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Development of Secondary Roads in the City-Province of Kinshasa Methodology Based on Multi-Criteria Mathematical Programming

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ABSTRACT
The city of Kinshasa, capital of the Democratic Republic of the Congo, is distinguished by its glaring lack of adequate and high-quality road infrastructure. This situation contributes to making the Congolese capital the most chaotic and disorganized center in Central Africa, affecting not only its administrative functioning but also its economic and social development. The lack of secondary roads. The absence of alternative routes to relieve congestion on the main arteries often generates significant traffic jams. This hinders on the one hand the proper functioning of road controllers' work and on the other hand the maximization of benefits for users. To remedy this situation, a new urbanization scheme is necessary, by creating secondary axes while delimiting the road space of Kinshasa. Consequently, decision-support mathematical models have been developed to solve this problem.

KEYWORDS: *Secondary roads, Multi-criteria programming, Sectorization, mathematics.*

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INTRODUCTION

The objective of this study is to provide a guide that points to the recent results of a survey conducted among road transport users in the city of Kinshasa and to indicate potentially rewarding research directions. The colonial construction of the city-province of Kinshasa aimed to facilitate the permanent control of the population in its movements. The administration, which employs the majority of the population, is concentrated in a portion of the city, which is the commune of Gombe. The same goes for large shops, big stores, and the Grand Market commonly called "Zando." Thus, the movement of the population occurs in the same direction, both going and returning; this explains the observed traffic jams. Everyone is in a hurry during rush hours and wants to be the first to have priority. Finally, there is a lack of secondary roads and poor quality of road infrastructure. There are no good secondary roads to relieve congestion on the main roads.

To solve this problem, we need to use mathematical decision-support tools to sectorize the road space of the city of Kinshasa and facilitate the allocation of vehicles in the sectors.

The structure of this document is as follows:
The first section is devoted to the conceptual approach to transport. The second section deals with the multi-criteria transport problem. In the third section, we address the problem of road sectorization in the city of Kinshasa. Finally, in the fourth and last section, a new road development plan is proposed for the city of Kinshasa.

1. CONCEPTUAL APPROACH TO TRANSPORT

1.1. Definition of transport

Etymologically, transport, from the Latin "trans" meaning beyond and "portare" meaning to carry, is the act of carrying something or someone from one place to another. In the most common sense, transport is the movement of goods or people over a fairly long distance by special means [1] [2].

1.2. Transport categorization

There are two categories of transport: the first concerns the transport of people and goods, the second distinguishes between public and private transport.

1.2.1. Transport of people and goods

The transport of people and goods refers to all activities involving moving individuals or goods from point A to point B, via various modes such as road, rail, air, or sea. These two types of transport differ in their purpose: the first aims at human movement (individual or collective), while the second concerns economic freight. They can be carried out on own account (by the company itself), or on behalf of others (by specialized carriers)[2].

1.2.2. Public and private transport

Public transport is a collective service open to all, organized by the State, local authorities or approved operators. It is characterized by: accessibility to a large number of people, generally subsidized and more affordable fares, fixed routes and schedules, aims to reduce congestion and promote social equity. [3]

Advantages: less expensive for the user, reduces the number of individual vehicles on the road and more environmentally friendly if well organized.

Private transport involves trips made with individual or semi-collective means, not organized by the State. They are characterized by: freedom of choice of route and schedule, higher cost (fuel, maintenance, taxi fare), more flexible and faster, especially in the absence of efficient public transport.

Advantages: comfort and privacy, total flexibility and speed in some cases.

1.3. Role of transport

The analytical accounting of a nation's economic development is not based solely on the level of production and technological advancement it knows, but also by inventorying the nation's buildings and transport infrastructures.

Transport is involved in all the gears of economic life. It corresponds to the human need to move and to move their goods. Thus, transport activity can cumulatively appear under two factors:

- - As a factor of progress, truly a political instrument;

As a criterion of economic development of a nation [2] [5] [7].

Transport plays a central role in economic development by facilitating the movement of goods, people and services, while promoting trade and attracting investments.

1.4. Mathematical decision-support tools in road transport management

The role of optimization is to generate a set of optimal solutions rather than a single one. Mathematical programming is a powerful decision-support tool in this regard as it allows modeling the conflict between the objectives to be achieved in a decision-making process.

