# OPTIMISING PUBLIC TRANSPORT FOR REDUCING EMPLOYMENT BARRIERS AND FIGHTING POVERTY

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## ABSTRACT

Alleviating poverty in low-income and developing nations is integral to social stability, attracting investments and generating employment opportunities which in turn elevate people's well-being. Employment could be encouraged through a combination of direct (travel time and training) and indirect measures (social institutions like childcare and elder care). Other factors such as legal reform and infrastructure services could help as well. Transit is perhaps the first element (but not the only one) required to provide better access to the labor market, to health and educational facilities and to social institutions. Transit should be cheap, fast, safe, and secure to reach to most travelers within the influence area. The main objective of this research is to propose a method to fight poverty through better access to employment by a proactive cost-effective planning of investments in existing and future public transit systems. A decision-making system is developed to assess the current employment situation in different geographical regions considering unemployment rate, access to jobs and public transportation systems. Real data from a case study of the Costa Rica metropolitan area is used to illustrate the applicability of the proposed approach. The results show that the proposed model can lead governments to a cost-effective solution that decreases the employment barrier index by more than 50% during the first 5 years. The proposed model will be beneficial for transit agencies in charge of BRT, Tramway, and suburban trains.

*Keywords: Poverty, Employment, Sustainable Development, Transportation Asset Management.*

## 1 INTRODUCTION

Fighting poverty in developing nations is integral to sustainable development, social stability, and people's well-being. However, it requires a multidisciplinary integrated approach that addresses the many dimensions of this problem; including legal issues, the vulnerability of informal settlements, the inadequacy of infrastructure/transportation services, and deficient social support institutions as well as the inability of governments to reverse and fix the situation. Improper urban planning results in deficient community development with informal settlements [1] often in sites vulnerable to flooding or landslides [2], commonly through fragile housing located in remote places with poor transportation, and no social support institutions or recreational facilities [3]. As such, poverty cannot be tackled solely with the creation of jobs. It rather requires additional and simultaneous improvements in other factors related to urban development, transportation, infrastructure, social support institutions and the legal framework as can be seen in Table 1. Improper provisioning of civil infrastructure and transportation plays a significant role in poor economic development and poverty [4]. Effective transportation is fundamental to fighting poverty in developing countries because it provides access to the labor market, to health and educational facilities or to the good markets; however, it is up to people to engage and take advantage of those opportunities. The maturity of the transportation system is commonly used as an indicator to assess economic and social development in developing nations (Fig. 1). One of the most critical roles of mature transit systems in fighting poverty is increasing employment and commuters' mobility rate through affordable, fast, safe, and secure transit options as acknowledged by most transportation master plans in developing nations [5]. In this sense, business growth and employment are impacted by transportation investments across a territory [6–8].


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Table 1: Poverty factors for nations

| | Poor Nations | Developing Nations | Developed Nations |
|---|---|---|---|
| Urban Development Transit oriented, resilient to natural hazards, and sustainable | Informal settlement, very vulnerable and unsustainable | Renewal processes in place | Transit oriented, resilient, sustainable |
| Transportation Accessibility to regional facilities, work markets, and leisure activities | Poor: Walk or automobile | Fair: Walk, bus, automobile | Good: Transit oriented, multimodal, and integrated |
| Infrastructure Water, Sanitation, Energy, and Telecommunications | Deficient (Unreliable and questionable quality) | Fair issues on reliability and quality | Adequate (Reliable and good quality) |
| Social Support Retirement homes, childcare, job counseling, and addiction counseling | Inexistent | Deficient | Existent and effective |
| Legal Framework | Weak or inexistent | Deficient (Complex and ambiguous) | Robust (Clear and simple) |

