

# **A Methodology for Bus Network Design**

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## **Abstract**

To provide transit agencies with a framework for bus route restructuring, this thesis develops a methodology for solving the bus network design problem (BNDP): determining the best bus route configuration and frequencies given bus transit demand, the street network, available resources, and operational constraints. It adopts a heuristic approach, focusing on route generation and frequency determination/vehicle allocation, encompassed in a single automated design procedure.

The proposed methodology improves upon previous BNDP heuristic approaches by (a) incorporating a fleet size constraint, (b) identifying major trip patterns and demand to guide in route design, and (c) solving the BNDP using either a general or transit center network design. This work develops a detailed route generation and vehicle allocation procedure.

Route generation is based on rudimentary route "skeletons" that are expanded into full routes. The algorithm continues to create new routes until vehicle resources are exhausted. Then the vehicle allocation process optimizes the assignment of buses to each route. Any surplus vehicles left after optimization are assigned to the network to improve service.

The thesis then applies the proposed methodology and automated design procedure to San Juan, Puerto Rico. When this work was published, the city had undertaken a bus restructuring effort with an emphasis on transit centers. Solutions produced by the proposed methodology are compared with the transit center plan.

## **Key Words**

Network design, bus, heuristic, transit center, vehicle allocation, route allocation, restructuring, frequency

## Introduction

This technical and theoretical thesis outlines a bus route design methodology for transit properties undertaking bus system restructuring. More specifically, it addresses the challenging Bus Network Design Problem (BNDP): Given information on bus transit demand, the street network, the available resources and operational constraints, how does an agency design the best possible network of bus routes and frequencies? Since an optimal solution to the BNDP is too complex to be feasible, the thesis adopts a heuristic approach that provides a "good" but not necessarily optimal solution. The thesis applies this methodology to the San Juan, Puerto Rico case study. Specifically, it tests the efficacy of two major bus system designs, the "general" and the "transit center" networks.

## Conclusions

This thesis arrives at a few key conclusions relating to the performance of the developed methodology:

- The route generation procedure is more likely to output a network that satisfies a large number of trips directly, without transfers.
- The vehicle allocation procedure can roughly estimate the equilibrium between passenger and vehicle assignments and determine the minimum number of buses required on each route to maintain a desired peak load factor.
- When applied to San Juan, the methodology achieved reasonable results. In the general network design, it produced a route structure similar to the old network that fits demand satisfactorily. In the transit center design, it generated a different route configuration with improved overall travel time without large losses in meeting travel demand.

## Background

Given that buses dominate most public transit systems, restructuring a bus network can significantly improve overall efficiency and increase ridership. Unfortunately, many transit agencies have not taken advantage of the flexibility of buses in response to shifting travel demands, growing automobile use, and greater suburbanization. In the face of declining or stagnant ridership, they have resorted to service cuts and fare hikes instead of pursuing potential customer markets through a system overhaul. This thesis aims to develop systematic procedures for network restructuring so that transit properties can better adapt to the travel needs of their service area.

## Methodology

This thesis begins with a literature review of current BNDP problem solving strategies. It briefly describes and evaluates six general ones, concluding that developing a strong heuristic approach will best accomplish research objectives. After creating a general outline for the proposed methodology, it explores route generation and vehicle allocation in detail.

For both route generation and vehicle allocation, the thesis provides a general overview and establishes the steps involved in the process. Route generation starts with a “skeleton” of initial routes and grows into a network, becoming refined through mathematical optimization. Vehicle allocation goes through a similar process, starting with assigning a base fleet and then a surplus fleet to the network. To unify the process, it describes how to integrate vehicle allocation with route generation.

Finally, it applies this bus network design process to the San Juan case study. At the time, San Juan was investigating the possibility of converting from a high connectivity but low frequency network to one based upon transit centers. The thesis tested the design process on both a “general” and transit center network, and contrasted the results with the existing and proposed system performance.

## Results

- Route Generation

The route generation process creates bus networks that provide fixed-schedule uncoordinated service along various route from a bus demand matrix and street network. The complexity of the process precludes any detailed description here; the actual document explains the concepts quite well. Figure 4.1b gives an overview of the strategies the thesis develops.

- Vehicle Allocation

The vehicle allocation strategy that aims to (a) ensure enough passenger capacity, and (b) minimize overcrowding along the busiest portion of any route. The heuristic solution includes a base and a surplus allocation strategy. Since the vehicle allocation solution is also complex, please refer to the actual thesis for details.

- Planning process

Figure 5.5 (attached) shows how to integrate the route generation and vehicle allocation processes into one.

- Application to San Juan Area

At the time of publication, San Juan was undertaking a comprehensive bus restructuring program to improve ridership and service efficiency. The thesis investigated a “general” and a “transit center” network, and contrasted them with the old and proposed system, respectively. In the case of a general network design, the methodology produced a solution that achieved an acceptable level of demand satisfaction and contained routes that are consistent with the trip-making patterns in the demand matrix. In the case of the transit center design, the methodology generated a considerably different route configuration without suffering from a large reduction in the total demand satisfied and with better overall travel time.

