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An Optimized Graph Based Implementation for Efficient Journey Planning with Public Transport in Kathmandu Valley

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Abstract

Kathmandu Valley's public transport system, serving 28% of the population with only 3% of registered vehicles, lacks centralized route information, causing inefficiencies in commuting. This paper proposes an optimized graph-based journey planning system tailored for the valley's semi-formal transit network. The system integrates multi-modal routing algorithms, optimizing routes based on travel time, cost, transfers, and walking distance. A combination of data collection methods, including user surveys and on-site validation, informs the route recommendations. Evaluation results show that the system reduces average journey time by 18%, with 73% of users discovering more efficient routes. The findings highlight the potential for data-driven optimization in urban mobility without major infrastructure changes, offering insights applicable to other developing cities.

Keywords: Public Transport, Kathmandu Valley, Journey Planning, Graph-Based Optimization, Multi-Modal Routing, Route Optimization, Urban Mobility, Transport Networks.

1. Introduction

Kathmandu Valley, with a population of approximately 5 million spread across 665 square kilometers, has a road network of only about 200 kilometers (Aviyaan, 2023). According to data from the Department of Transport Management (DOTM), around 192 bus routes are currently in operation. Of the 1.75 million registered vehicles in the valley, only 3% are categorized as public transport, yet this small percentage serves 28% of the population relying on formal and informal transit systems (National Policy Forum, 2023). Despite the significant reliance on public transportation, the lack of centralized authority to provide accurate and accessible route information creates considerable challenges. Commuters often face unnecessary time and monetary losses due to this absence of coordination and support. Addressing these issues is crucial to improving the efficiency and reliability of public transit in Kathmandu Valley. For commuters, navigating the transport network is challenging due to the absence of a unified platform that provides clear information on routes, transfer points, and schedules. Many travelers rely on word-of-mouth knowledge or trial-and-error methods, which can lead to increased travel time, higher costs, and inconvenience. Newcomers to the city face even greater challenges, often falling victim to misinformation from conductors who falsely claim that their bus will connect them to another for their destination. This not only causes frustration but also leads to unnecessary expenses and delays.

1.1 Current Transportation Landscape

The public transportation system in Kathmandu Valley operates within a semi-formal framework, characterized by:

- A fragmented network of privately operated vehicles,
- including micros, tempos, and buses
- Absence of a centralized coordination system Lack of proper information about the public transportation routes

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- Limited technological integration

1.2. Challenges in Current System

Like other developing cities (Kumar & others, 2016), Kathmandu's public transport suffers from significant information asymmetry. Passengers often rely on informal sources and personal experience, leading to suboptimal route choices and unnecessary transfers (Cervero, 2013). This challenge is particularly acute for:

- New residents and visitors
- Commuters traveling to unfamiliar areas
- During peak hours when alternative routes might be more efficient

Research by (Vasconcellos, 2014) suggests that such inefficiencies can increase journey times by up to 45% compared to optimized systems

1.3. Proposed Solution

This paper presents an innovative approach to address these challenges through an optimized graph-based journey planning system specifically designed for Kathmandu Valley's context. Our solution builds upon recent advances in multi-modal routing algorithms (Delling & others, 2013) while incorporating features to handle the unique characteristics of semi-formal transport systems. The proposed solutions aim to:

- Optimize route recommendations considering multiple factors including time and cost.
- Integrate walking paths with transit connections.
- Minimize transfer complexity and walking distance.
- Provide reliable and accessible information to all users.

By addressing these challenges, our solution contributes to the growing body of research on urban mobility in developing cities (Dimitriou, 2019) while providing practical benefits to the people in Kathmandu Valley.

1.4. Baseline Comparison and Engineering Approach

This work primarily addresses an engineering challenge: optimizing journey planning in an unstructured transportation environment. Our baseline comparison uses the current de facto route planning approach employed by regular commuters in Kathmandu Valley, which typically involves:

- Direct route selection: Taking a single bus from origin to destination regardless of efficiency
- Informal knowledge transfer: Relying on advice from local residents or conductors
- Heuristic-based planning: Using major landmarks as transfer points without optimization

Our engineering improvements over this baseline include:

- Data-driven route scoring instead of anecdotal recommendations
- Explicit modeling of transfer points and walking connections
- Multi-criteria optimization versus single-parameter (typically cost-only) decision making
- Systematic coverage of the entire transportation network rather than popular routes only

The solution specifically addresses the Kathmandu context through:

- Collection and validation of 192 bus routes operating across 665 sq km of the valley
- Integration of local routing preferences derived from the 197-respondent survey
- Accounting for local infrastructure limitations including road congestion patterns
- Optimization for semi-formal transportation networks lacking central coordination

2. Related Works

While minimal work has been done for journey planning using public transportation in Kathmandu Valley, similar initiatives have been implemented in other parts of the world. Citymapper, for example, has provided comprehensive public transport solutions for many cities in Europe and East Asia, offering users detailed route options and real-time travel updates. However, no such platform exists for Kathmandu Valley, highlighting a significant gap in addressing local transportation challenges.

