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ECONOMIC EVALUATION OF PAVING RURAL ROADS WITH *ADOQUINES**

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Note: The following is the notation used in this paper: (.) for decimals and ( ) for thousands.

Editorial note: Adoquín (adoquines, in plural) is the Spanish word for "paving block" and refers to stone units used for road surfacing. Nowadays it is used as the root word for other units for the same purpose as "adoquines de piedra, concreto o arcilla" (stone, concrete or clay paving blocks).

Summary

The paper presents an illustrative economic evaluation of paving rural roads with *adoquines* (small hexagonal concrete blocks) in developing countries. International experience shows paving roads with bituminous pavements is typically economically justified for roads with traffic higher than 300 vehicles per day, while for roads with less traffic, the economic justification is uncertain; therefore, road agencies need to search for alternative pavement options to seal low volume unsealed roads because these roads provide unreliable access, are difficult to maintain, and most poor countries do not have a large enough fleet of motor graders, nor the logistical capacity, to meet the theoretical maintenance requirements of their unsealed roads.

The paper compares the level of service, maintenance requirements and economic impact of unsealed and *adoquines* roads and outlines the short term and long term advantages of sealing the roads with *adoquines*. The paper shows that *adoquines* represent an economically viable alternative for roads with traffic exceeding 50 vehicles per day (vpd), especially when there is a significant share of trucks in the traffic stream.

The paper presents the comparison of keeping a rural road as earth road, improving to gravel standard, paving with *adoquines* or paving with bituminous pavement. The comparison is made in relation to construction costs, maintenance costs, service level, road user costs, and total society costs (road agency plus road user costs). The economic evaluation results are given in terms of the benefits Net Present Value (NPV). A sensitivity evaluation is presented that outlines some recommended ranges of construction costs and traffic that justifies economically the *adoquín* option.

1. INTRODUCTION

The level of service of provided by rural roads is essentially characterized by the road width, geometry and surface type, which should be determined based on a technical and economic evaluation. To determine a proper level of service of a road, traditionally a Cost Benefit Analysis (CBA) [The

World Bank, 2009] is done evaluating, over a pre-determined period, several variables including the road agency costs (construction and maintenance costs) and road user costs (vehicle operating, passenger time and accident costs) for different project alternatives, which are added in present value terms at a given discount rate. The optimal project alternative among the ones evaluated is the one with least present value of total society costs (road agency plus road user costs) or maximum net benefits compared to a without project alternative.

International experience with CBA has shown that it is almost certain that a paved surface with bituminous materials or concrete is warranted for roads with traffic higher than 300 vpd, but for roads with less than 300 vpd, the proper surface type needs to be evaluated case by case. Bituminous roads and gravel roads are the traditional choices for roads with less than 300 vpd, but in many cases it is difficult to economically justify paving with a bituminous pavement. Gravel roads alternatively present problems with the sustainability of maintenance, poor ride quality and the generation of suspended dust clouds. Therefore, paving with *adoquines* can be an alternative, typically, for road with traffic higher than 50 vpd.

2. GRAVEL VS *ADOQUINES* ROADS

The ride quality of gravel roads relies on the thickness and condition of a gravel layer that diminishes over time with traffic and the environment; also important is the provision of recurrent maintenance, particularly the frequency of grading. The cost of replacing a gravel layer is high, ranging from US$ 5 000 to 60 000/km, and the concept of spot regravelling is difficult to implement. Grading requires specialized equipment and a program for systematically grading gravel roads is typically not sustainable. The overall annualized costs of maintaining a gravel road ranges from US$ 2 000 to US$ 8 000/km-year. Furthermore, gravel roads demand a continuous cycle of extraction of high quality rock and other natural materials from borrow pits, at times an operation of high environmental cost, and the placement of these materials in the roadbed to be deteriorated by traffic and climatic conditions. The dust from gravel road deterioration causes health problems to the population living along the roads and represents a serious safety problem particularly on narrow, winding roads. All-weather access cannot be guaranteed with gravel roads, particularly on the rainy season in mountainous terrain. Therefore, gravel roads are not a sustainable option in the long term for roads that carry heavy vehicle traffic, and for traffic volumes exceeding about 50 vpd.

