , compute the arrival times of all the set departures  $p = 1,2,3 \dots \min(f_i, f_{i^*})$  to each ‘possible’ and ‘new’ nodes on the route as:

$$T^K_{ip} = D_{ip} + t_{ik} \forall k = 1 \dots N \text{ Present on } i.$$

$$T^K_{i^*p} = D_{i^*p} + t_{i^*k} \forall k = 1 \dots N \text{ Present on } i^*.$$

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

#### 4.5.2 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 as the route passing through and all the departure times are already set using

*PROCEDURE 1*: Set arrival times of  $i^*$  from the origin to  $k^*$  as:

$$T^{K^*}_{i^*p} = D_{i^*p} + t_{ik^*} \quad \forall p = 1 \dots f_{i^*}$$

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

For each  $T^{K^*}_{i^*p}$  that is  $T^{K^*}_{i^*1} T^{K^*}_{i^*2} \dots T^{K^*}_{i^*f}$  set  $w = WTmin_{k^*}$

**Step 3:** For route  $i$  if  $0 \leq (T^{K^*}_{i^*p} - w - t_{ik^*}) \leq Hmax_i + D_{i(p-1)}$

for  $p = 1$ , set  $D_{ip} = (T^{K^*}_{i^*p} - w - t_{ik^*})$  And go to Step 4

for  $p > 1$  if  $(T^{K^*}_{i^*p} - w - t_{ik^*}) - D_{i(p-1)} \geq Hmin_i$

set  $D_{ip} = T^{K^*}_{i^*p} - w - t_{ik^*}$  And go to step 4

Else if  $0 \leq T^{K^*}_{i^*p} + w - t_{ik^*} \leq Hmax_i + D_{i(p-1)}$

for  $p = 1$ , set  $D_{ip} = (T^{K^*}_{i^*p} + w - t_{ik^*})$  And go to step 4

for  $p > 1$  if  $((T^{K^*}_{i^*p} + w - t_{ik^*}) - D_{i(p-1)}) \geq Hmin_i$ ,

set  $D_{ip} = (T^{K^*}_{i^*p} + w - t_{ik^*})$  And go to step 4

Otherwise set  $w = w + 1$  and if  $w \leq WTmax_{k^*}$  repeat step 3. Otherwise set

$$T^{K^*}_{i^*p} = T^{K^*}_{i^*(p+1)} \text{ and set } w = WTmin_{k^*} \text{ And go to step 3 Else exit.}$$

**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:

$$T^k = D_{ip} + t_{ik} \forall k = 1 \dots N \text{ on rout } i$$

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

### 4.5.3 PROCEDURE 3

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

If there is only one unassigned departure on route  $i$  and set  $p$  as the minimum unassigned frequency where  $p(1 \dots f)$

Set this departure time using the minimum headway from the last departure as

$$D_i = D_{i(p-1)} + Hmin_i \text{ And exit.}$$

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

$$i. e D_i = D_{i(p-1)} + Hmin_i$$

All the nodes through which the identified route passes are labeled as ‘possible’ again.

This will allow the algorithm can to set additional simultaneous arrivals at ‘possible’ nodes.

### 4.6 Numerical Example

The network with three routes and four nodes along with the Travel time on each link is shown in Figure 7. The inputs for this network are given in Table 1 and Table 2. The planning horizon is [0, 50] minutes. Routes are assumed from Urael-atlas to bole and from Megenagna to Bole lines.

**Step 1:** Initialize Node 1 and Node 2 as ‘new’.

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

1. No arrival times are set.

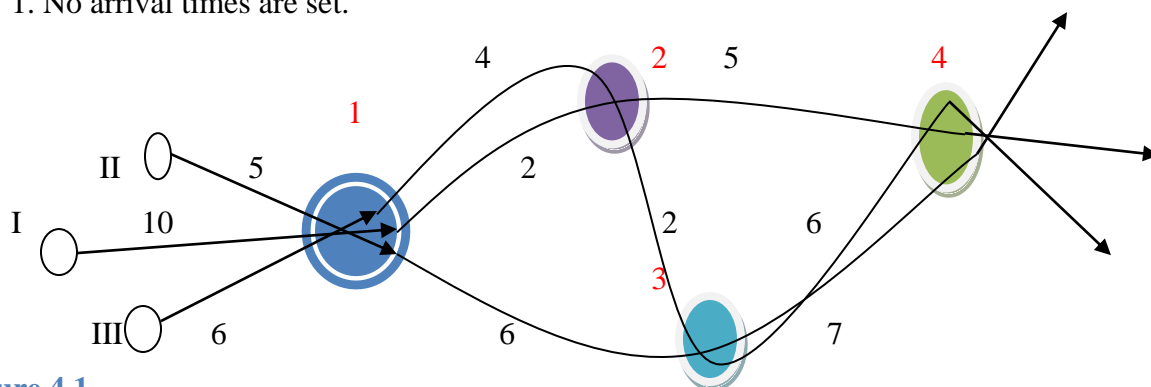


Figure 4.1

Table 2 : Inputs for the Routes in Example – 1

routes $i$	Minimum Headway $Hmin_i$	Maximum Headway, $Hmax_i$	Frequency, $f_i$
<i>I</i>	3	6	4
<i>II</i>	4	8	3
<i>III</i>	2	5	3

**Table 3: Inputs for the Nodes in Example – 1**

Nodes $k$	Number of Routes	Minimum waiting time, $WTmin_k$	Maximum waiting time, $WTmax_k$
1	3	4	8
2	2	7	10
3	2	8	11
4	3	5	8

2. The number of routes crossing Node 1 = 3, Node 2 = 2, and node 3=3

3. Maximum travel time for node 3: maximum (17, 18, and 19) = 19

For node 2: maximum (12, 11, and 10) = 12.

And for node 1: maximum (10, 5 and 6) =10 so that minimum is 10

$k$ = Node 1.

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

1. The  $d$  value obtained is,  $d = \min [4, 5] = 4$ .

$maxtime = 10$  and the route  $i^*$  is route I.

2. For route I, set the first departure ( $D_{I1}$ ) at zero minutes.

3. For route II, ( $maxtime - WTmin_I - t_{II1}$ ) = 10 - 4 - 5 = 1 which is greater than zero,

Hence set the first departure time of route II ( $D_{II1}$ ) =  $maxtime - WTmin_1 - t_{II1} = 1$

4. For routes I and II the number of subsequent departures set by this procedure are

$$p = 2 \dots \dots \min(f_I f_{II}) = \min (4, 3) = 3.$$

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

For route  $i$ , ( $i = II$ ):

$$D_{II2} = D_{II1} + d = 1 + 4 = 5$$

$$D_{II3} = D_{II2} + d = 5 + 4 = 9$$

Similarly for route  $i^*$ , ( $i^* = I$ ):

$$D_{I2} = D_{I1} + d = 0 + 4 = 4$$

$$D_{I3} = D_{I2} + d = 4 + 4 = 8$$

$$D_{I4} = D_{I3} + d = 8 + 4 = 12$$

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

$$T^1_{II1} = 1 + 5 = 6; T^1_{II2} = 10; T^1_{II3} = 9 + 5 = 14$$

And to node 3 they arrive at,

$$T^3_{II1} = 6 + 6 = 12; T^3_{II2} = 10 + 6 = 16; T^3_{II3} = 14 + 6 = 20$$

To node 4  $T^3_{II1} = 6 + 6 + 7 = 19; T^3_{II2} = 10 + 6 + 7 = 23; T^3_{II3} = 14 + 6 + 7 = 27$

Similarly, the arrival times of route I buses at node 1 are 10, 14, 18, and 22 and 12, 16, 20, and 24 are at node 2 and for node: 4 are 17, 21, 25, and 29 minutes are the arrival times.

