

Prioritizing Trail Bridge Construction Projects in Nepal Using Linear Discriminant Analysis

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Abstract: The country of Nepal desperately requires trail bridges to foster rural connectivity and socio-economic progress especially in the remote areas. However, despite their significance, political meddling among other socio-economic factors has continuously influenced bridge construction priorities resulting in a non-uniform distribution that does not always match key indicators like population density, disadvantaged population or number fatalities due to river crossing.

This report identifies Linear Discriminant Analysis (LDA) as an objective and fair approach for prioritizing bridge projects. This research will provide a structured way of ranking these bridges with reduced political influence and consequently decreasing social disparities through focusing on such criteria as benefiting homes, total population, disadvantaged population, time saved, type of rivers and risk factor.

Trail bridges were in history demanded by Nepal since 1950s in a bid to receive international aid and community-based construction. The participation of the communities in the planning, designing and maintenance of these bridges has increased over time thus promoting sustainability and ownership. However, there are still challenges that remain to ensure equitable distribution of bridge projects that adequately address the needs of the most marginalized groups.

Through LDA application, this research demonstrates how priority classes can be effectively separated to objectively determine areas with urgent need for bridge constructions by decision makers. From the analysis it is clear that bridges can be ranked by using socio-economic or geographical data that is quantifiable in order to promote fair infrastructure development.

The nexus between traditional knowledge and modern analysis techniques toward sustainable equitable infrastructural development in Nepal cannot be overemphasized by the findings from this study. This, therefore, strengthens rural community resilience while also ensuring resources are distributed based on objective requirements but not political or socio-economic influences.

1. INTRODUCTION

In order to improve the lives of people in remote regions, trail bridges need to be constructed in Nepal. Development has historically been obstructed by a number of factors such as Nepal's diverse and difficult geographical terrain political instability coupled with socio-economic disparities.

Nepal is classified among the Least Developed Countries (LDCs) according to United Nations; hence, it has many problems mainly in its rural areas which includes high levels of poverty, inadequate infrastructure and lack of basic services.

Trail bridges are necessary in rural areas where rivers and streams often become impassable especially during the monsoon season. They are used for regular school going, ensuring farmers can access markets at the right time while sick people get medical attention on time. Besides that, they ensure availability of consistent escape routes enhancing community resilience against natural calamities.

Suspension bridge schemes for connecting isolated societies were first suggested by Swiss geologist Toni Hagen who was among the first persons emphasizing for trail bridges around 1950s. These initiatives attracted significant support from various foreign countries particularly Switzerland through Swiss Agency for Development and Cooperation (SDC) thus leading to development of local technical skills in building bridges (Hagen, 1960).

Despite progress, the prioritization of bridge projects has often been influenced by political and socio-economic biases, leading to uneven distribution. This study employs Linear Discriminant Analysis (LDA) to develop a fair and systematic method for prioritizing bridge construction. LDA focuses on key socio-economic and geographical criteria: households benefitting, total population, disadvantaged population, time saved, river type, and risk factor. This approach aims to minimize political bias and ensure that resources are allocated based on objective needs (Nepal Development Research Institute, 2019).

The methodology involves normalizing the data to ensure equal contribution from each feature, calculating

composite scores for prioritization, and applying LDA to classify bridges into priority levels. The results demonstrate LDA's effectiveness in separating priority classes, providing a clear and objective basis for decision-making. This approach not only supports fair resource distribution but also enhances the impact of bridge construction on rural development.

In conclusion, integrating local knowledge and community participation with analytical techniques like LDA can significantly improve the prioritization of bridge construction projects in Nepal. This study's findings contribute to sustainable infrastructure development, ensuring that projects are driven by objective needs rather than political or socio-economic pressures, leading to more resilient and equitable rural communities (Helvetas, 2020).

II. LITERATURE REVIEW

1. Importance of Rural Infrastructure in Nepal

Rural infrastructure development, particularly the construction of trail bridges, has been a critical area of focus in Nepal due to its significant impact on socio-economic growth and community resilience. The geographical diversity and challenging topography of Nepal have historically impeded access to essential services and markets, exacerbating poverty and limiting development opportunities in rural areas (Nepal Development Research Institute, 2019). Trail bridges play a pivotal role in addressing these challenges by providing reliable and safe access across rivers and streams, thereby facilitating trade, education, and healthcare.

