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Problem of Multiflow with Application in the Road Transportation Network Exploited by Transco Company in Kinshasa City

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Abstract: *This article deals with the problem of maximal multiflow and applies it on the Kinshasa city transportation network exploited by the transport company called "Transco". It aims to determine additional equipment which permits the company to accomplish itself the trafic in the actual network. The two kinds of buses used by this company have been selected in the study as the two types of products moving in the system. The capacity of a one-way road (500 vehicles per hour) has been taken as the maximal capacity of each road band. The linear program obtained is solved by means of the "Linear Program Solver" software and the results show that the company covers now about 1.25 % of the flow in the network. Thus, we end the study showing additional equipment which allows the company to assure itself the transport in the network.*

Keywords: *Fuzzy multiflow, types of products, standard capacity, linear program solver, Transco Company*

1. Introduction

The problem of multiflow concerns the transportation in a network in which various types of products must be transported from their sources to specific destinations. Each road has some transportation capacity, and there are inquiries (demands) associated with each pair of source-destination. The network that connects sources to destinations may be modeled by the theory of graphs like a transportation network. The multiflow problem is a generalization of the flow problem which deals with the case of one type of product, one source and one destination.

In the literature, there are plenty of problems dealing with the flow in transportation network (see e.g. Harris and Ross [6]; Ford and Fulkerson [5]; Edmonds and Karp[4]). But only a few works among them such as Bentz [1]; Karima [7]; Costa [2], Mamanya[10] and Renfrey [11] have been devoted to the multiflow problem. In these both problems, the practical and theoretical interest were to provide answers to some questions in numerous industrial applications, namely in the design and processing of telecommunication, road transportation network, etc.

In the present article, we show how to apply the multiflow theory to the system transportation in Kinshasa city. The essential contribution of this article consists in modeling and solving the problem of multiflow in a concret case of Kinshasa city transportation. Through the maximum multiflow calculation, our aim pursued is split into three questions:

- What proportion of the flow Transco covers nowadays comparatively to the maximal flow in the network?
- What additional equipment (number of vehicles) this company needs to assure the maximal flow in the actual configuration network by itself?
- Among this equipment, what is the minimum quantity of each type of vehicle must be provided?

This article is organized as follows: Section 2 recalls the multiflow problem theory. Section 3 states the system of road transportation exploited by Transco Company in Kinshasa city. Section 4 presents the road network of Transco Company and its graph. Section 5 gives the modeling and the solution of the problem. Section 6 presents the results and discussion and Section 7 puts a conclusion.

2. Statement Of The Problem Of Multiflow

Let G = (P,A,C,X) be an oriented or non valued graph where P is a set of n nodes, A is a set of m edges (or arcs) and C a set of capacities noted cij(i,j adjacent). X = {xij | i,j ∈ G} is a set of flows of goods moving in G. To each edge is associated a capacity cij which describes the upper bound of the flow on this edge ; xij ≤ cij. To each edge is associated equally an unit cost δij which describes the cost per unit of flow on this edge. Let L be a list of pairs (sources si, destinations (sinks) pi) of the nodes in G (with si 6= pi,∀i). These pairs are called links; si and pi are called terminals. G is called support graph. Let us consider the flow for k types of distinct products between pairs of sources-destinations (k = 1,2,...,K). On each edge aij ∈ A(i,j adjacent), such a flow is often note d $x_{ij}^{(k)}$.

On each path source - destination having q nodes (si,...,pi) = (1,2,...,q), the flow of one product of type k moving on the path, note d $X_{s_ip_i}^{(k)}$, is calculated by :

$$x_{ij}^{(k)} = \sum_{i=1}^{n} \sum_{j=1}^{n} C_{ij}^{(k)} \qquad (k \text{ constant}) \qquad (1)$$

i=1 j=1

According to? [], using all k types of products, the multiflow of the entire network noted $X_G^{(k)}$ is given by the following formula:

$$x_G^{(k)} = \sum_{k=1}^{K} \sum_{\substack{i=1 \\ j=1}}^{n} C_{ij}^{(k)} n \qquad (2)$$

under constraints (*Mamanya [9]* :

$$\begin{cases} \sum_{k=1}^{K} x_{i.j}^{(k)} \leq Cij, \quad i = 1, \dots, n, j = 1, \dots, n \; et \; k = 1, \dots, K & (3a) \\ \sum_{k)1}^{K} x_{i.j}^{(k)} = Xi = Xj = \sum_{k}^{K} x_{j.i}^{(k)}, i = source \; et \; j = destination & (3b) \\ \sum_{k)1}^{K} x_{i.j}^{(k)} - \sum_{k=1}^{(K)} x_{j.i}^{(k)} = 0 \;, i \neq sources \; et \; j \neq destination & (3c) \\ x_{i.j}^{(k)} \in N & (3d) \end{cases}$$

3. System Of Road Transportation

There exist two types of roads (Déléphanque [3]):

- Road with continuous flow: it is essentially about the type of road on which traffic is uninterrupted. Its flow is regular.
- Road with discontinuous flow: it is about a type of road on which traffic is broken. Its flow is irregular.