An alternative pavement option for rural roads is the use of *ADOQUINES* (hexagonal concrete blocks) that are typically constructed by the local industry and have low maintenance requirements that could be provided by unskilled labor. *Adoquines* are traditionally used worldwide in streets and avenues in urban areas and have started to be used in rural roads in some countries. For example, *adoquines* are being used in Nicaragua [Nicaragua, 2006] in rural areas along more than 300 km of secondary roads as a pilot program (one of the longest section being the 70 km Mosonte – Teotecacinte road that has over 1 000 vpd in some sections). *Adoquines* have long been deployed in Nicaragua and there are roads that have been in use for more than very long periods without the need for rehabilitation of a scale common to gravel or asphalt roads. For example, the 15k m Managua - Masachapa was *adoquined* more than 30 years ago and today carries more than 1,500 vpd. Maintenance of this road over the years has consisted mostly of the replacement of broken or missing *adoquines* and road border repairs.

The use of *adoquines* in rural areas is allied also with significant short term benefits including:

- A simpler and quicker project cycle.
- The potential to use mainly local labor.
- It is a highly labor intensive technology.

- The use of high proportion of unskilled labor.
- Roads can be paved more readily in sections.

The medium term benefits are:

- Development of local contractors and consultants.
- No requirement for costly asphalt plants.
- Lower requirements for consumption of foreign exchange during construction since it is a low machine intensity approach.
- Better ride quality, particularly on the rainy season.
- Lower and safer speeds relative to asphalt roads.
- The hard surface fosters the use of bicycles by local residents.

Finally, the long term benefits are:

- The ride quality (roughness) remains relatively constant over many years.
- Low maintenance costs.
- Routine maintenance can be done essentially by unskilled or semi-skilled labor.
- Little or no foreign exchange resources required for maintenance.
- No need to continue the environmentally costly cycle of repeatedly extracting selected materials from a borrow pit to repair the roads.
- The *adoquin* pavement offers excellent skid resistance in rainy climates.

3. ILLUSTRATIVE COST BENEFIT ANALYSIS

The economic benefits of *adoquines* can be determined by a CBA using the Road Economic Decision Model (RED) [SSATP, 2006] developed by the Sub-Saharan Transport Policy Program (SSATP) and the World Bank, which compares different project alternatives in terms of: (i) construction costs, (ii) maintenance costs, (iii) road user benefits, (iv) ride quality, and (v) road safety. This paper presents an illustrative CBA comparing upgrading a road carrying 120 vehicles per day (50 percent heavy vehicles) with either an earth, gravel, *adoquin* or surface treatment pavement. The traffic growth rate considered was 4 percent per year for all vehicles. The first step of a CBA is to determine the construction costs of different project alternatives. Figure 1 presents typical construction costs/km in Latin America that shows that in comparison to the cost of using *adoquines*, surface treatment costs 67 percent more and the gravel costs 40 percent less. Note that these costs are from before the 2008/2009 fuel and economic crisis and there are indications that current costs are higher due to the crisis, with asphalt pavements having a higher cost increase.

To compare the different project alternatives one needs to compute the annualized maintenance requirements of the different pavement alternatives that are composed of the annual recurrent maintenance costs (i.e., routine maintenance, spot regravelling, patching, grading) and the annualized periodic maintenance costs (i.e., annualized cost of resurfacing gravel roads or annualized cost of resealing surface treatment roads). Figure 2 presents typical annualized maintenance costs in Latin America that shows that with relation to the *adoquines* option, the surface treatment cost is 264% higher and the gravel cost is 309% higher.