7. Label node 1 as 'possible' since route III departure is not assigned.

**Step 3:** As node 1 is 'possible' **PROCEDURE 2** is performed.  $i^*$  Is I and  $T^1_{I1}, T^1_{I2}, T^1_{I3}, T^1_{I4}$  are arrival time 10, 14, 18, and 22 respectively.

For Route III no departure have been assigned, so set  $p = 1$ . For  $T^1_{II} = 10$  set  $w = 4$

3. The first departure time on route III is set as,

$$D_{III1} = T^1_{I1} - w - t_{III1} = 10 - 4 - 6 = 0 \text{ minutes.}$$

4. Second and third departure is still unassigned, go to Step 2.

$p = 2$  And for,  $T^1_{I2}$  set  $w = 4$ .

The procedure sets the second departure as,

$$D_{III2} = T^1_{I2} - w - t_{I1} = 14 - 4 - 6 = 4 \text{ Departure minutes}$$

$$D_{III3} = T^1_{I3} - w - t_{I1} = 18 - 4 - 6 = 8 \text{ Departure minutes}$$

Since  $p = f_I$  label Node 1 as 'not possible'. The arrival times of route III buses at Node 1 are 6, 10, and 14 minutes.

At node 2 are 10, 14, and 18.

At node 3 12, 16, and 20

At node 4 are 18, 22, and 26.

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

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

The results of this procedure are summarized in Table 4 and 5 Showing departure time and arrival time of the example.

**Table 4 departure time**

Departure	Route 1	Route 2	Route 3
1	0	1	0
2	4	5	4
3	8	9	8
4	12		

Table 4 shows lists of departure time for each route in the frequency list. Departure time should be assigned to get arrival time of the routes for each node.

**Table 5 arrival time**

Arrival at node 1			Arrival at node 2		Arrival at node 3		Arrival at node 4		
R-I	R-II	R-II	R-I	R-3	R-2	R-3	R-1	R-2	R-3
10	6	6	12	10	12	12	17	19	18
14	10	10	16	14	16	16	21	23	22
18	14	14	20	18	20	20	25	27	26
22			24				29		

R-I means route one in which arrival is calculated for all frequencies. For every routes arrival time shown to get simultaneous arrivals at the nodes.

**Table 6: Table Showing Simultaneous Arrivals for Example – 1**

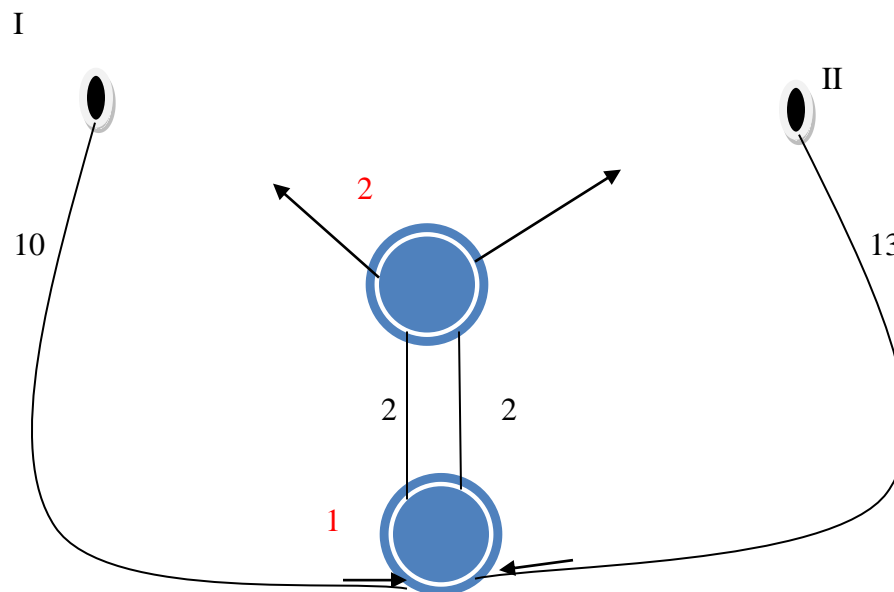
At Node 1	At node 2	At Node 3	At node 4
$S_{I,II,1,1,1} = 1$	$S_{I,III,2,3,1} = 1$	$S_{II,III,3,1,3} = 1$	$S_{I,II,4,1,2} = 1$
$S_{I,II,1,1,3} = 1$	$S_{I,III,2,4,2} = 1$	$S_{II,III,3,3,1} = 1$	$S_{I,II,4,2,3} = 1$
$S_{I,III,1,1,1} = 1$			$S_{I,II,4,3,1} = 1$
$S_{I,III,1,1,3} = 1$			$S_{I,II,4,4,2} = 1$
$S_{I,II,1,2,1} = 1$			$S_{II,III,4,1,3} = 1$
$S_{I,III,1,2,1} = 1$			$S_{II,III,4,2,1} = 1$
$S_{I,III,1,2,2} = 1$			$S_{II,III,4,3,2} = 1$
$S_{I,II,1,3,2} = 1$			
$S_{I,II,1,3,3} = 1$			
$S_{I,III,1,3,2} = 1$			
$S_{I,III,1,3,3} = 1$			
$S_{I,III,1,4,3} = 1$			
$S_{I,II,1,4,3} = 1$			
$S_{II,III,1,1,2} = 1$			
$S_{II,III,1,1,3} = 1$			
$S_{II,III,1,2,1} = 1$			
$S_{II,III,1,2,3} = 1$			
$S_{II,III,1,3,1} = 1$			
$S_{II,III,1,3,2} = 1$			

The above table shows lists of simultaneous arrival in which 19 at node one, 2 at node two and three and 7 at node four.

$S_{I,II,1,1,1} = 1$  Means simultaneous arrival of route one and route two at node one within assigned waiting time limit. Simultaneously arrival depends on the waiting time limit.

The next example is a bus network with two routes and two nodes. The network and the travel times are shown in Figure 2. The inputs are given in Table 7 and Table 8. The planning horizon is  $[0, 45]$  minutes. A network is planned for route assumed from Kotebe-Kara to Megenagna and route from Yarer-Garage to Megenagna.