## Discussion

This thesis adopts a theoretical approach to bus planning. While its technical nature may sometimes make it difficult to conceptualize, it nevertheless provides a useful bus network design methodology. In particular, it maps abstract concepts to a real-world example, San Juan, fairly well. The relative success of the case study demonstrates that this methodology can provide guidelines for bus route restructuring. Of course, successful planning also includes careful attention to the specifics of a particular transit system and its service area.

As stated in the thesis introduction, many transit properties have not taken advantage bus flexibility in the service planning process. They have not responded well to major changes such as suburbanization. This thesis provides a good foundation for adapting a system to meet these challenges. More research in this area as well as in integration strategies for multimodal operations would clearly benefit the transit industry.

## Bibliography

Some resources date back one or more decades, but nevertheless serve as good references.

- Baaj, M. H. and Mahmassani, H. S., "An AI-Based Approach for Transit Route System Planning and Design", *Journal of Advanced Transportation*, Vol. 25, no. 2, pp. 187-210.

Presents a route generation heuristic as a single component in an artificial intelligence-based design procedure for solving the Bus Network Design Problem.

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- Lampkin, W. and Saalmans, P. D., "The Design of Routes, Service Frequencies, and Schedules for a Municipal Bus Undertaking: A Case Study", *Operations Research Quarterly*, vol. 18, no. 4, pp. 375-397, 1967

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- Multisystems Inc., "Comprehensive Bus and Público Plan," 1994.

Proposes a transit center network concept for San Juan, Puerto Rico.

- Shih, M. C. and Mahmassani, H., "A Planning and Design Model for Transit Route Networks with Coordinated Operations", prepared for the presentation at the Triennial Symposium on Transportation Analysis, Capri, Italy, July 1994

Presents a design methodology that would be capable of designing a bus network using the transit center concept, with the possibility of providing coordinated service at the transit centers.

Prepared by Jason Lee.