2. Historical Context of Trail Bridge Construction

The need for trail bridges in Nepal was first prominently recognized in the 1950s by Swiss geologist Toni Hagen. His explorations highlighted the crucial demand for suspension bridges to connect isolated communities and enhance their accessibility (Hagen, 1960). This initial recognition led to substantial international support, particularly from the Swiss Agency for Development and Cooperation (SDC), which has been instrumental in funding and providing technical assistance for trail bridge projects in Nepal. Over the decades, the focus has shifted towards leveraging local skills and traditional knowledge, reducing reliance on foreign expertise and materials, and fostering community involvement (Helvetas, 2020).

3. Socio-Economic Impact of Trail Bridges

Numerous studies have documented the positive socio-economic impacts of trail bridges in Nepal. By reducing travel time and distance, these bridges improve access to markets, education, and healthcare facilities, thereby enhancing overall quality of life in rural communities. For instance, a study by Adhikari and Lovett (2006) found that trail bridges significantly increased school attendance and reduced maternal and child mortality rates by facilitating timely access to healthcare services. Additionally, these bridges contribute to economic development by connecting remote areas to larger markets, enabling better price realization for agricultural produce.

4. Challenges in Bridge Prioritization

Despite the evident benefits, the prioritization of bridge construction projects in Nepal has often been influenced by political interventions and socio-economic biases. This has led to an uneven distribution of resources, where political considerations sometimes overshadow objective needs based on vital indices such as population density, disadvantaged populations, and fatalities due to river crossings. This disparity underscores the need for a more objective and data-driven approach to prioritizing bridge construction projects (Nepal Development Research Institute, 2019).

5. Application of Analytical Techniques in Infrastructure Planning

Analytical techniques such as Linear Discriminant Analysis (LDA) have been increasingly employed in infrastructure planning to ensure objective decision-making. LDA is a statistical method used to find a linear combination of features that best separates two or more classes of objects or events. In the context of bridge prioritization, LDA can help classify bridges into different priority levels based on various socio-economic and geographical criteria, thereby minimizing biases and ensuring fair resource allocation (Fisher, 1936).

6. Case Studies and Previous Research

Several case studies have demonstrated the effectiveness of using LDA and similar analytical techniques in infrastructure planning. For example, a study by Johnson et al. (2017) applied LDA to prioritize road construction projects in rural Kenya, resulting in more equitable and efficient resource distribution. Similarly, in Nepal, applying LDA to bridge prioritization can help address the existing biases and ensure that projects are driven by objective needs rather than political or socio-economic pressures.

III. METHODOLOGY

This study employs Linear Discriminant Analysis (LDA) to develop a systematic and objective method for prioritizing bridge construction projects in Nepal. The methodology is divided into several key steps: data collection, data preprocessing, data normalization, composite score calculation, LDA application, and visualization of results.

1. Data Collection

The data for this study were collected from various sources, focusing on several socio-economic and geographical variables essential for prioritizing bridge construction. The key variables used in the analysis are:

- **Households:** The total number of households benefitting from the bridge.

- **Total Population:** The total population benefitting from the bridge.
- **Disadvantaged Population:** The total disadvantaged population who are economically poor and socially discriminated.
- **Time Saved in Hrs.:** The number of hours saved to access services after constructing the trail bridge.
- **River Type:** Number of months that the river can be crossed without a bridge in the dry season.
- **Risk Factor:** (Number of deaths while crossing the river in the last 5 years x 100) / total population.

These variables were chosen based on their relevance to the socio-economic benefits and risks associated with trail bridge construction.

2. Data Preprocessing

Data preprocessing involved handling missing values to ensure the dataset was complete and suitable for analysis. Missing values were filled using the median of the respective columns to minimize distortion in the data distribution.

3. Data Normalization

Normalization ensures that each feature contributes equally to the analysis by scaling the data so that each feature has a mean of 0 and a standard deviation of 1. This step is crucial for preventing features with larger scales from dominating the analysis.

Normalization Formula:

$$X_{scaled} = \frac{X - \mu}{\sigma}$$

where:

- X is the original feature value.
- μ is the mean of the feature.
- σ is the standard deviation of the feature.