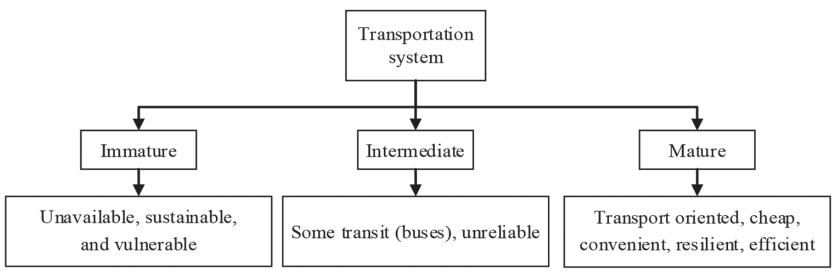


Figure 1: Transportation system maturity

By investigating 15 Sub-Saharan African countries from 1980 to 2006, which were experiencing rapid urbanization, evidence was provided to policy makers of the positive effect of road infrastructure on urban poverty [9]. Ramadan and Feng [10] claimed that a transit system is a tool for poverty alleviation in urban planning. In the meantime, several studies show that there is a direct relationship between improving transportation systems and employment rate [11–13].

Hess [14] examined the access to employment for low-income populations in Erie and Niagara Counties in western New York State. He analyzed the relationship between residence and employment locations using geographic information systems (GIS) and provided certain measures for employment and access to jobs. This study recommended the enhancement of the public transit in places with large concentrations of low-wage jobs. A similar approach is followed by New South Wales region in Australia with measures to boost villages and towns with good transit accessibility to become employment centers [7]. Lichtenwalter et al. [15] studied the relationship between transportation and employment outcomes using regression analysis based on a sample of 62 low-income single mothers. Results indicated better employment outcomes for women with private vehicles than those using public transport.

Providing access to transportation services for rural families may have significant positive influence on employment. The lack of reliable transportation contributes to several challenges for low-income families including difficult access to employment, the prohibitive cost of private vehicles, and the basic management of everyday family life [16]. In the Russian Federation, the quality of transport infrastructure is a critical factor that influences the regional development. A group of attributes was used to form particular indicators with corresponding weights in a recent study. This study concluded that high transport accessibility contributes to creating jobs and attracting investors. As such, improving the economic development requires modernization of the existing infrastructure and creation of new ones [17]. Finally, Starkey and Hine [18] conducted a comprehensive literature review for United Nations (UN) in order to see the effects of transportation infrastructure on poor people focusing on developing countries. This study strongly concluded that by improving road connectivity to rural villages significant social and economic prosperity will be generated. Also, new transportation infrastructure brings short and long-term job opportunities.

Several studies have pointed to the positive impact of a mature transit system in fighting poverty and decreasing unemployment rate, particularly in developing nations since mass poverty regions may not have many accessible job opportunities such as industrial parks. However, there is a lack of proper decision-making models for municipalities and governmental agencies to prioritize maintenance, upgrading, and expanding of transportation systems while considering employment goals. Transport planners should be capable to assess revamping of old obsolete transit systems through numerical indicators that incorporate employment poverty factors to arrive at optimal plans.

The main objective of this research is developing a decision support system to represent the current employment situations in different regions and advocate a proactive cost-effective planning of investments for existing transportation systems as well as expansion projects as a means of reducing the unemployment, and thus, fighting the poverty. For this purpose, the proposed model provides a comparison of the current and proposed transportation alternatives based on their ability to facilitate commuters from remote poor neighborhoods with pockets of poverty and few employment opportunities to main labor markets. Potential areas for employment and public transit projects are mapped to optimize transit assets maintenance and upgrade planning by minimizing travel time/cost for daily commuters across districts. A case study of the railway system in Costa Rica is used to illustrate the proposed approach and its applicability.