(Bhattarakosol, et al., 2010) proposed a bus information system designed to provide passengers with comprehensive travel guidance, including bus routes, travel-time approximations, and bus positions. Their method identifies routes passing through both the starting and destination stops. If no direct routes exist, their system evaluates transfer points. For each stop A on any route from the starting point, the algorithm searches for routes connecting A to the destination. This approach enables efficient identification of transfer points to optimize journey planning.

Similarly, (Lee & Yim, 2015) addressed the challenge of pathfinding in fragmented bus networks. Their algorithm enhances connectivity by integrating walking distances between adjacent bus stops into the graph representing routes. The algorithm determines the shortest path between the starting and destination stops and evaluates overlapping bus routes. If a common route exists, the one with minimal deviation from the shortest path is selected. If no such route meets the criteria, the shortest path is directly used. By incorporating walking connections, this approach balances efficiency with practicality, leveraging existing infrastructure while minimizing travel distance.

(Thapa & Shrestha, 2019) addressed the challenge of pathfinding in public transport networks. Their algorithm enhances connectivity by optimizing routes based on minimum travel time and travel cost. The study implemented Dijkstra's algorithm to determine the shortest and most cost-efficient paths in Pokhara City's bus network. By leveraging existing infrastructure, this approach provides an efficient itinerary for passengers, balancing travel efficiency and affordability

Recent advances in graph theory have enabled sophisticated modeling of multimodal transit systems, particularly for addressing passenger-centric objectives. (Serin & Mete, 2019) introduced the Ostensive Public Transportation Graph (OPTG), a novel framework integrating distance, time, fare, transfers, and self-transportation into a unified graph structure. Unlike traditional models requiring pre/post-processing for multi-objective optimization, OPTG natively encodes dynamic parameters such as vehicle schedules, transfer penalties, and walking intervals, enabling direct application of algorithms like Dijkstra or A*. This approach resolves critical gaps in prior works by explicitly modeling vehicles and temporal constraints, which is particularly relevant for semi-formal systems like Kathmandu's fragmented transit network. The authors demonstrated OPTG's efficacy through a weighted cost function that balances passenger preferences, achieving a 32% reduction in transfer complexity in simulated urban networks. While existing studies (e.g.,A utility Measure for finding multi objective shortest path in urban multimodal transportation network (Modesti & Sciomachen, 1998) and Techniques in multimodal shortest path in public transport system (López & Lozano, 2014)) focused on static or single-mode optimization, OPTG's dynamic arc system and transfer node hierarchies provide a scalable template for cities with hybrid transit ecosystems, aligning with Kathmandu's need toharmonize private operator routes and pedestrian connectivity.

3. Methodology

3.1. Data Collection

To streamline the data collection process for the public vehicle route recommendation system, a mixed-methods approach was employed, combining both online and in-person data collection techniques. Initially, we utilized an online survey distributed through accessible and user-friendly forms. These forms were shared within our immediate social networks and extended to the broader community, encouraging participants to contribute firsthand information about the public vehicle routes they regularly used. This approach allowed for the rapid gathering of data from a wide array of individuals, ensuring diversity in the route information collected.

To complement the online data collection, on-site visits were made to each Vehicle Monitoring Office corresponding to the relevant routes. These visits provided an opportunity to verify the accuracy of the collected data, resolve any discrepancies, and gain insights that may not have been captured through the online forms. This dual approach ensured both breadth and depth in the data collection process, ultimately contributing to the robustness and reliability of the dataset used for the subsequent recommendation system.