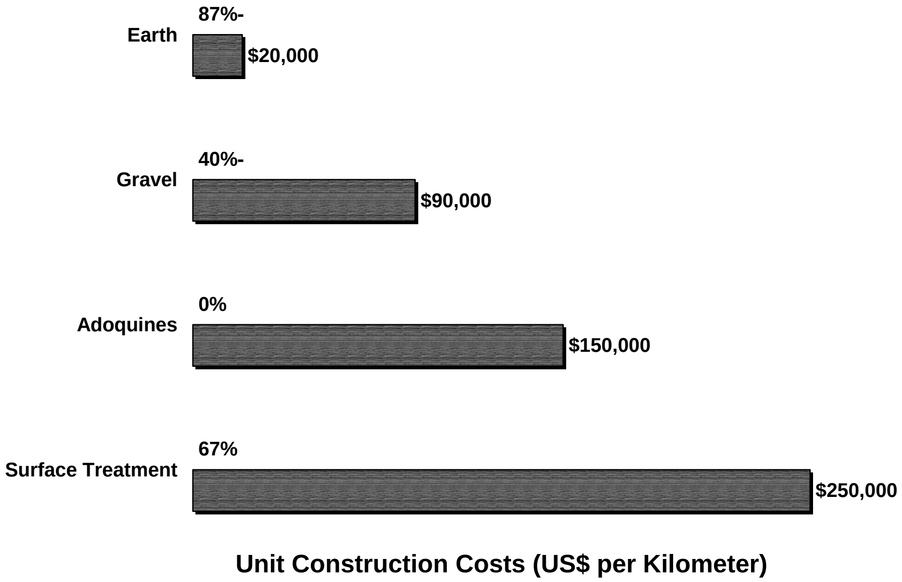

Figure 1 – Unit Construction Costs per km

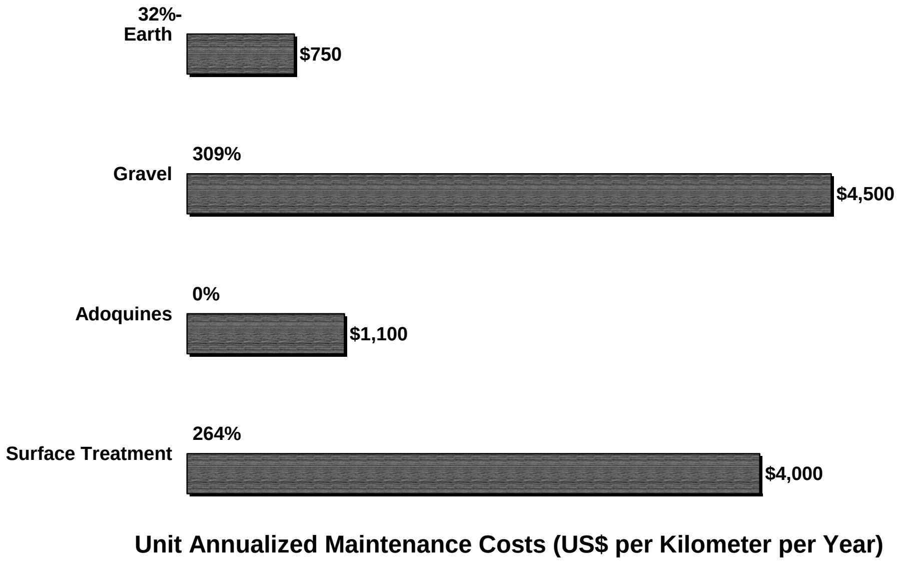

Figure 2 – Unit Annualized Maintenance Costs per km per Year

Different pavement alternates provide a different ride quality that can be expressed in terms of the road roughness. This is a key element of a CBA because international research has proven that road user costs (i.e., vehicle operating costs, speeds, and passenger time costs) are a direct function of road roughness (unevenness of the road). *Adoquines* have a better ride quality than gravel and earth roads but worse ride quality than new surface treatment roads. There is high uncertainty in relation to the average roughness of earth and gravel roads because the roughness of unsealed roads varies greatly during the year due to the rainfall and is highly impacted by the grading frequency that many times is not done in a systematic manner. There is some uncertainty regarding the average roughness of *adoquines* because of the small international experience monitoring the condition of this type of pavement. There is good confidence with the average roughness of surface treatment roads due to the good international experience monitoring the condition of this type of roads. Figure 3 presents typical representative average roughness values for different pavement types that shows that with relation to the *adoquines'* roughness, the surface treatment roughness is 25% lower and the gravel roughness is 150% higher.

Road user costs are comprised of vehicle operating costs (i.e., fuel costs, tire costs, depreciation, maintenance costs, crew costs, etc.), passenger, and cargo time costs that are a function of the road roughness, geometry and the vehicle speeds. Figure 4 shows the typical average vehicle fleet unit road user costs, in US$/vehicle-km, for the different pavement types, for a vehicle fleet composed of 50 percent of heavy vehicles (trucks and buses) in Latin America. As shown on Figure 5, with relation to the *adoquines* cost, the surface treatment cost is 7% higher and the gravel cost is 51% lower. The unit road user costs savings in relation to the earth surface (without-project alternative) when multiplied by the total traffic carried during the year yield the economic annual benefits of the different pavement options compared to the earth surface.