## 2 METHODOLOGY

Transit asset management systems could regularly undergo interventions to sustain the appropriate level of asset conditions and safety while respecting budget constraints. However, employment and poverty concerns have not been part of common prioritization process used to allocate annual funds towards investments to maintain or expand a transit network. As seen in Fig. 2, the goal of this research is to develop an optimization tool that prioritizes the use of funding to rehabilitate a transit network. This is expected to remove a travel barrier, impeding poor and middle-income laborers from reaching several otherwise long-commute labor intense districts, which results in reducing the unemployment. This goes in line with the need

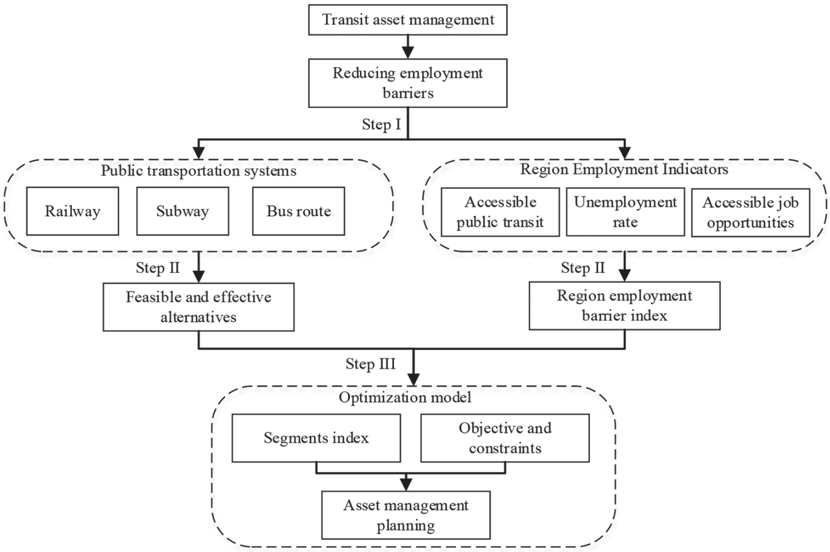


Figure 2: Research methodology for reducing employment barriers through public transport

of governments to objectively use their financial resources and regulations to seek the well-being of the population and to provide welfare to fragile individuals and communities. It also goes in line with the need to maintain safe and convenient transportation that provides access to job markets and to other well-being related facilities (shopping, recreation, health, and education). As explained in Fig. 2 the idea is to transform such goal into a tangible objective that could be modeled and optimized through a mathematical formulation.

Framework starts by estimating the indicators that measure the current situation in terms of job accessibility, public transit accessibility and unemployment. Then, we turn to integrating such indicators to create an *employment barrier index* for each district. This index could be used as a poverty index that provides insight for better management of any transit system including buses, BRT, Tramways, and Light Rail Transit (LRT). Finally, we assign an employment barrier index to each district and the transit segments contained within it. This approach provides the municipalities, and transit agencies with a tool to evaluate their asset management decisions based on employment targets.

## 2.1 Employment barrier index

Three commonly available indicators are used as the foundation for the employment barrier index: the unemployment rate of the district, number of commuters across districts for work, and distance to public transit. The idea is that for any given district, the higher the level of unemployment the more the need for better transit, hence, this captures how many people could be benefitted by improvements on the transit system. The second indicator used in this study is the percentage of people who work in other districts. This indicator provides us with an indication of the lack of local employment and the need for traveling to other districts. The third indicator is the distance to public transit which is estimated geometrically between the centroid of the district and the closest transit segment or stop (e.g. railway, or bus). A lower distance indicates a higher priority for investing in improvements, pointing to a higher potential to improve the region's accessibility to the labor market. This indicator can be extended to include multiple centers based on urban density and mixture.