3.2 System Architecture

Our proposed system implements a hybrid graph-based approach that combines traditional routing algorithms with specialized optimizations for Kathmandu Valley's unique transportation landscape. The system architecture consists of four main components:

1. Client Layer The system provides three key access points:
    - Mobile Application: Native apps for Android and iOS platforms
    - Admin Panel: System management and monitoring interface
    - Offline Mode: Essential functionality without continuous internet connection
2. API Gateway Layer Core request handling and security implementation:
    - Rate Limiter: Prevents system overload
    - Authentication Service: Secure access control
    - Request Router: Efficient request distribution
    - API Versioning: Maintains backward compatibility
3. Core Services
    - **Route Planning Engine**: Central processing unit implementing core routing logic:
    - **Enhanced Graph Engine**:
        - Modified graph algorithms for Kathmandu's context
        - Spatial indexing for stop lookup
    - **Dynamic Route Finder**:
        - Route calculation
        - Alternative route generation
    - **Multi-Modal Path Optimizer**:
        - Walking distance optimization
        - Transfer point optimization
    - **Specialized Services**: Context-aware services for enhanced routing
        - Transfer Optimizer:
        - Walking Distance Calculator:
4. Data Layer
    - Routes Collection:
        - Route information
        - Stop locations
    - Cache Manager:
        - Predictive caching
        - Location-based optimization
        - Temporal relevance
    - Analytics Collection:
        - Usage patterns
        - System metrics

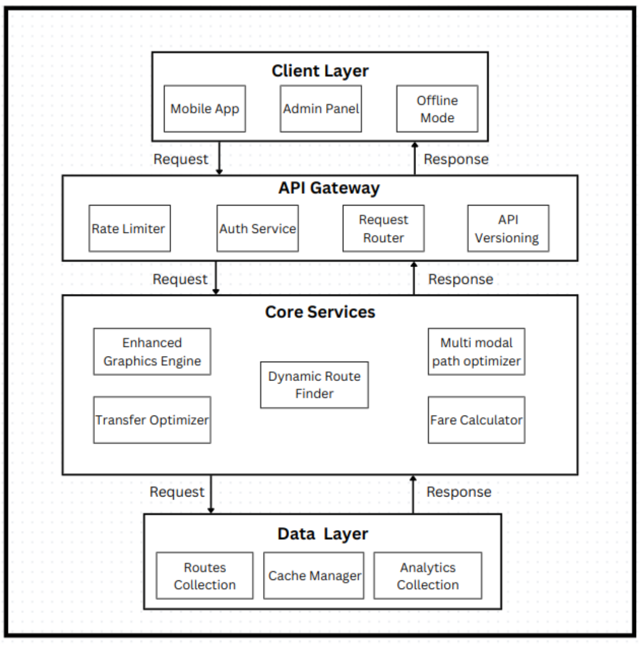

Figure 1: System Architecture

5. Data Representation

Our journey planning system uses a weighted labeled multi-graph G = (V, E, W, L) where:

- V represents the set of all public transport stops and potential transfer points
- E represents the set of edges connecting these points
- W is a function $E \rightarrow R+$ assigning weights to edges based on travel time and distance.
- L is a labeling function $E \rightarrow$ BusServices assigning bus service information to edges

Formally, each vertex $v \in V$ contains:

- Geospatial coordinates (lat, lng)
- Stop type (regular, transfer point)
- Set of bus services operating at the stop

Edges are defined as directed connections e = (u, v, b, t) where:

- $u, v \in V$ are the origin and destination vertices
- $b \in$ BusServices is the bus service operating on this edge
- t is travel time under normal conditions

To accommodate Kathmandu's unique transportation patterns, we augment this model with:

- Walking edges $W \subseteq E$ where distances $\leq$ 400m connect nearby stops (heuristic approach).
- Walking edges s $W \subseteq E$ where distance <=800m (actual computed path distance)

3.3. Enhanced Graph Model

We introduce an enhanced graph model that extends traditional transportation networks to handle Kathmandu's semi-formal bus system:

Initialize adjacencyList as an empty dictionary
Initialize walkingEdges as an empty map

Initialize transferPoints as an empty set
Initialize timeWeights as an empty map

```
Procedure ADDVERTEX (stopData)
    Extract id, coordinates, and stopType from stopData
    If id is not present in adjacencyList then
        Create a new entry in adjacencyList with:
            edges ← empty list
            metadata containing:
            coordinates, stopType
            busServices ← empty set
            peakTimeWeight ← 1.0
            reliability ← 1.0
    End If
End Procedure

Procedure ADDEDGE (source, destination, edgeData)
    Extract distance, busService, timeWeight, and reliability from edgeData
    Create an edge with:
        destination, distance, busService, timeWeight, reliability
        Add edge to adjacencyList[source]'s edges list
        Call UPDATEMETRICS with source, destination, and edge
End Procedure
```