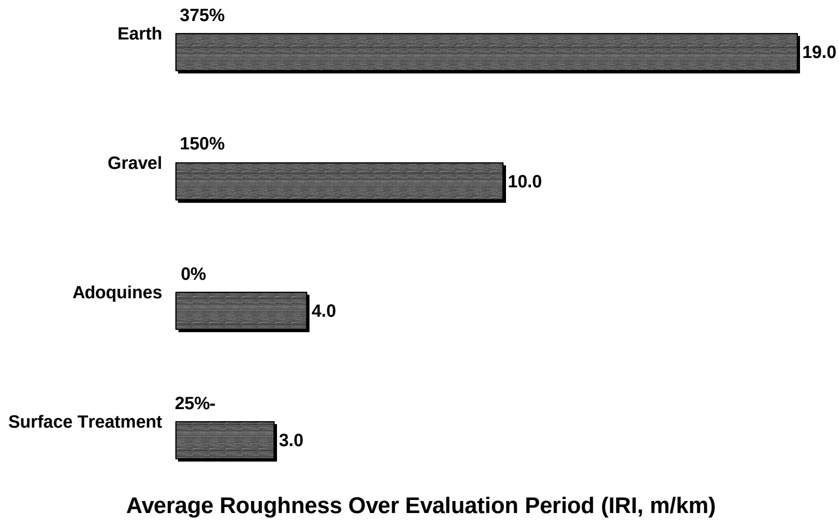

Figure 3 – Average Ride Quality

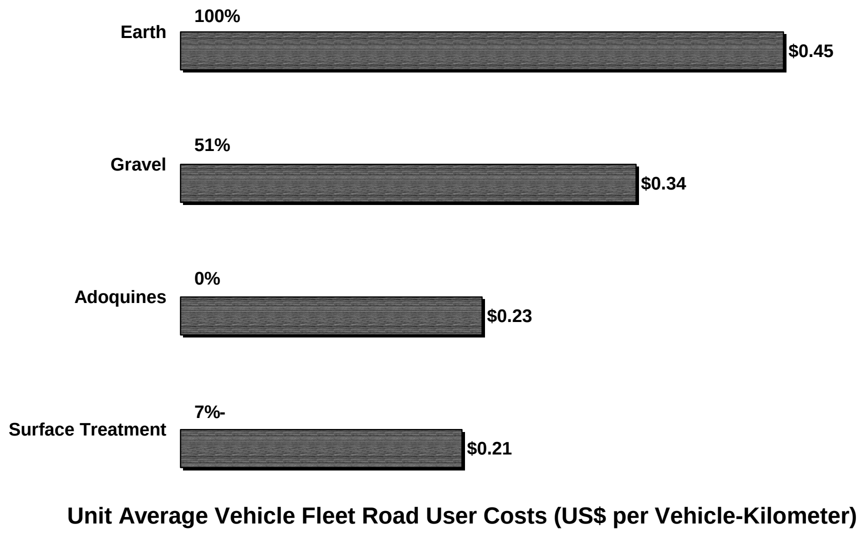

Figure 5. Unit Average Vehicle Fleet Road User Costs.

A CBA compares the different project-alternatives in tern of the Net Present value (NPV) that is the present value of the net benefits (reduction of road agency plus road user costs) of the different project-alternatives compared with the without project-alternative. In this case, the without project-alternative is keeping the road as an earth road and present values are computed using a 12% discount rate that is traditionally used in developing countries to represent the opportunity cost of capital. Figure 6 presents the NPV of the different project-alternatives compared to the construction costs, which show that in this case to upgrade the road with a surface treatment pavement is not economically justified (negative NPV) and to upgrade the road with *adoquines* is the preferred option instead of gravel because it has a higher NPV. This means that the incremental costs of surfacing with *adoquines* are exceeded by the additional benefits provided by the *adoquines* in terms of better ride quality and lower maintenance costs thereby resulting in overall lower total society costs over the evaluation period in net present value terms.