1.4.1. Basic concepts

Mathematically, a multi-objective optimization problem (POMO) is described as follows:

Optimize $f(x) = [f1(x), \dots , fk(x)]$ (k functions to optimize)

With $g(x) \leq 0$ (m inequality constraints)

And $h(x) = 0$ (p equality constraints)

Where $x \in R^n$, $g(x) \in R^m$, $h(x) \in R^p$, $f(x) \in R^k$

Solving this problem involves best minimizing these k objective functions so as not to greatly degrade the values of the optima obtained compared to those obtained during a single-objective optimization carried out objective by objective. On note therefore f1,…, f2…, fk designate the different objectives to optimize. The variables x1,…, x2…, xn represent the decision variables. The evaluation of a solution x is described by an objective vector:

$$f(x) = [f1(x), \dots , fk(x)]$$

Hence, we are faced with two types of spaces:
- The decision space. Optimize x of n which designates of solutions x = [x1,…,
- The space of objectives of dimension k which designates the set possible corresponding to the f(x) [5] [6].

1.4.2. Multiplicity of solutions

Solving a POMO problem does not yield a unique solution, but several possible solutions because POMO shave objectives that are often conflicting (minimizing one objective can lead to maximizing another). Thus, we obtain a set of non-optimal solutions, as they do not minimize all functions at the same time. These solutions are called compromise solutions.

2. MULTICRITERIA TRANSPORT PROBLEM

2.1. Definition and formulation

The base model of the multicriteria transport problem is an extension of the multicriteria assignment problem.

Suppose we need to transport a product from r sources (factory, warehouses,…) with quantities q1,…, qr to s destinations (workshops, stores,…) where some

demands d1,…, ds must be

(Of course, ∑ qi ≥ ∑ dj i=nr

We assign values Cij k(transport cost, delivery time, delivery security, quantity supplied, deterioration risk, unsatisfied demand, unused capacity,…) for transporting one unit of product from origin i to destination j.

The multicriteria transportation problem can be formulated as follows:

$$\begin{cases} "\min" \sum_{i=1}^{r} \sum_{j=1}^{s} C_{ij}^{k} \cdot x_{ij} & ; k-1,\dots,k \\ \sum_{j-1}^{j} x_{ij} = q_i & ; i = 1, \dots, r \\ \sum_{i=1}^{r} x_{ij} = d_j & ; j = 1, \dots, s \end{cases}$$

$$x_{ij} \geq 0, \text{Entier}, \forall\, i, j$$

3. SECTORISATION OF THE ROAD SPACE OF THE CITY OF KINSHASA

3.1. Tree search algorithm applied to road transport in Kinshasa

3.1.1. Separation and Evaluation (Branch & Bound)

Principle of B&B

The principle of the separation and evaluation algorithm, more commonly known by its English name Branch and Bound (BB or B&B), is quite simple [5].

Consider a state tree, with nodes and leaves representing solution states. Let us have a cost function with the following property: the cost of the solutions could be reached from this node. The principle, when looking for a solution with minimal cost, is to memorize the lowest-cost solution encountered during operation, and to compare the cost of each node traversed to that of the best solution. If the cost of the considered node is higher than the best cost, exploration of the branch is stopped. All solutions of this branch will necessarily be solutions already found.

If c(node) > Best_c then cut the branch otherwise continue exploration. Here, c is the cost function, and Best_c is the best cost found for a solution. To solve this problem concretely, one can imagine that the elements are control sectors, and the clustering configuration partitions, and that we seek to balance the workload among the groups of sectors.

The cost of a transition from the parent node to a child node is then simply the distance between the last commune of the parent node and the new commune added in the child node. Let's choose the distance to the destination commune as the heuristic. It is a lower bound for all routes leading to the destination.

For each child node, one can thus calculate the sum of distances traveled to reach the last commune step, and add the distance between that commune and the starting commune. The node is added to the queue with a priority that is a function of this value.