These indicators are normalized for each district to create an indicator with values with a consistent range from zero (minimum priority) to one (maximum priority) as shown on eq (1).

$$I_{i,j} = \frac{(x_{i,j} - xmin_i)}{(xmax_i - xmin_i)} \tag{1}$$

Where $I_{i,j}$ is the normalized indicator $i$ for region $j$, $x_{i,j}$ is the measured variable for indicator $i$ in region $j$, $xmax_i$ and $xmin_i$ are the maximum and minimum observed values for indicator $i$ in all regions. In the next step, the above-mentioned indicators are aggregated to generate an employment barrier index. The aggregation could take additive or multiplicative functional forms. The multiplicative model could itself take two different shapes. The generic expression for the additive model is shown in eq (2), where $E_j$ is the employment barrier index for region $j$ and $\alpha_i$ is the corresponding weight for indicator $i$ that reflecting the importance of each indicator.

$$E_j = \sum_{i=1}^{3} (\alpha_i \times I_{i,j}) \quad \text{With} \quad \sum_{i=1}^{3} \alpha_i = 1 \tag{2}$$

The multiplicative approach could be represented by a weighted geometric average model as the one shown in eq (3), which in case of equal weights ($\alpha_i$) can be simplified as shown in eq (4):

$$E_j = \left[ \prod_{i=1}^{3} \left( I_{i,j} \right)^{\alpha_i} \right]^{1 / \sum_{i=1}^{3} \alpha_i} \tag{3}$$

$$E_j = \sqrt[3]{\prod_{i=1}^{3} \left( I_{i,j} \right)} \tag{4}$$

## 2.2 Assigning employment barriers index into public transit segments

The employment barrier index characterizes each region and needs to be assigned to transit segments in a manner that it considers the network structure. In addition, it is important to acknowledge the population being served for each segment as the network deepens into more suburban and even rural settings. Thus, to capture this, a population factor $P_j$ is used on eq (5) to represent the population served by the corresponding segment in region $j$:

$$S_r = \frac{\sum_{j \in R_r} \left( E_j \times P_j \right)}{\sum_{j \in R_r} P_j} \tag{5}$$

Where $S_r$ is employment barrier index for segment $r$, $E_j$ reflects employment barrier index and $P_j$ is the population of the region $j \in R_r$. Regions are assigned to the closest segment to set the affected regions group ($R_r$) for each specific segment $r$. The size of a segment should be selected (large enough) to capture a reasonable impact for job seekers with access to potential job markets. In this regard, the refurbishing of railways, for instance, must incorporate corridors to reach places with significant numbers of available employment opportunities.

### 2.3 Optimization model

An optimization model is used to minimize the total level of employment barriers (obtained from the aggregation of the employment barrier indicators across the network). In doing so, the model prioritizes (from highest to lowest index) the rehabilitation of rail links which are currently not operational. The optimal solution is the one associated with the best use of resources. A binary decision variable $X_{r,t}$ will identify the set of segments that are rehabilitated at different points of time achieving the minimum levels of barriers to employment index from improved public transportation systems. A dynamic programming algorithm is then used to select the best combination of investments under currently available budget, minimizing overall employment barrier index ($z_t$) (eqs (6) to (8)).

Objective function:
$$MIN\, z_t = \sum_{r=1}^{R} (1 - X_{r,t}) w_r S_{r,t} \tag{6}$$

Subject to:

$$0 < \sum_{r=1}^{R} C_{r,t} X_{r,t} \le B_t \tag{7}$$

Where

$$w_r = \frac{P_r}{\sum_{r=1}^{R} P_r} \tag{8}$$

and

$$X_{r,t} = \begin{cases} 1 \text{ if rehabilitation is recommended for segment } r, \text{ in year } t \\ 0 \text{ if no rehbailitation is recommended on segment } r, \text{ in year } t \end{cases} \tag{9}$$

$S_{r,t}$ reflects employment barrier index of segment $r$ in year $t$, and $w_r$ shows the segment's weight that could be estimated in relation to the served population ($P_r$) by segment $r$ (eq (7)). $C_{r,t}$ is the assigned cost for segment $r$ in year $t$, $X_{r,t}$ is the binary decision variable on rehabilitation, and $B_t$ is the available budget for year $t$.