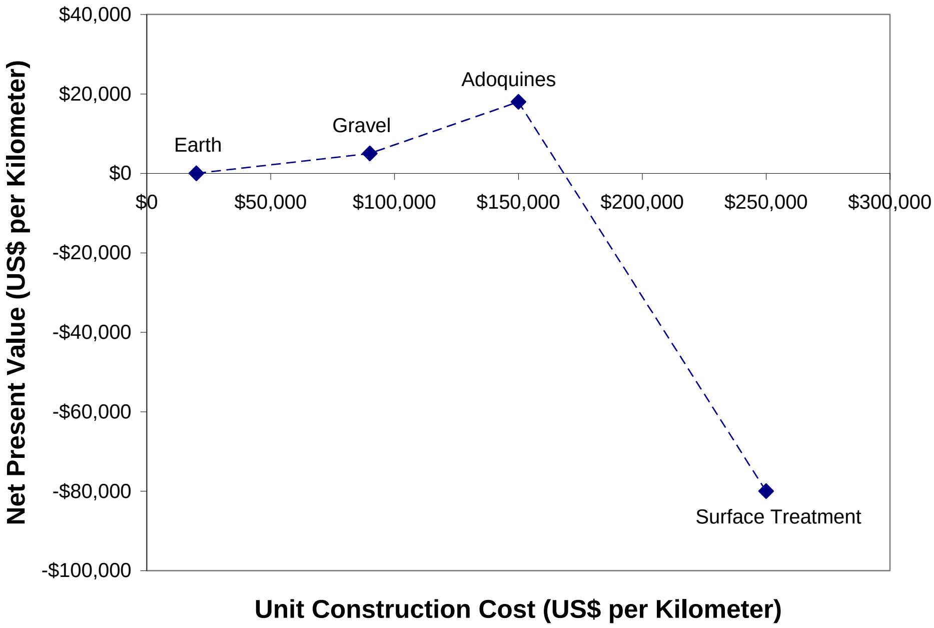

Figure 6 – Net Present Value.

4. SENSITIVITY ANALYSIS

This illustrative CBA evaluation considered that the construction cost of the *adoquine* pavement is US$ 150 000/km. As shown on Figure 7, a sensitivity analysis indicates that the construction cost could increase up to US$ 167,000/km to still be an economically justified project for traffic volumes around 100 vpd. The results of a CBA are a function among other things of the vehicle fleet composition and traffic growth rate. A sensitivity analysis shows, for example, that the *adoquines* construction costs could increase up to US$ 184,000/km with 60% of heavy vehicles on the vehicle fleet to still be an economically justified project at this traffic level. It should be noted that this analysis does not capture the additional benefits accruing from the improved rural mobility outcomes as evidenced by increased bicycle and pedestrian traffic observed in Nicaragua, as well as the health savings reported by local households. In addition, rural merchants also report increases in sales of goods that were prone previously to damage by dust particles from gravel roads e.g vegetables, refreshments, prepared foods, etc.

Figure 8 shows the recommended traffic range for the different pavement options that yields an economically justified project for the construction costs adopted on the illustrative CBA. The evaluation shows that gravel roads are essentially economically viable for traffic higher than 50 vehicles per day, *aoquines* for traffic higher than 100 vehicles per day, and surface treatment roads for traffic higher than 200 vpd. Although, given the fact that most countries do not possess the sizeable fleet of graders needed to maintain gravel roads, the feasible range for *adoquines* starts more at the 50 vpd level when there is a significant share (> 40%) of heavy vehicles (buses and trucks) in the traffic stream.