#### 4.2: Numerical Example – 2



**Table 7: Inputs for the Routes in Numerical Example – 2**

Routes	Minimum Headway, $Hmin_x$	Maximum Headway $Hmax_x$	Frequency, $f_i$
I	5	7	2
II	4	8	3

**Table 8: Inputs for Nodes in Example – 2**

Nodes, $k$	Number of routes	Minimum Waiting Time, $WTmin_k$	Maximum Waiting Time, $WTmax_k$
1	2	4	6
2	2	5	8

**Step 1:** Initializes all the nodes as ‘new’.

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

1. Number of set departure times (= 0) for all nodes.
2. Number of crossing routes (= 2) for all nodes.
3. Maximum travel times at node 1 10, and 13= maximum is 13 and for node 2 is 12 and 15= maximum is 15. The minimum value is 13, so  $k^* = \text{Node 1}$ .

**Step 3:** Performs *PROCEDURE I* at node 1 on routes *I* and *II*.

1. The value of  $d$  is 5. The route  $i^*$  is *I* and *maxtime* = 10 minutes.
2. The first departure on route *I* ( $D_{I1} = 0$  is set at zero minutes.
3. set  $w = 4$
4. for  $w = 4$  the conditions are satisfied and the first departure is assigned as,

$$D_{II1} = \text{maxtime} + w - t_{II3} = 10 + 4 - 13 = 1$$

5. The number of departures created for route *I* and *II* are  $\min(2, 3) = 2$ . They are set as,

For route *II*

$$D_{II2} = D_{II1} + d = 1 + 5 = 6$$

For route *I*

$$D_{I2} = D_{I1} + d = 0 + 5 = 5$$

6. The arrival time of route *II* buses at Node 1:  $T^1_{II1}, T^1_{II2}$  are 14 and 19 and at Node 2:  $T^2_{II1}, T^2_{II2}$  are 16, and 21 minutes.

For route *I* the arrival times at

Node: 1  $T^1_{I1}, T^1_{I2}$  are 10, and 15

At node 2:  $T^2_{I1}, T^2_{I2}$  are 12, and 17

7. Label Node 2 as ‘possible’ and Node 1 as ‘not possible’.

**Step 3:** *PROCEDURE 1* creates only first and second departure,  $D_{I1}$  and  $D_{I2}$  for route  $I$ . For route  $I$  only two departure times is set using this procedure.

**Step 4:** No more ‘possible’ node, continue.

**Step 5:** Route  $I$  has an unassigned departure. Perform *PROCEDURE 3*. Since only one unassigned departure, assigns it as,

$$D_{I3} = D_{I2} + Hmin_I = 6 + 4 = 10$$

Arrival time at node:  $T^1_{I3}$  and  $T^2_{I3}$  are 20 and 22 minutes

The departure times are shown in Table 9. It was observed that the number of simultaneous arrivals obtained mainly depends on the waiting time limits considered at each node.

**Table 9: departure time**

Departures	Route $I$	Route $II$
1	0	1
2	5	6
3	10	-

Table 9 shows departure time for each route. For example route  $I$  first bus departure is zero while the next one is after five minutes. For route two the first bus departs at one minute after the departure time of the route one of the first bus.

**Table 10 arrival time**

Arrival at node 1		Arrival at nod 2	
R-I	R-II	R-I	R-II
10	14	12	16
15	19	17	21
20		22	

Table 10 shows arrival time of routes at the node. For example route one arrived node one with ten minutes and the next bus of the route arrive after five minutes.

**Table 11: Table Showing the Simultaneous Arrivals for Example – 2**

At Node 1	At Node 2
$S_{I,II,1,1,1} = 1$	$S_{I,II,2,3,1} = 1$
$S_{I,II,1,2,2} = 1$	
$S_{I,II,1,3,1} = 1$	

Table 11 shows simultaneous arrivals at the node in the given waiting time. For example route one bus of first departure arrives simultaneously with route two bus of the same departure at node one. Simultaneously arrivals depend on the range of waiting time.

## CHAPTER 5

### APPLICATION FOR REAL LIFE PROBLEM AND DISCUSSION

In this Chapter, the heuristic developed is applied to real-life problems that incorporate realistic data on number of routes, nodes and waiting times. The model is tested for different waiting time ranges. The total number of synchronization for each node is given and compared with the maximum value of possible synchronizations. This network has three nodes and seven routes. The headway limits, and waiting time were set to be in minutes respectively for each routes  $i$ . The planning horizon is  $[0, 250]$  minutes and frequency of each route is give accordingly. The travel times on each link are shown in the Figure 3. For this problem the waiting time limits is assigned in table 13.

**Table: 12.input data for real life problem**

Routes, $i$	Assigned for	$Hmin_i$	$Hmax_i$	Frequency $f_i$
$I$	CMC – torhayiloch LRT	6	10	7
$II$	Anfomeda to mexico-legahar	15	20	2
$III$	Karra -mexico	15	20	2
$IV$	Sebeta - Legehar	25	30	2
$V$	Gurara-legahar	20	25	3
$VI$	Lafito-stadum	15	20	3
$VII$	Legehar –shiro meda	15	20	4

Table 12 shows lists of head ways of routes and frequency for the real problems. The routes are assigned for origin to destiny in the table. For example route III is karra to mexico line of the city bus.

