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Transportation network optimization for the movement of indigenous goods in Amazonian Ecuador

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ABSTRACT

This paper presents an unusual case study and a new network optimization model for transportation of agricultural products in a largely roadless region of Amazonian Ecuador. One proposed sustainable economic development strategy to help protect the biodiversity and indigenous cultures of this region is to grow and transport locally produced organic crops to markets outside the region. Transportation options include for-hire modes such as small planes that can land at grass airstrips and truck transport available from only one node. Other options include self-owned modes such as motorized canoes, which can be purchased and based at certain villages for use on a few navigable rivers. To analyze this unique logistics problem, this paper develops a hybrid mixed-integer linear programming model combining elements from cost-minimizing multimodal network flow models and location–routing models with vehicle-capacity constraints. Because of the small volumes shipped, the keys to minimizing transport costs for both for-hire and self-owned modes are the economies of scale of larger vehicles as well as high utilization of the capacity of those vehicles. The model solves for optimal modes, sizes, routes, bases, stops, and volumes, as well as location of storage and transshipment facilities. The five different scenarios demonstrate the substantial cost savings achievable with network optimization as opposed to direct routing from each community. This type of model could be adapted to help address logistics problems facing other inaccessible regions in mountainous, polar, or rainforest ecosystems.

1. Introduction

Despite widespread economic development around the world over the last several centuries, many regions remain largely unserved by road or rail transportation. Remote, isolated communities in mountainous, polar, and rainforest ecosystems often rely on transportation by small airplanes, perhaps supplemented by other modes with limited geographic availability. The building of new roads into these regions would be costly, not only economically but in other ways as well. Many of these regions are also important wilderness reserves of high biodiversity or unique species, and often are home to threatened indigenous cultures. One proposed strategy of sustainable economic development in remote regions has been to set aside contiguous blocks of ecologically and culturally important lands for preservation while developing markets for locally produced crops and handicrafts. The logistics of moving goods from such regions to market is, however, a major economic hurdle for this strategy.

This paper reports on one component of a larger project on sustainable development and preservation in Ecuador, jointly undertaken by the University of Texas (UT) and EcoCiencia, an Ecuadorian conservation organization, with funding from the Gordon and Betty Moore Foundation. The paper offers a case study of minimizing transport costs from this remote area as well as a new network-optimization model that could be modified for application to other remote regions. In the Upper Pastaza region of Ecuador (Fig. 1), as in most of the forested lands of the Western Amazon, the vast majority of the indigenous communities lacks direct access to roads. Most communities have small airstrips (Fig. 2) that can accommodate small aircraft, however, while others can use their proximity to nearby rivers to transport goods by motorized dugout canoes. Planes currently move most manufactured goods and people into, out of, and occasionally among these communities. These communities, however, have not used planes *or* canoes for the mass shipment of agricultural exports in the past except on an occasional experimental basis supported by the UT–EcoCiencia team. The lack of transportation infrastructure in the Oriente presents unique challenges when attempting to develop a sustainable local economy based on the production, transport, and sale of agricultural products.

To capitalize on the commercial potential of locally produced goods, an economically efficient system for transporting them to market must first be determined considering the cost, capacity,