Note: the capacity of a road is the hourly flow of vehicles, goods or individuals that it can support in a given period of time. That value is a function of three concepts ([8], [10]):

- Road conditions: these are the characteristics of a road, such as its type, the number of ways or bands, the width of ways, and the expected circulation speed.
- Traffic conditions: characteristics of control structure as well as road regulations like speed limit, one-way road, and rules of priority.

Thus, according to that precedes, the standard capacity of a road is nearly 1000 vehicles per hour for roads with continuous flow having two ways, and nearly 500 for roads with discontinuous flow having one single way.

In this article, the road capacity per hour is considered as the number of ways that it has, multiplied by 500. Traffic can be approached from three elementary measurements: speed, volume, and density. Speed relates to the distance run per time unit. Average speed is the parameter the most used.

4. PRESENTATION OF TRANSCO COMPANY

4.1. Historical background [11]

Everything started from a strike by the cooperation of (professionals of transportation) of private transporters of Kinshasa city launched in April 2012). In front of that disaster which paralyzed the city of Kinshasa and, exhausted by the permanent difficulty of the Congolese population to move decently, the central government opted to act. So, during the council of Ministers held in June 2012, it was decided to buy new buses and entrust their management to a new company. It is, then, in this context, that the "Transportation in the Congo", TRANSCO in short, arose in January 2013 on a decree by the prime Minister in order to meet the needs for the mobility of the Congolese population. The government of RDC appealed to the expertise of the "Régime Autonomies des transports Parisiens-international, RATP-I. So, in April 2013, a contract of technical assistance was signed between the Congolese government and the RATP-I. And, dewing 15 months, TRANSCO worked with the RATO-I until October 2015, when a new committee took over the management of the company. TRANSCO is a public Congolese establishment specialized in the field of urban and inter-urban transportation. Its head office is based in Kinshasa. Supported by 2,687 men and women, it has an annual turnover of CDF 23 995 057 556.29. The main jobs there are: regulators, drivers, collectors, controllers, technicians, and mechanizes. The vehicle stock consists of 499 buses among which 369 standard buses and 130 mini-buses. Those buses transport an annual average of 44 648 375 passengers, be them a monthly average of 3 720 698 passengers, and a daily average of 200 000 passengers. TRANSCO offers services of school bus subscription and bus renting. It also exploits a Kinshasa-Kikwit inter-urban transportation network, with the project to cover the town of Matadi very soon. Its urban network includes 28 lines shared throughout the network of Kinshasa city below.