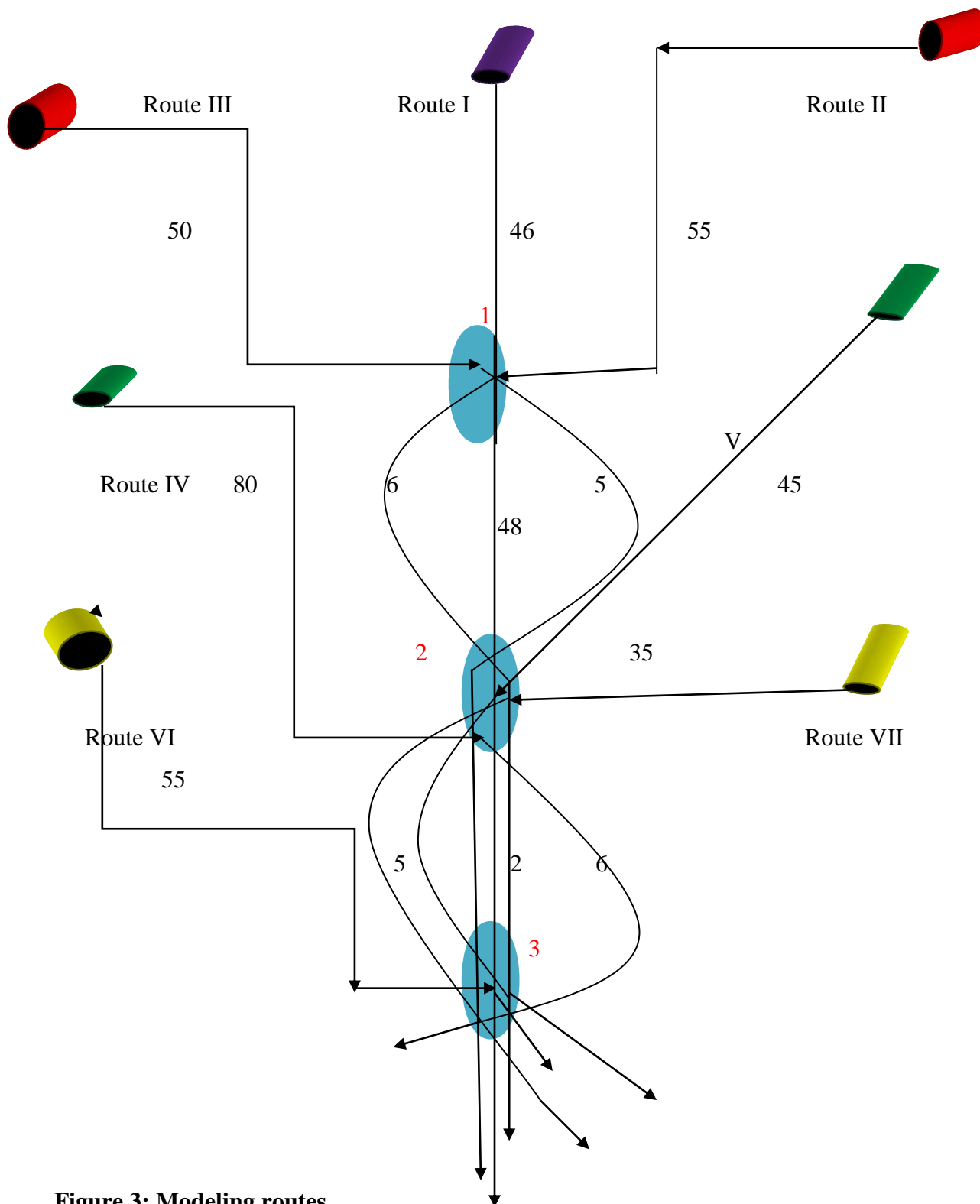


Figure 3: Modeling routes

**Table: 13 Inputs for nodes**

Nodes, i.	No of routes	$WTmin_k$	$WTmax_k$
1	3	12	16
2	6	14	22
3	7	16	24

$WTmin_k$  Is minimum waiting time at the node and both the maximum and minimum values are given.

**Step 1:** Initializes all the nodes as ‘new’.

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

1. Number of set departure times (= 0) for all nodes.
2. Number of crossing routes (3, 6, and 7 respectively) for nodes.
3. Maximum travel times are 55, 86, and 57 respectively. The minimum value is 55, so  $k^* = \text{Node 1}$ .

**Step 3:** Performs *PROCEDURE 1* at node 1 on routes I and II.

1. The value of  $d$  is calculated as:

$$d = \text{Min}_{i=1,2..M} [\text{Max}_{i=1,2..M} (Hmin_i), \text{Min}_{i=1,2..M} (Hmax_i)] \forall i$$

$$= \min(15, 10) = 10$$

The route  $i^*$  is II and  $maxtime = 55$  minutes.

2. The first departure on route **II** ( $D_{II1} = 0$ ) is set at zero minutes.

$$3. \text{ set } w = WTmin_k \quad \text{which is } w = 12$$

4. for  $w = 12$  the conditions are not satisfied and the first departure is assigned as,

$$\text{set } w = w + 1$$

$$D_{I1} = maxtime + w - t_{I1} = 55 + 13 - 46 = 22$$

5. The number of departures created for route I and II are  $\min(10, 2) = 2$ . They are set as,

For route I:

$$D_{I2} = D_{I1} + d = 22 + 10 = 32$$

$$D_{I3} = 42$$

$$D_{I4} = 52$$

$$D_{I5} = 62$$

$$D_{I6} = 72$$

$$D_{I7} = 82$$

For route II

$$D_{II2} = D_{II1} + d = 0 + 10 = 10$$

6. The arrival time of **route I** buses at **Node 1**:

$T^1_{I1}, T^1_{I2}, T^1_{I3}, T^1_{I4}, T^1_{I5}, T^1_{I6}, T^1_{I7}, T^1_{I8}, T^1_{I9}, T^1_{I10}$  Are 68, 78, 88, 98, 108, 118, 128

And arrival times to **node 2**:

$T^2_{I1}, T^2_{I2}, T^2_{I3}, T^2_{I4}, T^2_{I5}, T^2_{I6}, T^2_{I7}$   
Are 73, 83, 93, 103, 113, 123, 133

And **node 3**:  $T^3_{I1}, T^3_{I2}, T^3_{I3}, T^3_{I4}, T^3_{I5}, T^3_{I6}, T^3_{I7}$   
Are 75, 85, 95, 105, 115, 125, 135.

**For route II the arrival times at**

**Node 1:**  $T^1_{II1}, T^1_{II2}$  are 55, and 65.

And arrival times to **node 2**  $T^2_{II1}, T^2_{II2}$  are 61, and 71.

And **node 3**:  $T^3_{II1}$   $T^3_{II2}$  are 63, and 73.

7. Label **Node 1 as 'possible'** since departure time of route III is not assigned.

Step 4: There are 'possible' and 'new' nodes - go to step 2.

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

1. Ten arrival times have been set at nodes 1 by route I and two at node by route II.

Hence the number of set arrivals at node 1 are = 12,

2. Number of routes passing through these nodes is three

3. The maximum travel time of node 1 is route III. Therefore  $i^*$  is route I

**Step 3:** As node 1 is 'possible' **PROCEDURE 2** is performed.

Route  $i^*$  is route **I**

$T^2_{I1}; T^2_{I2}, T^2_{I3}, T^2_{I4}, T^2_{I5}, T^2_{I6}, T^2_{I7}$ .

are 73, 83, 93, 103, 113, 123, and 133.

For Route **III** no departures have been assigned, so set  $p = 1$ . For  $T^1_{I1} = 68$  set  $w = 12$

3. The first departure time on route **II** is set as,

$$D_{III1} = T^1_{I1} - w - t_{III1} = 68 - 12 - 50 = 6 \text{ minutes.}$$

4. Second departure is still unassigned, go to Step 2.

$p = 2$  And for,  $T^1_{I2}$  set  $w = 12$ .

The procedure sets the second departure as,

$$D_{III2} = T^1_{I2} - w - t_{III1} = 78 - 12 - 50 = 16 \text{ Departure minutes}$$

Since  $p = f_{II}$  label Node 1 as 'not possible'.