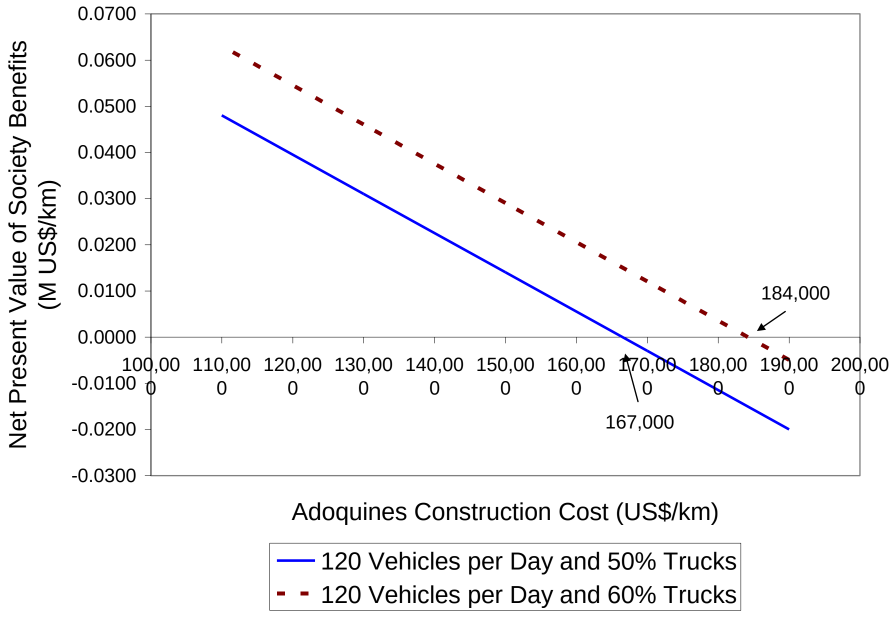

Figure 7 – Construction Costs Sensitivity Analysis

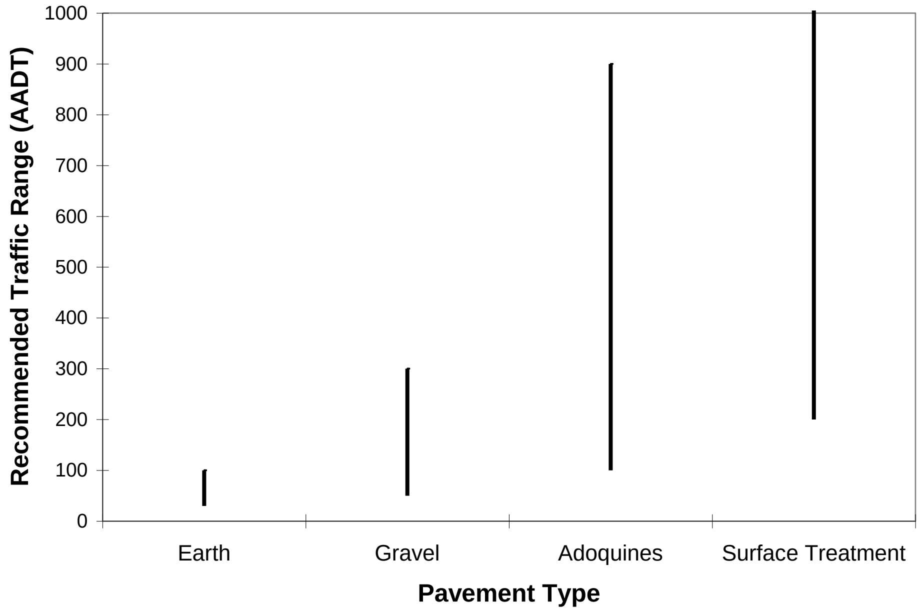

Figure 8 – Traffic Sensitivity Analysis.

5. CONCLUSIONS

A CBA provides a measure of the economic worth of investment alternatives and maintenance choices in order to help guide the optimal allocation of resources. It quantifies the economic benefits and costs of each project-alternative compared to a "without project-alternative," which typically is based on a do-minimum scenario. For each project-alternative, road agency and road user costs are computed for a defined analysis period, and the resulting flow of net benefits, compared to the without project-alternative, is discounted at a given discount rate. The economic comparison of project-alternatives is done analyzing their benefits Net Present Value (NPV).

The illustrative CBA done comparing earth, gravel, *adoquines* and surface treatment pavement options for a road with 120 vpd, shows that the *adoquines* option yields the highest NPV; therefore, it is the recommended option from an economic point of view. The paper outlines other short, medium and long term benefits of *adoquines* and the limitations of unsealed roads, which confirm that *adoquine* pavements are a valid and cost-effective pavement option for rural roads. A sensitivity analysis shows that *adoquines* are a valid option from an economic point of view for roads with traffic higher than 50 vpd, considering the given construction costs of US$ 150 000/km and the other assumptions adopted on the CBA.

The results presented in this paper should be considered no more than a first approximation of country specific results. To obtain country specific results, the methodology should be replicated and adapted with refined country data for construction costs, maintenance costs, total traffic, traffic composition, traffic growth rate, climate, geometry, average roughness, and discount rate.

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