## 3 CASE STUDY

Costa Rica railway network is selected for the model implementation in this study. Railways in the country were operated until the 1980s and then abandoned for almost 30 years until two of the lines were brought back into service again in the early 2010s. The rest of the network still remains abandoned to this date and some rural segments are occasionally used for the movement of bananas and other crops (Fig. 3). This is aggravated by high-automobile ownership, poorly connected bus routes, mountainous terrain and a road network that relies on local streets for regional movements with only four highways connecting the capital region to other provinces. For this reason, there is an urgent need to boost transit systems because there is a significant mismatch of jobs at various industrial areas and service clusters with candidates from remote regions. The availability of old railways become the cheapest way to create a fast movement of passengers. Thus, this study concentrates on railway transit; however, the model could be expanded to consider other modes of public transportation like Bus Rapid Transit (BRT). The main decision is to identify which rail-lines should be refurbished first.


Figure 3: Costa Rica railway network

Existing railway infrastructure and vehicles are presently associated with a high degree of deterioration. The infrastructure is in need of reconstruction and the vehicles should be replaced. The reconstruction of the railways is estimated to cost US$5,000,000 per kilometer.

### 3.1 Data collection and results

Socioeconomic characteristics from a household survey conducted in 2011 are used to obtain employment and unemployment rates; daily travel patterns for workers are collected from [19] for the whole country in 2011 as well. Data are analyzed, and indicators are estimated as per in eq (1). Fig. 4 presents the normalized results of unemployment, commuting workers and accessibility to transit indicators.

Employment barrier index is estimated following eq (4) and visualized in Fig. 5. A five-kilometer area is selected as the influence area proximal to the railway network (assuming

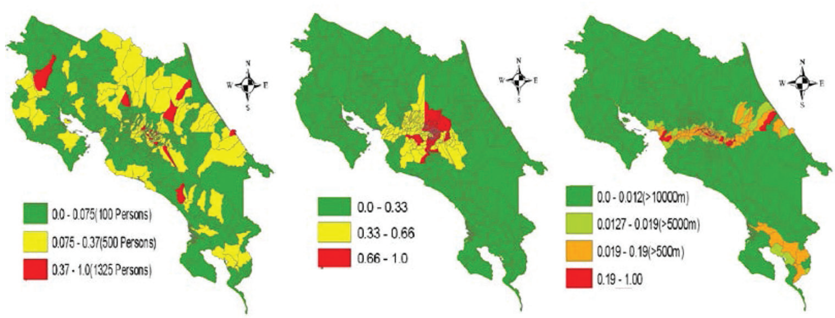


Figure 4: Unemployment (left), commuting worker (middle), and access to transit system (right).

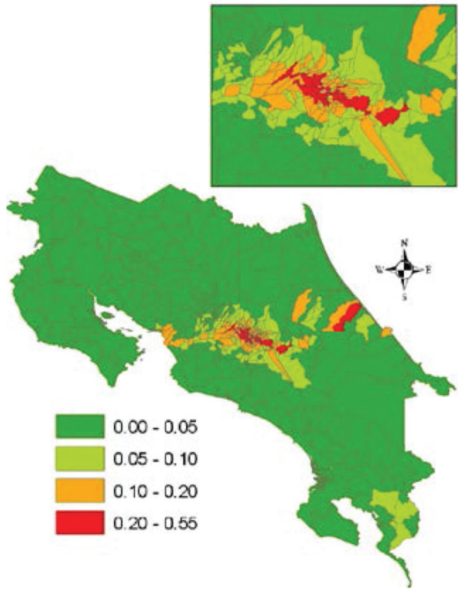


Figure 5: Employment barrier index

kiss and ride or park and ride habits) to estimate the served population. Districts beyond this distance are removed from the analysis. Table 3 shows each railway segment properties and assigned employment barrier index as per eq (5). At this stage, segments could be ranked provided that those with higher values will have the highest priority for reconstruction. Two railway lines called Limon and Sur have auxiliary lines that are ignored from this model.