The arrival times of route **III** buses at

**Node 1:**  $T^1_{III1} = D_{III1} + t_{III1} = 6 + 50 = 56$  minutes. And

$$T^1_{III2} = D_{III2} + t_{III1} = 16 + 50 = 66$$

**Node 2:**  $T^2_{III1} = D_{III1} + t_{III2} = 6 + 55 = 61$  minutes

And:  $T^2_{III2} = D_{III2} + t_{III2} = 16 + 55 = 71$  minutes

**Node 3:**  $T^3_{III1} = D_{III1} + t_{III3} = 6 + 57 = 63$  minutes.

$$T^3_{III} = D_{III2} + t_{III3} = 16 + 57 = 73 \text{ minutes.}$$

**Label Node: 2** as 'possible and **node 1** not possible.

**Step 1:** More 'possible' nodes, since IV, V, and VII are un- assigned routes go to step – 2.

**Step 2:** Identify the node '*SELECTED NODE*'.  $K^*$

1 The number of already set arrivals at node 2 is ten (from route I buses) and

Two from route II and two from route III

Hence  $K^* = \text{Node 2}$

2. Number of routes passing through these nodes is six

3. The maximum travel time of node 1 is route IV. Therefore  $i^*$  is route I

**Step 3:** Performs *PROCEDURE 2* at node 2 on routes I and IV .

1. Ten arrival times have been set at nodes 2 by route I and four at node by route II and III. Hence the number of set arrivals at node 2 are = 14,

2. Number of routes passing through these nodes is six.

3. The maximum travel time of **node 2** is route IV. Therefore  $i^*$  is route I

As **node 2** is 'possible' *PROCEDURE 2* is performed.

Route  $i^*$  is route I

$$T^2_{I1}; T^2_{I2}, T^2_{I3}, T^2_{I4}, T^2_{I5}, T^2_{I6}, T^2_{I7}.$$

are 73, 83, 93, 103, 113, 123, 133.

For Route **IV** no departures have been assigned, so set  $p = 1$ . For  $T^2_{I1} = 73$  set  $w = 14$

3. The first departure time on route **IV** is set as,

$$D_{IV1} = T^2_{I1} + w - t_{IV1} = 73 + 14 - 80 = 7 \text{ minutes.}$$

4. Second departure is still unassigned, go to Step 2.

$$p = 2 \text{ And for, } T^1_{I2} \text{ set } w = 14.$$

The procedure sets the second departure as,

$$D_{IV2} = T^1_{I2} + w - t_{IV2} = 83 + 14 - 80 = 17 \text{ Departure minutes}$$

Since  $p = f_{IV}$  label Node 2 as 'possible'.

The arrival times of route **IV** buses at

$$\text{Node 2: } T^2_{IV1} = D_{IV1} + t_{IV2} = 7 + 80 = 87 \text{ minutes. And}$$

$$T^2_{IV2} = D_{IV2} + t_{IV2} = 17 + 80 = 97$$

$$\text{Node 3: } T^3_{IV1} = D_{IV1} + t_{IV3} = 7 + 82 = 89$$

$$\text{And: } T^3_{IV2} = D_{IV2} + t_{IV3} = 17 + 82 = 99 \text{ minutes}$$

**Label Node: 2 Step 1:** More 'possible' nodes, since V, and VII are un- assigned routes go to step – 2.

**Step 2:** Identify the node '*SELECTED NODE*'.  $K^*$

1 The number of already set arrivals at node 2 is ten (from route I buses) and Two from route II and two from route III and two from IV.

Hence  $K^* = \text{Node 2}$

2. Number of routes passing through these nodes is six
3. Therefore  $i^*$  is route I since arrival time is set.

**Step 3:** Performs **PROCEDURE 2** at node 2 on routes I and V .

1. Ten arrival times have been set at nodes 2 by route I and four at node by route II and III. Hence the number of set arrivals at node 2 are = 16,
2. Number of routes passing through these nodes is six.
3. The maximum travel time of **node 2** is route V. Therefore  $i^*$  is route I

As **node 2** is 'possible' **PROCEDURE 2** is performed.

Route  $i^*$  is route I

$T^2_{I1}; T^2_{I2}, T^2_{I3}, T^2_{I4}, T^2_{I5}, T^2_{I6}, T^2_{I7}$ .  
are 73, 83,93,103,113,123,133.

For Route V no departures have been assigned, so set  $p = 1$ . For  $T^2_{I1} = 73$  set  $w = 14$

3. The first departure time on route V is set as,

$$D_{V1} = T^2_{I1} - w - t_{V1} = 73 - 14 - 45 = 14 \text{ minutes.}$$

4. Second and third departure is still unassigned, go to Step 2.

$p = 2$  And for,  $T^1_{I2}$  set  $w = 14$ .

The procedure sets the second departure as,

$$D_{V2} = T^2_{I2} - w - t_{V2} = 83 - 14 - 45 = 24 \text{ Departure minutes and}$$

$$D_{V3} = T^2_{I3} - w - t_{V2} = 93 - 14 - 45 = 34 \text{ Departure minutes and}$$

Since  $p = f_V$  label node: 2 as 'possible'.

The arrival times of route  $V$  buses at

**Node 2:**  $T^2_{V1} = D_{V1} + t_{V2} = 14 + 45 = 59$  minutes. And

$$T^2_{V2} = D_{V2} + t_{V2} = 24 + 45 = 69$$

$$T^2_{V3} = D_{V3} + t_{V2} = 34 + 45 = 79$$

**Node 3:**  $T^3_{V1} = D_{V1} + t_{V3} = 14 + 50 = 64$

$$T^3_{V2} = D_{V2} + t_{V3} = 24 + 50 = 74 \text{ minutes}$$

$$T^3_{V3} = D_{V3} + t_{V3} = 34 + 50 = 84 \text{ minutes}$$

### Label Node: 3

**Step 1:** More 'possible' nodes, since VI are unassigned routes go to step – 2.

**Step 2:** Identify the node '*SELECTED NODE*'.  $K^*$

1 The number of already set arrivals at node 3 is seven (from route I buses) and ten from route II, III, IV, and V

Hence  $K^* = \text{Node 3}$

2. Number of routes passing through these nodes is seven

3. Therefore  $i^*$  is route I since arrival time is set.

**Step 3:** Performs *PROCEDURE 2* at node 3 on routes I and VII .

1. Ten arrival times have been set at nodes 3 by route I and seven at node by route II, III, IV and V. Hence the number of set arrivals at node 2 are = 17,

2. Number of routes passing through these nodes is seven.

Therefore  $i^*$  is route I

As **node 3** is 'possible' *PROCEDURE 2* is performed.

Route  $i^*$  is route I

$T^2_{I1}; T^2_{I2}, T^2_{I3}, T^2_{I4}, T^2_{I5}, T^2_{I6}, T^2_{I7}$   
are 73,83,93,103,113,123,133.