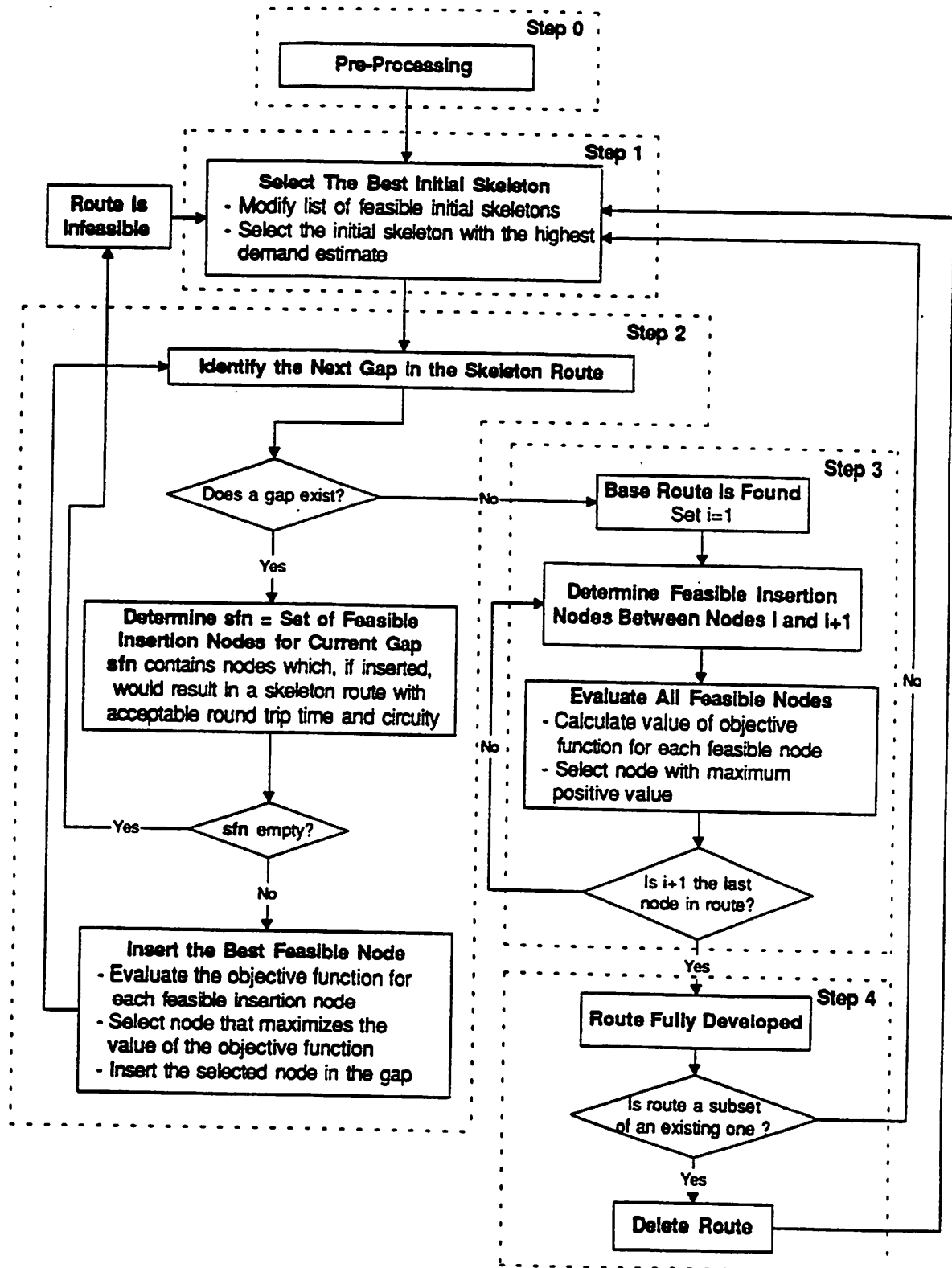


Figure 4.1b: The Single Route Generation Process

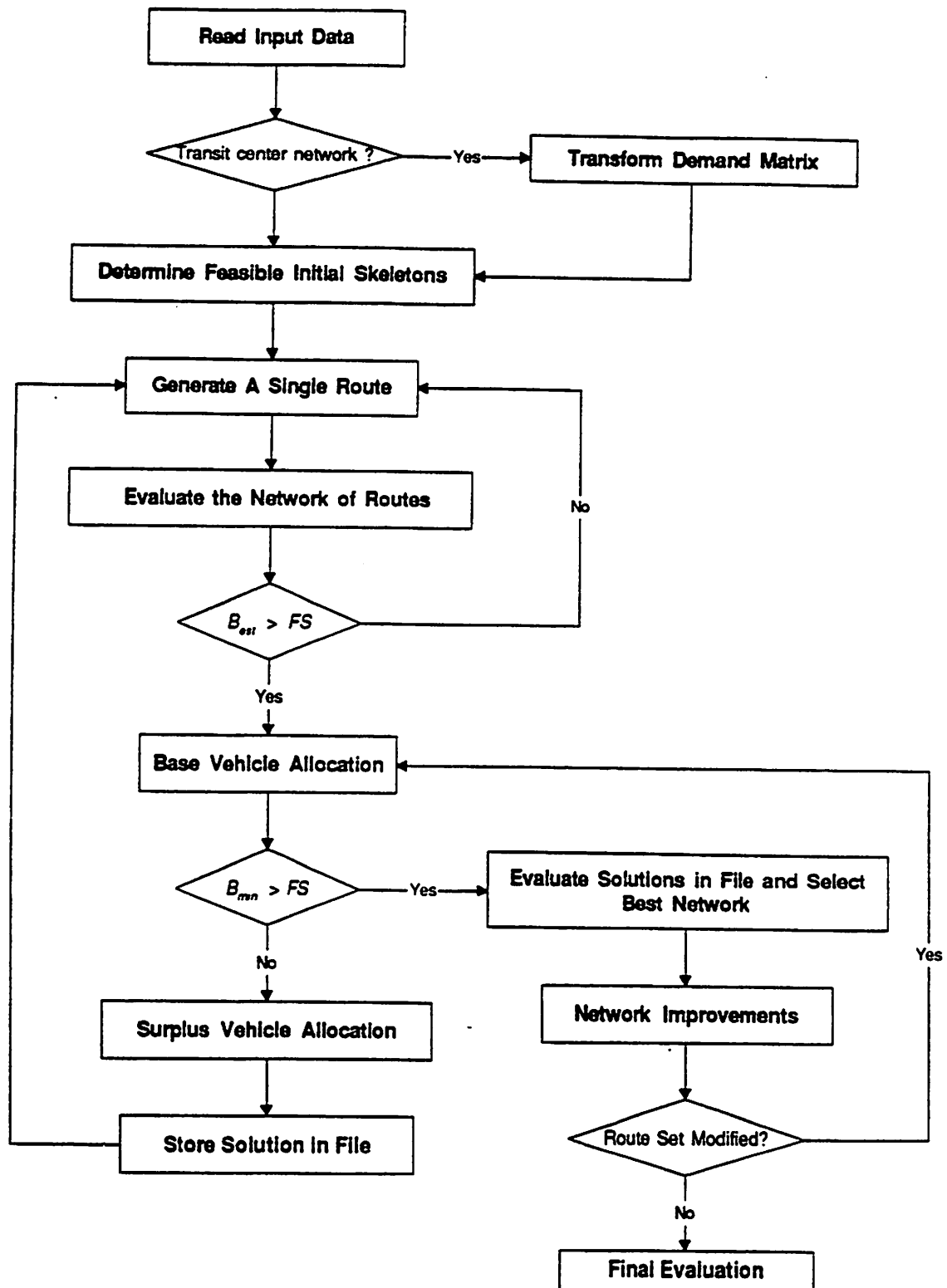


Figure 5.5: The Bus Network Design Process