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A LINEAR OPTIMIZATION APPROACH TO RURAL ROADS INVESTMENT PLANNING "THE CASE OF OFFINSO DISTRICT IN GHANA"

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1. INTRODUCTION

Adequate, reliable and economic transport is an essential requirement for regional and national development. In Ghana, however, a recent study by the Department of Feeder Roads has indicated that about 67 per cent of the feeder road network in the country are in poor state. Tracks, which also form a significant part of the rural road network, are even worse due to long neglect. Poor road conditions lead to rural accessibility problems which tend to inhibit the socio-economic and environmental development of rural areas with a consequent negative impact on urban as well as national development.

The government of Ghana has now placed emphasis on rural road maintenance and improvement. Conceivably, however, available resources for rural roads maintenance and improvement, from both domestic and external sources, are woefully inadequate to meet the great demand for improvement works. Moreover, rural roads improvement projects require the commitment of enormous local and foreign resources.

In view of the foregoing, careful and intelligent planning of rural roads investment is greatly important. Central to rural roads investment planning is the problem of road selection or the allocation of the limited budget to the roads so as to maximize the returns from such investments.

The objective of this study is, therefore, to attempt a solution to the rural road resource allocation problem using linear optimization technique, where the objective to be maximized is a measure of accessibility improvement or increase. The technique is applied to Offinso District in Ghana, West Africa.

2. CONCEPT AND METHODOLOGY

The main concern of rural roads investment planning in developing countries is considered to be the problem of optimally allocating the limited available budget to the various rural roads. It therefore becomes relevant to apply OR techniques. A linear optimization method has been utilized in this study.

It is considered in this study that the primary objective of rural roads investment is to improve physical access for farmers or villagers to the highway network. Improved rural roads could enhance accessibility of the villagers to urban-based economic, social and administrative facilities. This could then promote economic, social and environmental development in the rural areas.
The analytical framework of this study is depicted in Figure 1

Rural accessibility could be defined as the ability of the villagers to reach or be reached by the services or activities located in urban areas.

地方道路投資計画のための線形計画最適化法 ～ガーナのオフィンソ地区を事例として
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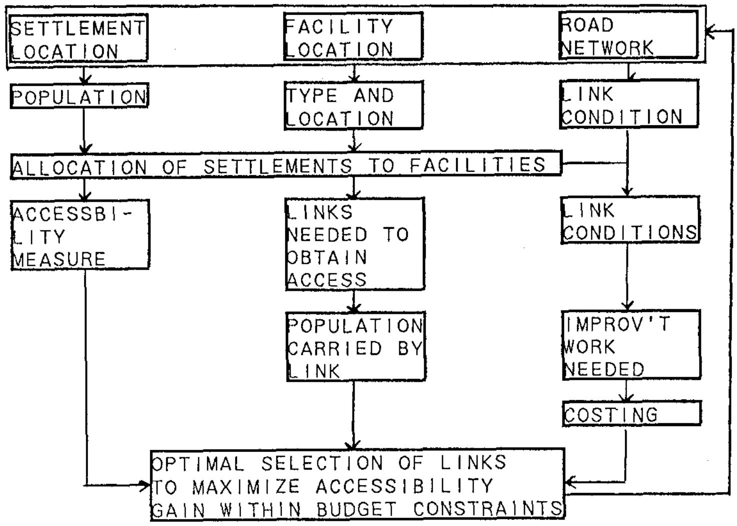

Figure 1 : Accessibility-based rural roads investment planning process

The facility potential for village i, considering all facilities in the region, can be defined as:

$$\Pi_i = \sum_j W_j \exp(-\beta T_{ij}) \quad .....[1]$$

Where: W_j = attractiveness of j
T_{ij} = travel time from i to j
β = parameter

The element "$\exp(-\beta T_{ij})$" represents accessibility for an individual living in i.

$$\text{Let } A_i = \exp(-\beta T_{ij}) \quad .....[2]$$

In the absence of data to calibrate β in [2], changes in T_{ij} may be used as a proxy measure of changes in A_i. From [2] A_i increases when T_{ij} decreases as the result of road improvement as shown in [3]

$$\Delta T_{ij} = X_{ij}/V_o - X_{ij}/V_a \ ; \quad V_a > V_o \quad ....[3]$$

where: V_o= average speed on road without improvement(km/hr)
V_a= average speed with road improvement(km/hr)
X_{ij}= distance from i to j

Considering the population accessed by a given road link the optimization problem becomes

$$\text{Maximize } Z = \sum_i P_i(X_i/V_o - X_i/V_a) \quad .....[4]$$

$$\text{Subject to} \quad d \leqq C_i X_i \leqq b \quad .....[5]$$

$$L_i \leqq X_i \leqq U_i \quad ......[6]$$

where: Z = increase in accessibility for population P_i
P_i = population accessed by road link X_i
X_i = length of road link (in km.)
C_i = cost of improving 1km of road
d, b = lower and upper limits respectively of budget
L_i, U_i = lower and upper limits respectively of road link