The solution for the optimization model is obtained subject to a budget of US$60,000,000 per year, which represents 50% of the gasoline excise tax collected in the country. However, since most segments are longer than 12 km, we run the model for periods of 5 years to enable corridor decisions, thus, reaching to US$300,000,000 per planning period. Each time one or more segments are selected for reconstruction, their employment barriers index ($S_{r,t}$) is changed to zero in the following years and the overall employment barrier index ($z_t$) drops. For an analysis period of 40 years, ranking prioritization and optimization results are compared in Table 4.

Figure 6 presents the overall employment index for both solutions as shown in Table 4. The model could decrease the overall employment barrier index by more than 50% during the first 5 years; however, mathematical optimization can drop it by 22% more after 10 years investment as compared to using a common ranking prioritization approach. In addition, Fig. 6 shows that after 10–15 years of full-level expenditure in reconstruction, the gains are small, and budget could be allocated in the expansion of the network to create additional links, enable new lines, or support other feeder modes such as bus routes. Also, the segments replaced during the first 10–15 years will need rehabilitation to remain in good condition. Two more scenarios with annual budgets of $40M and US$80M are investigated with their results compared in Fig. 7, revealing limited gains with a US$60M per year as the best investment alternative.

Table 3: Railway segment properties and ranking for reconstruction

| Railway Segment Name | Length(Km) | Population | Cost(M$) | $S_r$ | Ranking |
|---|---|---|---|---|---|
| San Jose Cartago | 21.72 | 327,560 | 108.6 | 0.190 | 7 |
| San Jose Belen | 15 | 307,432 | 72.5 | 0.251 | 2 |
| San Jose Heredia | 10 | 187,221 | 47.5 | 0.273 | 1 |
| Alajuela Heredia | 11.6 | 160,681 | 58 | 0.237 | 3 |
| Alajuela Ciruelas | 8.3 | 81,950 | 41.5 | 0.227 | 4 |
| Paraiso Casorla | 54 | 81,767 | 271.25 | 0.192 | 6 |
| Limon(South) | 60 | 69,335 | 300 | 0.169 | 9 |
| Pacifico Atlantico | 3 | 62,310 | 14.25 | 0.183 | 8 |
| Puntarenas Caldera Salinas | 32 | 45,542 | 159.5 | 0.108 | 12 |
| Ciruelas Balsa | 19 | 40,962 | 94 | 0.134 | 10 |
| Cartago Paraiso | 5 | 28,878 | 26.5 | 0.130 | 11 |
| Balsa Salinas | 47 | 28,846 | 237.4 | 0.089 | 13 |
| Belen Ciruelas | 8 | 24,245 | 41 | 0.196 | 5 |
| Limon(North) | 30 | 21,031 | 150 | 0.042 | 15 |
| Sur(South) | 47 | 19,992 | 234 | 0.064 | 14 |
| Sur(North) | 60 | 19,126 | 300 | 0.015 | 17 |
| Casorla Las Juntas | 20 | 1,505 | 100 | 0.041 | 16 |

Table 4: Ranking prioritization and optimization results for 5-year time periods over 40 years.

| Railway Segment | Ranking Prioritization | Optimization |
|---|---|---|
| San Jose Cartago | 3 | 1 |
| San Jose Belen | 1 | 1 |
| San Jose Heredia | 1 | 1 |
| Alajuela Heredia | 1 | 1 |
| Alajuela Ciruelas | 1 | 2 |
| Paraiso Casorla | 2 | 3 |
| Limon(South) | 4 | 4 |
| Pacifico Atlantico | 3 | 1 |
| Puntarenas Caldera Salinas | 5 | 5 |
| Ciruelas Balsa | 3 | 2 |
| Cartago Paraiso | 3 | 2 |
| Balsa Salinas | 5 | 5 |
| Belen Ciruelas | 1 | 2 |
| Limon(North) | 7 | 7 |
| Sur(South) | 6 | 6 |
| Sur(North) | 8 | 8 |
| Casorla Las Juntas | 7 | 3 |