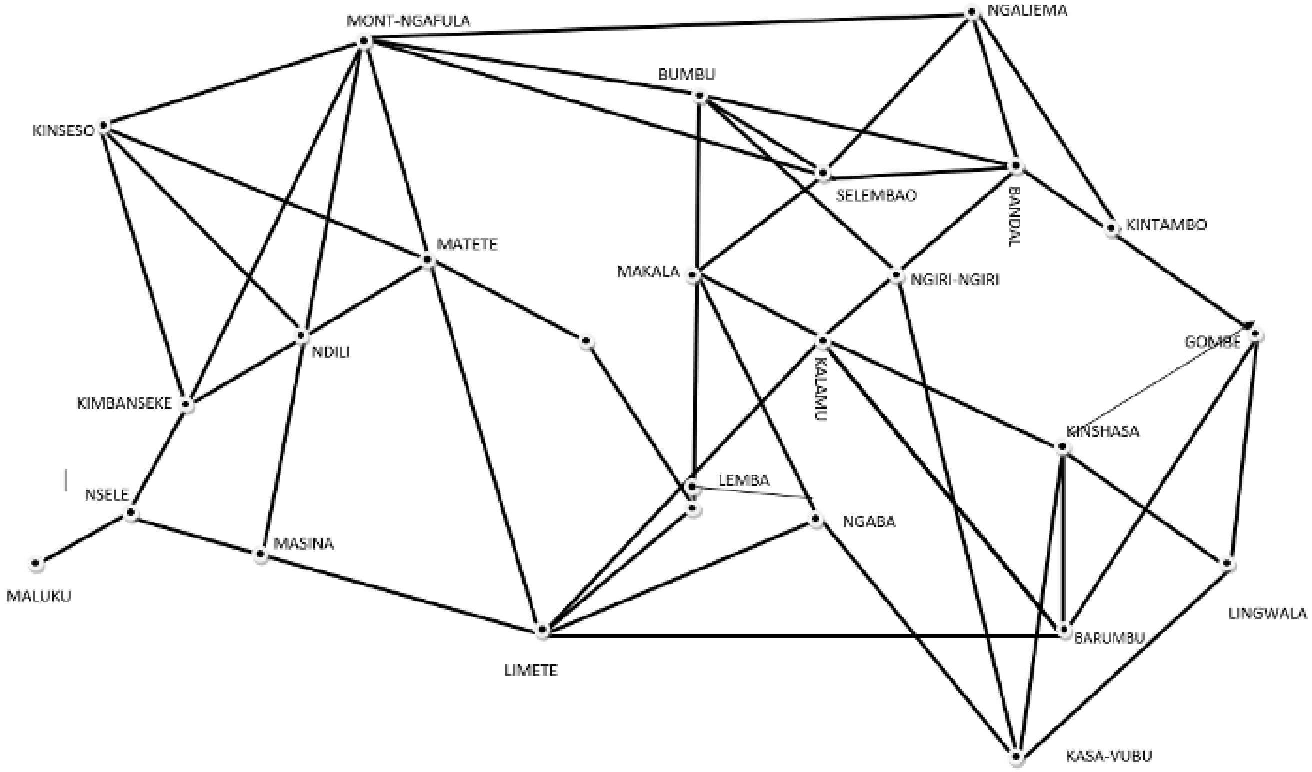
When a child node is the destination commune, the search is finished. The shortest path between the starting commune and the arrival one has been found [2] [3].

3.1.2. Illustration of B&B by an application to the city of Kinshasa

Consider the road transport network linking a number of communes in the city of Kinshasa, and suppose we are seeking the most direct route between the starting commune and a destination.

A node here will be a path in the network, with one end being the MALAKU district, which is the starting point. We will know that we have reached a leaf of the tree, that is, a solution state, when the other end of the path is the destination district, which is Gombe, as it is one of the longest paths. The root of the tree is a path of zero length containing only the MALUKU district. The child nodes are simply the paths obtained by considering the neighboring districts of the last district reached. We choose the distance traveled as the cost function.

4. NEW URBANIZATION PLAN OF THE CITY OF KINSHASA (SECONDARY ROADS) AND SECTORING OF THE ROAD SPACE BY B&B



CONCLUSION

Responsible for the mobility of citizens across the national territory, the public authority has, among other things, the prerogative to determine the relevance of establishing secondary roads and revising the transport network on a national scale. This research has shown that only mathematical tools can assist decision-makers in solving congestion issues that arise in the city-province of Kinshasa. Thanks to the Branch and Bound algorithm, a new urban planning scheme for the city-province of Kinshasa, in which all the municipalities are interconnected, has recently been developed. These edges constitute the secondary roads to be built.

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