During the rainy season deteriorated rural roads become impassable to vehicles and thereby the only mode of transport becomes walking. This can be incorporated into the measurement of accessibility gain by considering accessibility throughout the year. The objective function then becomes

$$\text{Max } Z = \sum_i P_i \{ (K_1 X_i / V_{om} + K_2 X_i / V_w) - 365 X_i / V_{am} \} \quad ..[7]$$

where: K_1, K_2 = number of passable and impassable, days resp. in a year
V_{om} = average vehicle speed on road without improvement
V_w = average walking speed
V_{am} = average vehicle speed on road with improvement

The solution to the optimization problem indicates the selection policy that will yield the maximum increase in accessibility given the budget constraint.

3. APPLICATION OF METHODOLOGY TO OFFINSO DISTRICT

3.1. Background of Offinso District

Offinso District is a sub-region of the Ashanti Region of Ghana which has Kumasi(the second largest city) as its capital. The district covers an area of about 1540 sq.km with Offinso as the administrative center. It is in the semi-deciduous forest region and is an important cocoa growing district. Average annual rainfall is about 1440mm. The sub-region is also a very important tomato producing area. Timber logging is an important economic activity in Offinso District with saw milling plants at Nkenkasu and Akomadan.

The population of the district in 1984 was about 70,500. In 1990, it is estimated that the district has a population of about 81,345 showing an average annual growth rate of about 2.3 per cent.

3.2. Road Network

The entire road network in the district is about 311.3km. giving a road density of about 4.95km./sq.km. There are 73.8km. of Highway, 135.7km. of Feeder roads and 101.8km. of Tracks. One major highway traverses the district, more or less centrally, with feeder roads and tracks joining it at various points and forming a dendritic road network pattern.

The roads under study comprise feeder roads and tracks collectively called rural roads. A feeder road links a zone of access to the highway network and is generally unpaved but engineered road with gravel surface when in good condition. A track is normally a single lane, unengineered, earth road mostly seasonally passable. The tracks in the district have developed as the result of timber logging activities and have not been improved. At the peak of the rainy season the tracks are not motorable. Tracks are generally not classified in Ghana.

The feeder roads in the district have not been maintained for the past 6 years and are therefore in deteriorated state due to the combined effect of traffic and environmental factors.

3.3 Location of Settlements and Facilities

About 90 settlements are found in the district. Of this,about 23.3 per cent are located along the highway with the rest located off the highway. However, about 67.3 per cent of the population in the district live in the settlements located along the highway. About 26,546 people live off the highway (see Figure 2).

The mean distance to the highway by settlement is about 9.9km and by population about 8.4 km. Almost all socio-economic facilities in the district are located along the highway. The main transport concern of the off-highway settlements is, therefore, to obtain access to the highway network in order to benefit from the facilities and to be effectively integrated into the national or world system. Consequently, a reasonable rural roads investment policy objective would be to achieve the maximum possible increase in accessibility for as many villagers as practicable within budget constraints.

3.4. Model Application

From the foregoing the main task in planning the rural roads investment in the district is how to select the links for improvement in order to achieve the maximum possible increase in accessibility for the villagers within budget constraint.

Table 1: Summary of road characteristics

	Without improvement	with improv't
passable days	feeder 350 track 275	365 365
average speed	feeder 20km/hr track 15km/hr	60km/hr 60km/hr

Given the condition of roads in the district as shown in Table1, the objective function becomes (basedon [7]):

$$\text{Max} \quad Z = \sum_{i=1}^{38} P_i \{ (350X_i/20+15X_i/4) - 365X_i/60 \} \qquad \text{(feeder road)}$$

$$+\sum_{j=1}^{39} P_j \{ (275X_j/15+90X_j/4) - 365X_j/60 \} \quad ....[8] \qquad \text{(track)}$$

We can simplify[8] as:

$$\text{Max} \quad Z = \sum_{i=1}^{38} 15.2P_iX_i + \sum_{j=1}^{39} 34.75P_jX_j \quad ....[9]$$

Where: P_i= population accessed by feeder road link X_i
P_j= population accessed by track X_j

There are 38 links of feeder roads and 39 links of tracks.
The average cost for rehabilitating 1 km of feeder road (requiring major regravelling) is estimated to be 2 million Cedis (about ¥1million), and that for track betterment is estimated at 3.5 million Cedis. The available budget for rural road improvement in the district is estimated at 120 million Cedis(¥60)

The constraint conditions then become:

$$\text{S.T.}\quad 0 \leqq \sum_{i=1}^{38} 2X_i + \sum_{j=1}^{39} 3.5X_j \leqq 120 \qquad \text{....[10]}$$

$$L_i \leqq X_i \leqq U_i \qquad \text{....[11]}$$

$$L_j \leqq X_j \leqq U_j \qquad \text{....[12]}$$

Where : L_i, U_i = lower and upper limits respectively of X_i

L_j, U_j = lower and upper limits respectively of X_j

X_i, X_j = length (in km.) of feeder road X_i and track X_j respectively

3.5. Results of Analysis

The linear optimization model in [8]-[12] was solved using Linear Interactive and Discrete Optimizer (LINDO) software on NEC PC-9801VX Personal Computer. The results are presented in Table 2 which indicate the optimal road selection policy for rural roads in Offinso district (see also Figure 2).