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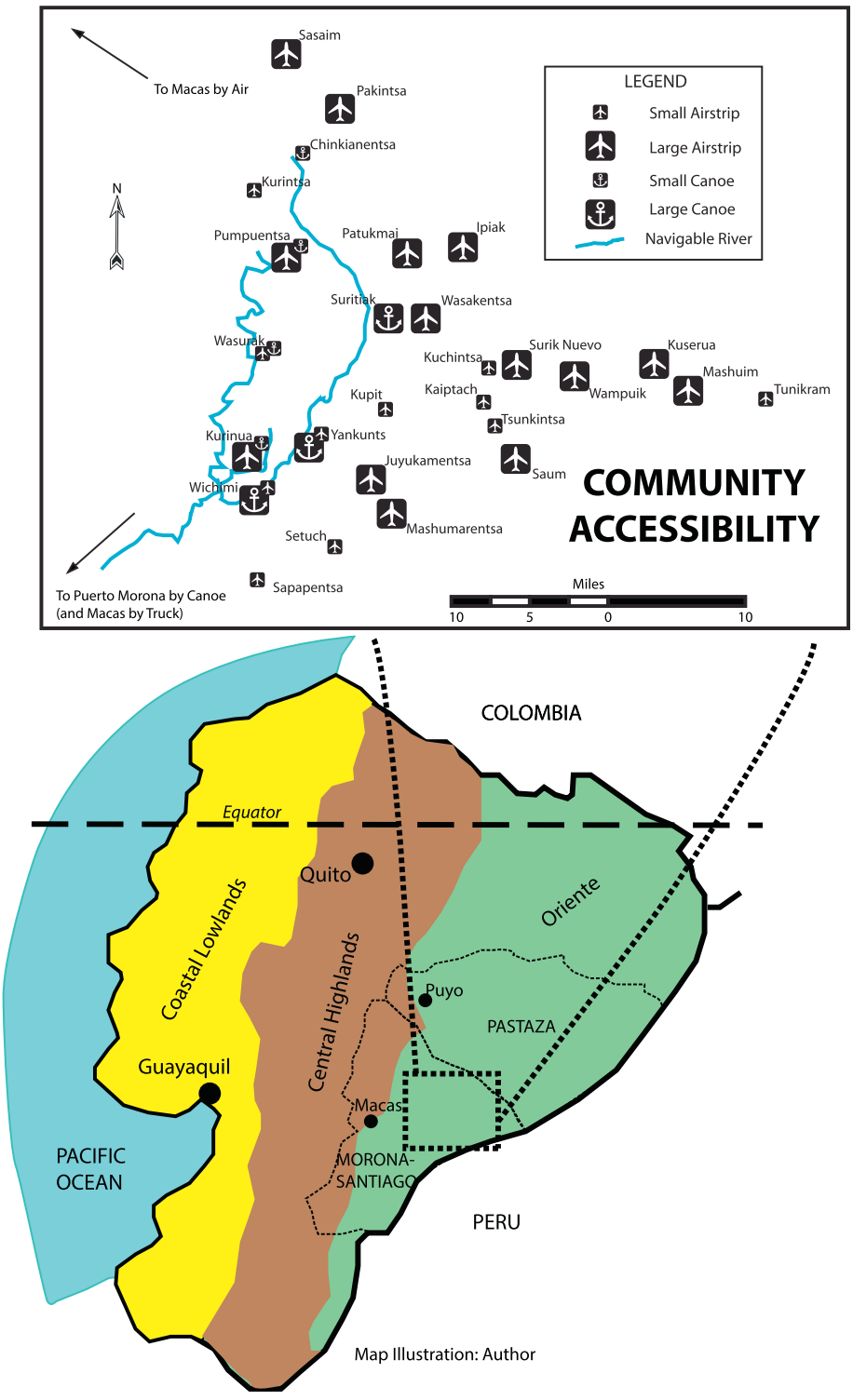

Fig. 1. Study area and community accessibility.

and economic efficiency of the various transportation modes. To address this issue, this paper develops and applies a mathematical programming network optimization model to assess the viability of such a system. The objective of the model is to minimize the total transport costs associated with shipping products from various communities to a single warehousing facility outside the roadless region. The model must determine how much product to ship between communities and by which transport mode and vehicle size, taking advantage of economies of utilization and scale. Different modeling structures are proposed for modeling the for-hire vehicles (air and truck in this case study) and self-owned vehicles (motorized canoes). For self-owned vehicles, the model must also determine base locations. Finally, the model must determine whether to build an intermediate storage facility to act as a primary transshipment point along the network. This paper develops and tests a hybrid multi-modal formulation, combining features from min-cost network flow and location–routing models, to solve this problem.