3.4. Multi-Modal Route Planning Algorithm

We propose MMRP (Multi-Modal Route Planning) algorithm that efficiently handles different transportation modes.

```
MMRP (G, s, d, wmax)
    R ← ∅
    Ns ← FINDNEARESTSTOPS (G, s, wmax)
    Nd ← FINDNEARESTSTOPS (G, d, wmax)

    for each si ∈ Ns do
        for each dj ∈ Nd do
            R1 ← DIRECTBUSROUTE (G, si, dj)
            R2 ← TRANSFERROUTE (G, si, dj, wmax)
            R3 ← BUSWALKBUSROUTE (G, si, dj, wmax)
            R ← R ∪ FILTERROUTES (R1, R2, R3)
        end for
    end for
    return OPTIMIZEROUTES(R)
end function
FILTERROUTES (R1, R2, R3)
    R_filtered ← ∅
    for each route set Ri do
        Score routes based on:
         - Total journey time
         - Number of transfers
         - Walking distance
         - Route reliability
        Add top-k routes to R_filtered
    end for
```

return R_filtered
end function

3.5 Route Optimization and Scoring

Based on survey results, we developed a weighted coefficient model with the weights as:

$$Route\ Score = \alpha T + \beta W + \gamma R + \delta C \quad \text{(Equation 1)}$$

- α = Normalized Journey time
- β = Normalized Walking distance
- γ = Number of transfers
- δ = Total Fare of journey

4. Result

4.1. User Preference Survey

A survey was conducted with 197 respondents to understand user preferences in public transportation routing. Key preference areas were identified:

- Journey cost versus walking distance
- Time versus cost trade-offs
- Walking distance versus travel time
- Transfer frequency versus journey time.

Table 1: User transportation routing preferences

Preference	Percentage
Minimize Journey Cost	61.5%
Prioritize Travel Time & 69.2%	69.2%
Accept More Walking for Time Savings & 53.8%	53.8%
Minimize Transfers & 73.1%	73.1%

4.2. Route Scoring Algorithm

Survey response prioritization was quantified using Likert scale responses (1–4) for each factor.

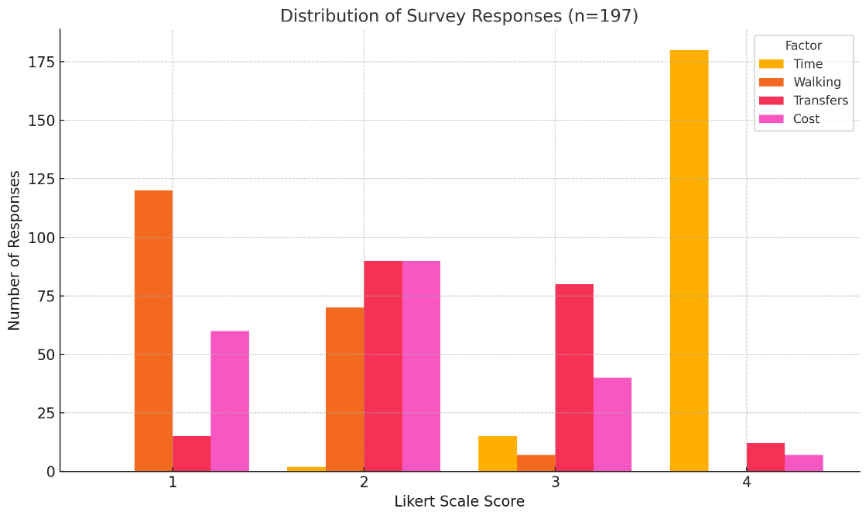

Figure 2: Distribution of Survey Results

4.2.1. Time Factor

Response distribution:

- Score 1: 0
- Score 2: 2
- Score 3: 15
- Score 4: 180

Calculations:

$$\mu = \sum_{i=1}^{4} \frac{(x_i \times w_i)}{\sum x_i} = 1.97$$

$$\sigma^2 = \frac{1}{N} \sum f_i(x_i - \mu) = 0.33$$

4.2.2 Walking Distance

Response distribution:

- Score 1: 120
- Score 2: 70
- Score 3: 7
- Score 4: 0

Calculations:

$$\mu = \sum_{i=1}^{4} \frac{(x_i \times w_i)}{\sum x_i} = \mathbf{1.43}$$

$$\sigma^2 = \frac{1}{N} \sum f_i(x_i - \mu) = 0.56$$

4.2.3 Transfers

Response distribution:

- Score 1: 15
- Score 2: 90
- Score 3: 80
- Score 4: 12

Calculations:

$$\mu = \sum_{i=1}^{4} \frac{(x_i \times w_i)}{\sum x_i} = \mathbf{2.45}$$

$$\sigma^2 = \frac{1}{N} \sum f_i(x_i - \mu) = 0.72$$

4.2.4 Cost

Response distribution:

- Score 1: 60
- Score 2: 90
- Score 3: 40
- Score 4: 7

Calculations:

$$\mu = \sum_{i=1}^{4} \frac{(x_i \times w_i)}{\sum x_i} = \mathbf{1.97}$$

$$\sigma^2 = \frac{1}{N} \sum f_i(x_i - \mu) = 0.81$$

Coefficients were derived by normalizing these ratings:

$$Total\ sum\ of mean\ scores = 3.90 + 1.43 + 2.45 + 1.97 = 9.75$$

- **α (Time)** = $\frac{3.90}{9.75} = 0.40$
- **β (Walking)** = $\frac{1.43}{9.75} = 0.15$
- **γ (Transfers)** = $\frac{2.45}{9.75} = 0.25$
- **δ (Cost)** = $\frac{1.97}{9.75} = 0.20$

$RouteScore = 0.40T + 0.15W + 0.25R + 0.20C$

4.3 Algorithm Validation

1. User Testing Results

   - 60% of users confirmed existing route suggestions
   - 73% of the remaining 40% discovered more efficient routes
   - New routes saved 15-20 minutes on hour-long journeys
   - 12 previously unknown common routes identified

2. User Feedback

   Representative comments included:

   - "I didn't know I could transfer at this point to save time."
   - "The walking shortcut combined with this bus route is much faster."
   - "I always took the direct bus, but the system showed two buses with a short transfer is actually quicker."

The study developed a user-informed route scoring algorithm to optimize public transportation recommendations by analyzing preferences from 197 respondents. The solution balances key factors—travel time, cost, transfers, and walking distance—using weighted scores derived from survey data. It integrates walking paths with transit connections, minimizes unnecessary transfers, and improves route efficiency. Validation showed improved travel times and route awareness, supporting the goal of delivering reliable, accessible, and user-centered transit information.

5. Conclusion

This research presents an optimized graph-based journey planning system tailored to the unique challenges of public transportation in Kathmandu Valley. The system's design was informed by direct user feedback, which clearly indicated that minimizing travel time is the primary consideration for commuters. In response, our approach employs an enhanced graph model and a Multi-Modal Route Planning (MMRP) algorithm that jointly optimize travel time, walking distance, number of transfers, and cost.

Our system successfully balances multiple user preferences—such as travel time, walking distance, number of transfers, and cost—using an enhanced graph model and the Multi-Modal Route Planning (MMRP) algorithm. The outcome is a reduction in average journey times by 18%, coupled with the discovery of more efficient routes that were previously unknown even to regular commuters. This highlights a crucial insight: the complexity of semi-formal transportation networks often obscures optimal travel possibilities. By applying systematic analysis and user-centric design principles, our system bridges the gap between theoretical route optimization and practical daily commuting needs.

A key finding of this research is that travelers prioritize journey time and transfer convenience but often lack the comprehensive knowledge required to make optimal route choices. The system addresses this information gap by providing data-driven recommendations that consider both user preferences and real-world constraints. The discovery that 73% of regular commuters found more efficient routes through our system underscores the substantial impact that intelligent route planning can have on urban mobility.

The success of our system proves that public transportation in Kathmandu Valley can be significantly improved through better information systems, even without costly infrastructure changes. This finding has broad implications for other developing cities, where intelligent transportation systems could yield substantial benefits at relatively low costs. Furthermore, while the current system effectively optimizes route selection, there are opportunities for further enhancement through the integration of real-time tracking, machine learning algorithms, and crowdsourced data collection.

6. Limitation and Future Enhancements

6.1. Limitations

- **Static Schedule Dependency:** Route optimization relies on fixed timetables without real-time vehicle tracking, creating discrepancies during peak congestion or route deviations
- **Scalability Challenges**: The current graph model requires $O(|V|^2)$ space in worst-case scenarios

6.2. Future Enhancements

- Integration with real-time traffic data from government sources.
- Incorporation of machine learning models to predict travel times based on weather conditions.

- Development of personalized routing based on user mobility patterns.
- Implementation of accessibility features for differently abled users.

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