Table 2: Optimal Road Selection

Link	class	length(km)
L3210	feeder	7.4
L3332	feeder	6.3
L3913	feeder	1.3
L4822	feeder	4.9
L5322	feeder	1.9
L5453	feeder	7.3
LJ24	feeder	2.8
L67J	track	2.5
L6867	track	2
L6968	track	1.1
L7628	track	6
LJ29	feeder	3.8
L82J	feeder	1.4
L8830	feeder	2.6
Total	-	51.3

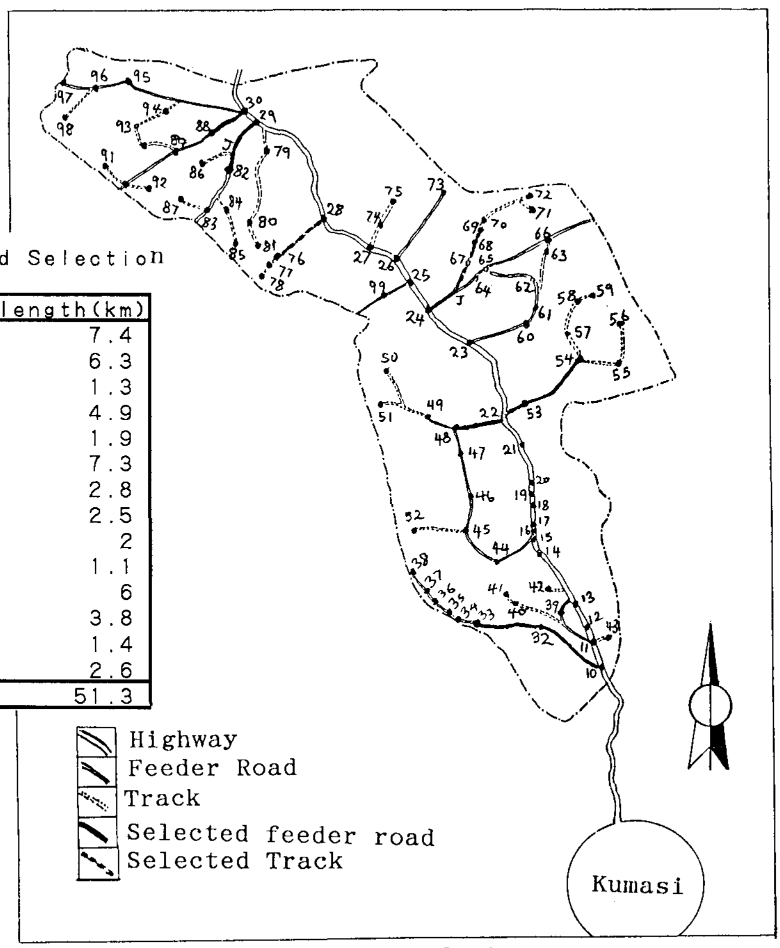

Figure 2. Optimal road link selection

The value of the objective function is 2,154,824. This can be interpreted as total man-hours saved as a result of the road improvement. It, however, represents a potential.

Changing the available budget, obviously, affects the objective function value and the number of road links that can benefit from the improvement program. Similarly, changes in construction cost also affects the number of road links selected.

One interesting observation is that optimal selection policy in this study involves improving part of a road (a number of links of the same road) instead of the entire road length. It is also observed that several tracks have been included contrary to current practice where they are often neglected.

4. CONCLUSION

This study has clearly indicated the applicability of OR techniques to rural roads investment planning. The practical utility of the method developed in this study has also been verified for a developing country. It could prove of great value to developing countries characterized by lack of data and high cost of data collection. The method could also eliminate most of the problems inherent in traditional rural roads appraisal techniques, notably, the problem of unquantifiable benefits. It again redresses the problem of subjectivity and double counting associated with socio-economic rating schemes used in many developing countries for ranking rural roads for investment. Monetary value could be obtained for the objective function value (man-hours) thus permitting simple cost-benefit evaluations.

It could be noted that linear optimization is a static approach. Notwithstanding, its utility could be appreciated considering the situation of most developing countries where future budget allocations to some districts are quite unpredictable. Under such circumstances, it is perhaps wise to formulate road selection policies on as is basis, that is based on the budget when and as it becomes available. The next stage of this study will, however, examine long-term and medium-term rural roads selection policies. Much more empirical research will also be conducted into the modeling of rural accessibility and travel behavior in a developing country like Ghana.

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