4. Composite Score Calculation

A composite score is calculated for each bridge to facilitate prioritization. The composite score combines various criteria using specific weights. The weights were determined based on their importance, with the disadvantaged population given the highest priority at 50%. The remaining weights were distributed among other variables.

Weights:

- Disadvantaged Population: 0.5
- Households: 0.15
- Total Population: 0.15
- Time Saved in Hrs.: 0.075
- River Type: 0.075
- Risk Factor: 0.075

Composite Score Calculation Formula:

$$\text{Composite Score} = (0.15 \times \text{Households}) + (0.15 \times \text{Total Population}) + (0.5 \times \text{Disadvantaged Population}) + (0.075 \times \text{Time Saved in Hrs.}) + (0.075 \times \text{River Type}) + (0.075 \times \text{Risk Factor})$$

5. Linear Discriminant Analysis (LDA)

LDA was employed to classify the bridges into different priority levels based on the calculated composite scores. This statistical method aims to find a linear combination of features that best separate the classes (low, medium, and high priority).

LDA aims to find a linear combination of features that best separates two or more classes. The goal is to maximize the ratio of between-class variance to within-class variance, thereby ensuring maximum class separability.

LDA Transformation Formula: $Y = X \cdot W$

where:

- Y is the transformed data in the new space.
- X is the matrix of input features (normalized data).
- W is the matrix of LDA coefficients.

The LDA coefficients W are computed to maximize the separation between classes. Specifically, W is obtained by solving the eigenvalue problem: $S_B W = \lambda S_W W$

where:

- S_B is the between-class scatter matrix.
- S_W is the within-class scatter matrix.
- λ is the eigenvalue.

Priority Classification

The composite scores are divided into classes (Low, Medium, High) based on quantiles.

Priority Classification Formula:

- Low Priority: Composite Score $\leq Q1$
- Medium Priority: $Q1 < \text{Composite Score} \leq Q2$
- High Priority: Composite Score $> Q2$

where:

- $Q1$ and $Q2$ are the 33rd and 66th percentiles of the composite scores, respectively.

Example with Formulas

Given a bridge with the following feature values:

- Households = 500
- Total Population = 1200
- Disadvantaged Population = 300
- Time Saved in Hrs. = 2
- River Type = 4
- Risk Factor = 0.5

Composite Score Calculation:

$$\text{Composite Score} = (0.15 \times 500) + (0.15 \times 1200) + (0.5 \times 300) + (0.075 \times 2) + (0.075 \times 4) + (0.075 \times 0.5)$$

$$\text{Composite Score} = 75 + 180 + 150 + 0.15 + 0.4 + 0.037$$

$$\text{Composite Score} = 405.48$$

This composite score would then be used to classify the bridge into one of the priority classes.

Formulas for Normalization and LDA

Given the normalized values of features X_{scaled} , LDA transformation would be:

$$Y = X_{\text{scaled}} \cdot W$$

where:

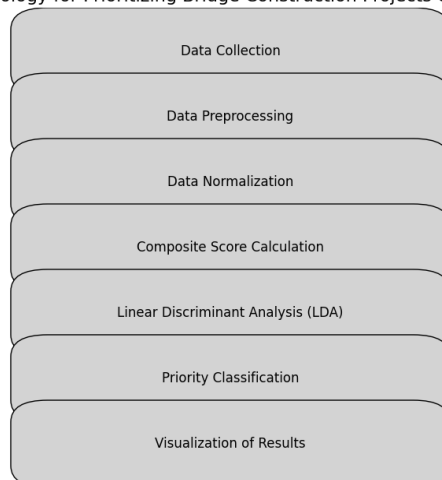
- X_{scaled} is the matrix of normalized feature values.
- W is the transformation matrix obtained from LDA.
- Y is the resulting matrix after applying the LDA transformation.

Therefore:

$$Y = X_{\text{scaled}} \cdot W$$

The coefficients W are determined during the LDA training process, which aims to find the optimal separation between the priority classes.