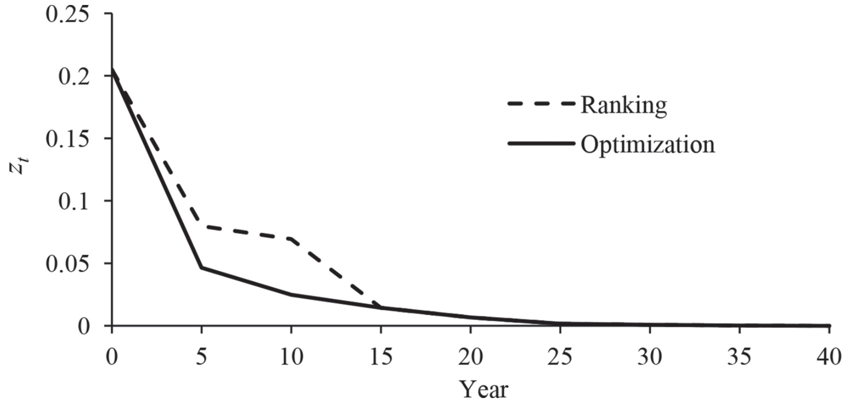


Figure 6: Ranking and optimization approach effectiveness

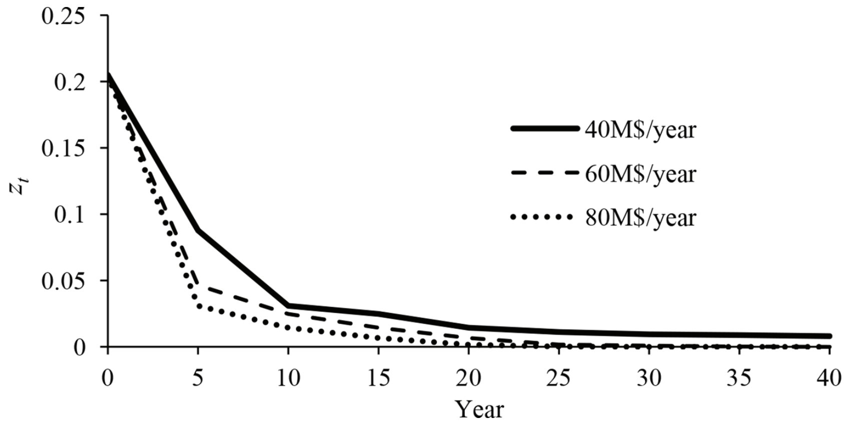


Figure 7: The optimization scenarios

## 4 CONCLUSION

Public transit could improve accessibility to the job market and reduce barriers often experienced by many potential workers, preventing them from accepting a job because of long commuting times, especially in metropolitan areas experiencing large levels of congestion. An employment barriers' index is developed composing of unemployment levels, availability of local employment (otherwise seen as the need to commute) and distance to public transit for each district or transportation analysis zone. A decision aide system is proposed to optimize the allocation of resources to reconstruct non-operational railways that could impact proximal laborers. A corridor analysis is carried out and investment priorities are estimated to achieve the highest impact through reductions in the employment barrier index for a case study of Costa Rica railways network. The model could decrease the overall employment barrier index by more than 50% during the first 5 years; however, mathematical optimization can drop it by 22% more after 10 years investment as compared to using a common ranking prioritization approach. Three additional scenarios are considered with varied budget levels of US$ 40, 60, 80 Million per year. The analysis revealed that minor impact can be obtained beyond a US$ 60 million spending and that resources could be reoriented after 10–15 years. The proposed model will also be beneficial for transit agencies dealing with BRT or Tramway. In future studies public transport level of service, employment clusters (e.g. industrial parks) locations and user preferences could be addressed to improve decision-making.

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