For Route **VII** no departures have been assigned, so set  $p = 1$ . For  $T^3_{I1} = 73$  set  $w = 14$

3. The first departure time on route **VII** is set as,

$$D_{VII1} = T^2_{I1} - w - t_{V1} = 73 - 14 - 35 = 24 \text{ minutes.}$$

4. Second, third, and fourth departure is assigned, as go to Step 2.

$$p = 2 \text{ And for, } T^2_{I2} = 83 \text{ set } w = 14.$$

The procedure sets the second departure as,

$$D_{VII2} = T^2_{I2} - w - t_{VII2} = 83 - 14 - 35 = 34 \text{ Departure minutes and}$$

$$D_{VII3} = T^2_{I3} - w - t_{VII2} = 93 - 14 - 35 = 44 \text{ Departure minutes and}$$

$$D_{VII4} = T^2_{I4} - w - t_{VII2} = 103 - 14 - 35 = 54 \text{ Departure minutes}$$

Since  $p = f_{VII}$  label Node 2 as 'not possible' and node 3 possible.

The arrival times of route **V** buses at

$$\text{Node 2: } T^2_{VII1} = D_{VII1} + t_{VII2} = 24 + 35 = 59 \text{ minutes. And}$$

$$T^2_{VII2} = D_{VII2} + t_{V2} = 34 + 35 = 69$$

$$T^2_{VII3} = D_{VII3} + t_{V2} = 44 + 35 = 79$$

$$T^2_{VII4} = D_{VII4} + t_{V2} = 54 + 35 = 89$$

$$\text{Node 3: } T^3_{V1} = D_{VII1} + t_{VII3} = 24 + 40 = 64$$

$$T^3_{V2} = D_{VII2} + t_{VII3} = 34 + 40 = 74 \text{ minutes}$$

$$T^3_{VII3} = D_{VII3} + t_{VII3} = 34 + 50 = 84 \text{ minutes}$$

$$T^3_{VII4} = D_{VII4} + t_{VII3} = 44 + 50 = 94 \text{ minutes}$$

**Label Node: 3** as 'possible and **node 2** not possible.

**Step 1:** More 'possible' nodes, since VI is un- assigned routes go to step – 2.

**Step 2:** Identify the node '*SELECTED NODE*'.  $K^*$

1. The number of already set arrivals at node 3 is seven (from route I buses) and Twelve from route *II, III, IV, V, and VII*  
Hence  $K^* = \text{Node 3}$

2. Number of routes passing through these nodes is seven

3. The maximum travel time of node 3 is route *VI*. Therefore  $i^*$  is route *I*

**Step 3:** Performs **PROCEDURE 2** at node 3 on routes *I* and *VI* .

1. Seven arrival times have been set at nodes by route I and Twelve by other route. Hence the number of set arrivals at node 3 are = 19

2. Number of routes passing through these nodes is seven.

3. The maximum travel time of **node 3** is route *VI*

As **node 3** is 'possible' **PROCEDURE 2** is performed.

Route  $i^*$  is route *I*

$$T^3_{I1}, T^3_{I2}, T^3_{I3}, T^3_{I4}, T^3_{I5}, T^3_{I6}, T^3_{I7} \text{ are } 75, 85, 95, 105, 115, 125, 135.$$

For Route *VI* no departures have been assigned, so set  $p = 1$ . For  $T^3_{I1} = 75$  set  $w = 16$

3. The first departure time on route *VI* is set as,

$$D_{VI1} = T^3_{I1} - w - t_{VI3} = 75 - 16 - 55 = 4 \text{ minutes.}$$

4. Second and third departure is still unassigned, go to Step 2.

$p = 2$  And for,  $T^3_{VI2}$  set  $w = 16$ .

The procedure sets the second departure as,

$$D_{VI2} = T^3_{VI2} - w - t_{VI3} = 85 - 16 - 55 = 14 \text{ Departure minutes}$$

$$D_{VI3} = T^3_{VI3} - w - t_{VI3} = 95 - 16 - 55 = 24$$

Since  $p = f_{VI}$  label Node 3 as not 'possible'.

The arrival times of route VI buses at

**Node 3:**  $T^3_{VI1} = D_{VI1} + t_{VI3} = 4 + 55 = 59$  minutes. And

$$T^3_{VI2} = D_{VI2} + t_{VI3} = 14 + 55 = 69$$

$$T^3_{VI3} = D_{VI3} + t_{VI3} = 24 + 55 = 79$$

**Step 4:** No more 'possible' node, continue.

The final departure results are shown in Table 14. The number of simultaneous arrivals obtained is 4, 18, and 14 at node 1, 2, and 3 respectively and are shown in Table 15. It was observed that the number of simultaneous arrivals obtained mainly depends on the waiting time limits considered at each node.

**Table: 14 showing departure time of routes.**

departure	R-I	R-II	R-III	R-IV	R-V	R-VI	R-VII
1	22	0	6	7	14	4	24
2	32	10	16	17	24	14	34
3	42	-	-	-	34	24	44
4	52	-	-	-	-	-	54
5	62	-	-	-	-	-	-
6	72	-	-	-	-	-	-
7	82	-	-	-	-	-	-

Table 14 shows departure time of real problem of each route. For example departure time of route one is 22 minute for the first trip and second, third continued up to the last departure of the route.

**Table: 15 arrival time for problem**

Arrival at node 1			Arrival at node 2						Arrival at node 3						
R-I	R-II	R-III	R-I	R-II	R-III	R-IV	R-V	R-VII	R-I	R-II	R-III	R-IV	R-V	R-VI	R-VII
68	55	56	73	61	61	87	59	59	75	63	63	89	64	59	64
78	65	66	83	71	71	97	69	69	85	73	73	99	74	69	74
88			93				79	79	95				84	79	84
98			103					89	105						94
108			113						115						
118			123						125						
128			133						135						

Table 15 shows arrival time of routes to the node. For example first bus of route II arrive node one at 55 minute and node three at 63 minute.