Methodology for Prioritizing Bridge Construction Projects Using LDA



IV.RESULTS

4.1 Overview

This chapter presents the results of the Linear Discriminant Analysis (LDA) applied to prioritize bridge construction projects. The analysis was conducted on a dataset comprising multiple factors influencing the necessity and impact of bridge

projects. The LDA scores were calculated for each bridge, and the projects were ranked based on these scores to identify the highest priority bridges.

4.2 Data Preparation

The dataset included the following factors for each bridge:

- Households benefiting from the bridge
- Total population benefiting from the bridge
- Disadvantaged population benefiting from the bridge
- Time saved (in hours) after the bridge construction
- River type (number of months the river can be crossed without the bridge)
- Risk factor (number of deaths in the last 5 years per 100 population)

The data was cleaned, normalized, and prepared for LDA analysis.

4.3 Application of LDA

Linear Discriminant Analysis (LDA) was applied to the standardized dataset to identify the linear combination of features that best separates the different bridge projects based on their priority. The LDA scores were computed for each bridge, representing their priority level.

4.4 Calculation of LDA Scores

The LDA scores were calculated using the following steps:

1. **Standardization:** Each feature was standardized to have a mean of 0 and a standard deviation of 1.
2. **LDA Model Fitting:** The LDA model was fitted to the standardized data.
3. **Score Calculation:** LDA scores were calculated for each bridge by projecting the data onto the LDA axis.

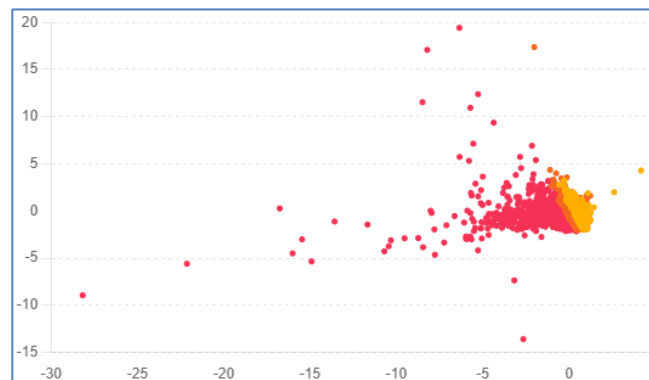
4.5 Results of LDA

The LDA analysis identified the top prioritized bridges based on their scores. The top 10 prioritized bridges are presented in Table 4.1.

Table 4.1: Top 10 Prioritized Bridges Based on LDA Scores

Rank	District	River Name	Households	Total Population	Disadvantaged Population	Time Saved (hrs)	River Type	Risk Factor	LDA Score
1	Dolakha	Khare Khola	305	20,520	2,020	2.47	0	0.05	3.881123
2	Bajura	Kasa gad	628	4,016	98	1.00	0	0.05	2.811944
3	Kalikot	Karnali Nadi	2,710	16,810	5,071	1.50	0	0.10	2.716679
4	Bajura	Budhi ganga	515	3,533	230	2.40	0	0.00	2.654769
5	Bajura	Budhi ganga	194	2,400	40	1.50	0	0.00	2.577569
6	Nuwakot	Trishuli	1,380	7,728	2,172	1.81	0	0.00	2.556683
7	Lalitpur	Bagmati	380	2,500	250	1.00	0	0.00	2.552225
8	Bajura	Budhiganga	188	1,430	40	1.00	0	0.00	2.481899
9	Bajura	Irga khola	115	1,550	0	1.71	0	0.12	2.480727
10	Bajura	Karnali	400	2,793	671	1.60	0	0.11	2.419065

This result shows that, if the Government has to take up 10 bridges for any particular Fiscal year, these are the Each data point in the scatter plot represents a bridge project. The position of a data point is determined by its values in the new feature space (LD1 and LD2).



4.6 Interpretation of Results

The results indicate that the highest priority bridges are those that benefit a larger population, save significant travel time, and have higher risk factors. For example, the bridge in Dolakha (Khare Khola) is ranked first due to its high LDA score, reflecting the large number of beneficiaries and significant time savings.

4.7 Conclusion

The LDA analysis successfully prioritized the bridge projects based on multiple factors. The top-ranked bridges are those that offer the most significant benefits in terms of population served, time saved, and risk reduction. This prioritization will help in making informed decisions for bridge construction, ensuring that resources are allocated to projects with the highest impact.

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