**Table 16: Showing the Simultaneous Arrivals for real life problem.**

Node 1	Node 2	Node 3
$S_{I,II,1,1,1} = 1$	$S_{I,IV,2,1,1} = 1$	$S_{I,IV,3,1,2} = 1$
$S_{I,II,1,2,2} = 1$	$S_{I,V,2,1,1} = 1$	$S_{I,VI,3,1,1} = 1$
$S_{I,III,1,1,1} = 1$	$S_{I,VII,2,1,1} = 1$	$S_{I,VII,3,1,4} = 1$
$S_{I,III,1,2,2} = 1$	$S_{I,VII,2,1,4} = 1$	$S_{I,II,3,2,1} = 1$
$S_{II,III,1,1,2} = 1$	$S_{I,II,2,2,1} = 1$	$S_{I,III,3,2,1} = 1$
$S_{II,III,1,2,1} = 1$	$S_{I,III,2,2,1} = 1$	$S_{I,V,3,2,1} = 1$
	$S_{I,IV,2,2,2} = 1$	$S_{I,II,3,3,2} = 1$
	$S_{I,V,2,2,2} = 1$	$S_{I,III,3,3,2} = 1$
	$S_{I,II,2,3,2} = 1$	$S_{I,V,3,3,2} = 1$
	$S_{I,III,2,3,2} = 1$	$S_{I,VI,3,3,3} = 1$
	$S_{I,V,2,3,2} = 1$	$S_{I,V,3,4,3} = 1$
	$S_{I,V,2,3,3} = 1$	$S_{I,VII,3,4,3} = 1$
	$S_{I,VII,2,3,2} = 1$	$S_{I,IV,3,5,2} = 1$
	$S_{I,VII,2,3,3} = 1$	$S_{I,VII,3,5,4} = 1$
	$S_{I,V,2,4,3} = 1$	$S_{II,IV,3,2,1} = 1$
	$S_{I,VII,2,4,3} = 1$	$S_{III,IV,3,2,1} = 1$
	$S_{I,VII,2,4,4} = 1$	$S_{IV,VI,3,1,2} = 1$
	$S_{I,IV,2,5,2} = 1$	$S_{IV,VI,3,2,3} = 1$
	$S_{II,V,2,1,3} = 1$	$S_{V,VII,3,1,3} = 1$
	$S_{III,V,2,1,3} = 1$	$S_{V,VII,3,2,4} = 1$
	$S_{IV,V,2,1,2} = 1$	
	$S_{IV,V,2,2,3} = 1$	

Since it was observed that the number of simultaneous arrivals obtained mainly depends on the waiting time limits considered at each node, we have to check varying waiting time to have different simultaneous arrival. 6 arrivals at node one, 22 arrivals at node two and 20 arrivals at node three observed for the real problem of leghar station. For example  $S_{II,III,1,2,1} = 1$  means route two second bus and route three first bus simultaneously arrive at node one. Using loop for varying waiting time will be further study of research.

## CHAPTER 6

### 6.1 CONCLUSION AND FUTURE STUDY

A summary of research methodology, findings and answers to research questions are presented in relation to the knowledge extracted from literature review and the conceptual framework developed from literatures and case studies. The research followed the process of identification of real world problem, formulation of theoretical framework and explored cases as methodological approach. In the context of Addis Ababa, the case study is also limited to the specific case of leghar stations. The research tried to address growing urban challenges and transport problems in the city of Addis Ababa especially integration problem of one mode of transport with other. The model that construct synchronized timetables for a bus and LRT transit network, incorporating waiting time limits at transfer nodes has been developed. The model assumes that the minimum waiting time at each node is a value greater than zero and a maximum waiting time value that does not exceeds the maximum headway of routes passing through that node. The proposed model reduces waiting time by transfer coordination rather than decreasing headways (which is other option to achieve synchronization). It is assumed that passengers making connections prefer some waiting time greater than zero but refuse too large waiting times. Hence our model creates timetables considering this factor and obtains possible number of simultaneous arrivals under these conditions. The synchronized arrivals set at each node, makes the transit system be 'on-time' standards and healthy.

## 6.2 FUTURE STUDY

The randomness of bus travel times can cause inconveniences in transfer's times because of traffic jamming, having no dedicated line for bus and management problems. Hence incorporating this randomness can be considered.

The model that construct timetables for a bus and LRT transit network, incorporating waiting time limits at transfer nodes has been developed but incorporating headways rather than waiting time of transit systems can be considered.

In the absence of communication and tracking technology, timed transfer systems must rely on set schedules, combined with driver observations, for bus coordination. Buses can be held beyond their normal departure time if drivers observe that connecting buses are late. However, they can have no idea of how late the buses will be, or whether they will arrive at a time. Therefore, modern communication technology can be considered.

Using  $C^{++}$  software and different approach possibility of developing algorithm for a loop and solving for the problem can be considered.

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## Appendix

### Appendix a: Route should be integrated Information leghar station

# routes	Origin destination	#buses planed	Km	tariff	Travel time /single trip	Daily trip /route	Trip/buses
1	Legehar - shiromeda	8	14.3	2.75	58	80	10
2	Legehar-gurara ference	4	9.5	2.75	57	58	15
3	Legehar-jemmo	8	10.6	2.25	48	130	16
4	Anfomeda Legehar	4	12	2.25	55	56	14
5	Legehar-sebeta	3	23.3	4.25	80	50	10
6	Lafito-Legehar	4	9.5	2.25	57	58	15

**Appendix b: Origin - Destination Route Information Legehar station**

# route	Origin-Destination	#Of buses planned	Km	Tariff	travel time /single trip	Daily trip per route.	trip/buses
1	SUMMIT - LEGEHAR	6	14. 3	2.7 5	58	80	13
2	LEGEHAR - AKAKI	4	19	3.7 5	80	41	10
3	LEGEHAR - KALITI	8	14. 9	2.7 5	65	90	11
4	LEGEHAR - SHIRO MEDA	8	7.4	1.6 0	35	180	23
5	HANA MARIAM - LEGEHAR	6	10. 6	2.2 5	51	97	16
6	KARA KORE - LEGEHAR	4	11. 7	2.2 5	55	60	15
7	MEGENAGNA - LEGEHAR	3	9.8	2.2 5	50	50	17
8	LEGEHAR - DIL BER	6	8.6	1.6 0	46	102	17
9	LAFTO - LEGEHAR	4	9.5	2.2 5	57	58	15
10	LEGEHAR - GURARA FERENSAY KELLA	4	9.5	2.2 5	45	72	18
11	KARA - LEGEHAR	4	14. 4	2.7 5	60	56	14
12	LEGEHALR - ALEM BANK	3	12	2.2 5	52	48	16
13	DEBR ZEIT - LEGEHAR	10	47. 2	9.0 0	100	60	6
14	CHEFE AYATE - LEGEHAR	6	18	3.0 0	65	72	12
15	SEBETA - LEGEHAR	3	23. 8	4.2 5	80	30	10
16	LEGEHAR - JEMMO	8	10. 6	2.2 5	48	130	16

	MEKANISSA						
17	LEGEHAR - RING ROAD VIS WINGET	6	10. 2	2.2 5	60	77	13
18	KOLFE EFOYTA - LEGEHAR	3	9.5	2.2 5	54	48	16
19	BETEL HOSPITAL - LEGEHAR	6	10	2.25	55	87	15
20	KARA - LEGEHAR	6	13.7	2.75	52	92	15
21	ANFO MEDA - LEGEHAR	4	12	2.25	55	56	14
	TOTAL	112	296.7	58.95	1223	1586	302

### Appendix b: Showing an ACB route that touches light railway transport in

#### A.A, IN megabit 2006 E.C. E.C

#route	Origin-Destination	No.of bus es pln ned	KM	LRT touch its route km	100 k m	LRT k m	
1	MEGENAGNA - KARALO	4	7.7	100.0	100		0
2	KORE MEKANISSA - ADDIS KETEMA	4	11.1	2.8		2.8	1
3	AYER TENA - MENELIK SQUAR	8	10.8	1.5		1.5	0
4	KALITI - ADDIS KETEMA	6	19.4	8.4		8.4	1
5	KORE MEKANISSA - MENELIK SQUAR	3	12.7	300	300		0
6	KERA - SEMEN GEBEYA SQUAR	8	9.9	400	400		0

7	MEGENAGNA - ALELTU	3	49	100	100		0
8	KECHENE - ADDIS KETEMA	3	9.4	900	900		0
9	BOLE BRASS CLINIC - PIASSA	3	10.5	1.3		1.3	0
11	KOLFE EFOYETA - MENELIK HOSPITAL	4	10	2.6		2.6	1
12	GURARA FERENSAY KELA - ADDIS KETEMA	6	9.9	1.6		1.6	0
13	ITALY EMBASSY - ADDIS KETEMA	3	9.9	1.3		1.3	0
14	SARIS ABO - MENELIK SQUAR	6	12.3	8		8	1
15	MEGENAGNA - ADDIS KETEMA	4	10.4	1.4		1.4	0
16	KIDANIMIHRET - ADDIS KETEMA	8	7.9	1.8		1.8	0
17	KUSQUM - ADDIS KETEMA	6	9.1	1.3		1.3	0
18	KERANIYO - ADDIS KETEMA	8	7.3	200	200		0
19	SANSUSI - PIASSA	5	12.8	200	200		0
20	DIL BER - ADDIS KETEMA	3	8.6	900	900		0
21	FELIDORO - ADDIS KETEMA	5	8.6	200	200		0
22	SUMMIT - LEGEHAR	6	14.3	11.6		11.6	2
23	LAMBERET - ADDIS KETEMA	3	12	1.6		1.6	1
24	DIRE SOLOLIYA -ADDIS KETEMA	4	15.9	200	200		0
25	LEGEHAR - AKAKI	4	19	7.9		7.9	2
26	ADDIS KETEMA - SEBETA	3	25.5	3.0		3.0	1
27	LEGEHAR - KALITI	8	14.9	7.9		7.9	1
28	ASKO SANSUZI -ADDIS KETEMA	5	11.1	200	200		0
29	SARIS ADDISU SEFER - ADDIS KETEMA	6	12.7	7.7		7.7	1
30	SULULTA -ADDIS KETEMA	5	25.8	1.6		1.6	0
31	LEGEHAR -SHIRO MEDA	8	7.4	1.1		1.1	0
32	HANA MARIAM -LEGEHAR	6	10.6	6.2		6.2	1
34	GERMAN SQUAR - ADDIS KETEMA	3	9.8	2.8		2.8	1
35	LEBU MUZIQA SEFER- ADDIS KETEMA	3	15	200	200		0
36	KARA KORE - LEGEHAR	4	11.7	2.3		2.3	1
37	KERANIYO - MENELIK SQUAR	4	12	1.9		1.9	0
38	GERMAN SQUAR - SIDIST KILO	4	11	350	350		0
39	BOLE SCHOOL - ADDIS KETEMA	3	9.6	1.3		1.3	0
40	KARALO - ADDIS KETEMA	3	17.9	1.3		1.3	0
41	EYESUS - ADDIS KETEMA	5	8.5	1.3		1.3	0
42	MEGENAGNA - LEGEHAR	3	9.8	400	400		0
43	MENAGESHA - ADDIS KETEMA	2	30.2	200	200		0
44	LEGEDADI - ADDIS KETEMA	2	30.4	1.3		1.3	1
45	LEGEHAR - DIL BER	6	8.6	350	350		0
46	GERJI - ARAT KILO	6	11.2	3.4		3.4	1

47	YENEGEW FIRE SCHOOL - ADDIS KETEMA	3	6	200	200		0
48	BOLE MICHAEL - MENELIK SQ;	6	10.9	250	250		0
49	AYAT CMC SQ; - MEGENAGNA	6	11	7.9		7.9	1
50	AYER TENA - MEGENAGNA	4	14.9	7.9		7.9	2
51	BETHEL HOSPITAL - ADDIS KETEMA	4	10.9	600	600		0
52	GERJI - ADDIS KETEMA	8	14.1	1.1		1.1	0
53	BOLE MICHAEL - SHIRO MEDA	4	11.5	100	100		0
54	LAFTO - LEGEHAR	4	9.5	100	100		0
55	LEGEHAR - GURARA FERENSAY KELLA	4	9.5	1.1		1.1	0
56	SARIS ABO - SHIRO MEDA	6	14.2	7.5		7.5	1
57	KARA - LEGEHAR	4	14.4	7.9		7.9	2
58	LEGEHALR - ALEM BANK	3	12	1.5		1.5	1
59	BETHEL HOSPITAL - MENELIK SQUAR	6	11.5	1.1		1.1	0
60	DEBR ZEIT - LEGEHAR	10	47.2	8.2		8.2	1
61	AYAT CMC AYAT SQ, - LEGEHAR	6	18	15.8		15.8	3
62	SEBETA - LEGEHAR	3	23.8	2.3		2.3	1
63	ADDIS KETEMA - MIKILILAND	3	9.1	200	200		0
64	SIDIST KILO - MEGENAGNA GORF ASWEGAJ	4	9.5	3.1		3.1	1
65	ADDIS KETEMA - ALEM BANK	3	11	3.0		3.0	1
66	ADDIS KETEMA - KARA QORRE	4	10.5	3.0		3.0	1
67	LEGEHAR - JEMMO MEKANISSA	8	10.6	200	200		0
68	MENELIK HOSPITAL - TORE HAILOCH	6	10.2	4.6		4.6	1
69	LOME MEDA - MERKATO	3	5.9	200	200		0
70	AWARE SQUARE - AYER TENA	4	12	1.5		1.5	0
71	GERJI - BALCHA HOSPITAL	3	10.9	4.4		4.4	1
72	HANA MARIAM - SARI ABO	4	3.8	900	900		0
73	LEGEHAR - RING ROAD VIS WINGET	6	10.2	2		2	0
74	CMC SQUARE - ADDIS KETEMA	6	14.2	9.5		9.5	2
75	SIDIST KILO - QERA	4	10.4	200	200		0
76	MEGENAGNA - KALITI	3	18.2	6.5		6.5	2
78	MEGENAGNA - GOFA CONDIMINIUM	3	12.4	5.6		5.6	2
79	ARAT KILO - SEMIT CONDIMINIUM	4	14.7	5.6		5.6	1
80	SEMEN GEBEYA SQUAR - MEGENAGNA	6	12.4	3.2		3.2	1
82	YERER SEFERA - BALCHA HOSPITAL	6	14.6	7.1		7.1	1
83	AYAT CMC SQ - SIDIST KILO	6	18	7.1		7.1	1
84	KOLFE EFOYTA - LEGEHAR	3	9.5	1.6		1.6	1