4.2 Network graph exploited by Transco

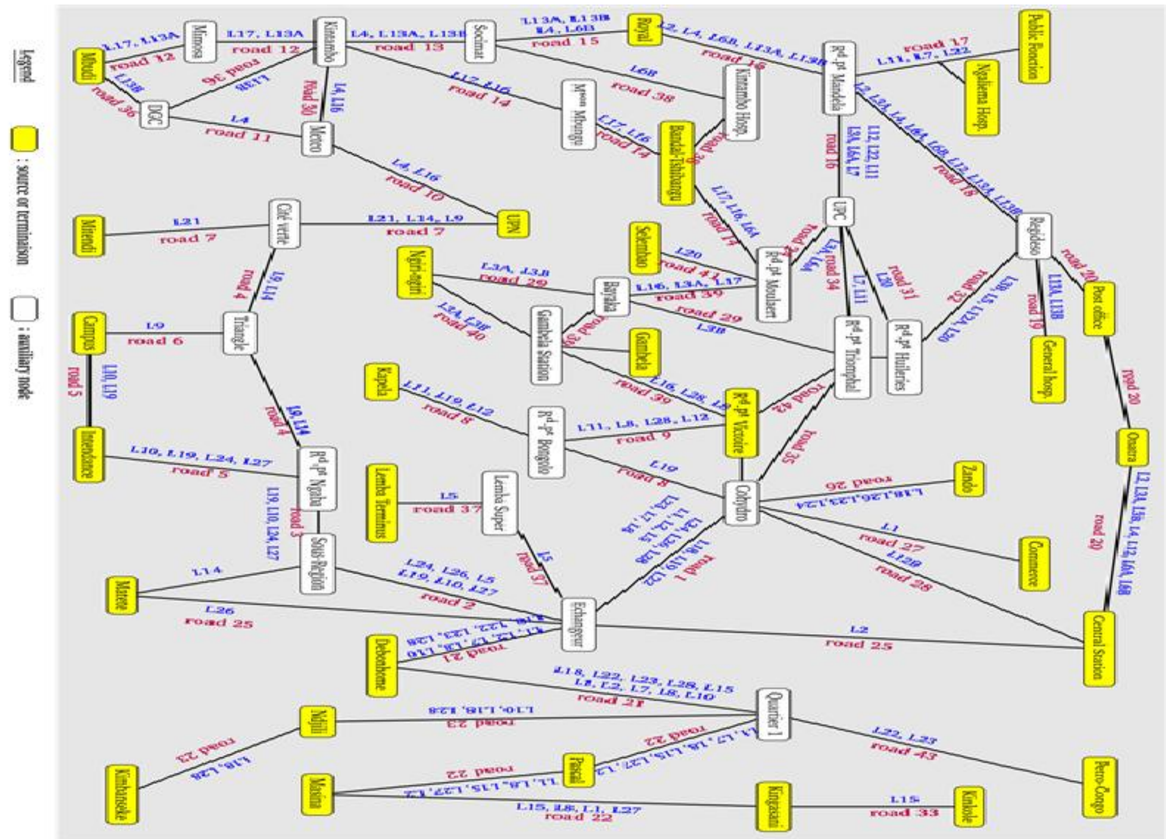

Figure 1 : Road system graph of Transco Company.

5. MODELING

The conformity to the multiflow network theory requires to provide the following steps:

- To set the way of circulation on each line (arc) and for each type of product. In our model, the way of circulation goes from the source to the terminus (destinations). However, the terminus may become a source, and a source may become a terminus. That compels us to consider a non-oriented network.
- To fix per hour the capacity of each road; this parameter is often considered as the maximal number of products observed registered in a fixed point of the network. For lack of standard capacity that must have a raad, we consider 500 vehicles by band and by hour([10)].

  To determine the different types of products transported from their sources to their destinations. The following table 1 shows how the two types of Tranco products (standard buses and mini-buses) are distributed in the network lines. Let us note that L25 is not working yet, and L14 and L9 are temporarily stopped.

Table 1. *Distribution of products on the lines*

Product of type 1 (Standard buses)							**Product of type 2 (Mini-buses)**				
L1	L2	L4	L5	L7	L8	L9	L3A	L3B	L6A	L6B	L11
L10	L13A	L13B	L14	L15	L16	L17	L 12A	L21	L22	L23	L26
L18	L19	L20	L24	L27	L28		L12B				

- Consider the flow as the amount of goods that effectively pass on a roadway during this specific moment of time. In this article, we consider as flow upon entry, the number of buses that Transco sends on each line as indicated on the table 2.
- To merge into one single edge (arc) different roads having a same source and the same terminus, by summation of their respective capacities. In our analysis, L3A and L3B, L6A and L6B, L12A and L12B as well as L13A and L13B have been merged respectively into L3, L6, L12, L13.

To assure the transport in the network, Transco has at one's disposal 499 buses among which 390 standards buses and 90 mini-buses turn effectively on about 32 lines as indicated on the table 2.

Table 2. *Transco network lines*

LINE	DEPARTURE		TERMINUS	LINE	DEPARTURE		TERMINUS
L1	Kingasani	-	Commerce	L13B	Mbudi	-	Gen. Hosp. via DGC
L2	Masina	-	Royal	L14	Matete	-	UPN
L3A	Ngiri-ngiri	-	Central Station via 24 Nov.	L15	Kinkole	-	Debonhome
L3B	Ngiri-ngiri	-	Central Station via Huileries	L16	UPN	-	Victoire
L4	UPN	-	Central Station	L17	Mbudi	-	Gambela
L5	Lemba	-	Post Office	L18	Kimbaseke	-	Zando
L6A	Bandal-Tshibangu	-	Onatra via Molaert	L19	Campus	-	Victoire
L6B	Bandal-Tshibangu	-	Onatra via Kintambo Hosp.	L20	Selembao	-	Zando
L7	Pascal	-	Public Fonction	L21	Mitendi	-	UPN
L8	Kingasani	-	Gambela	L22	Petro-congo	-	Public Fonction
L9	UPN	-	Campus	L23	Petro-congo	-	Zando
L10	Ndjili	-	Campus	L24	Intendance	-	Zando
L11	Kapela	-	Ngaliema Hospital	L25			Non-operational
L12A	Kapela	-	Central Station via Huileries	L26	Matete	-	Zando
L12B	Kapela	-	Central Station via Kasaï	L27	Kingasani	-	Intendance
L13A	Mbudi	-	Gen. Hosp. via Tourisme	L28	Kimbaseke	-	Gambela

As for distribution of flows in the network, we have splintered the network into 43 roads as indicated on the table 3.

Table 3. *Routes du réseau exploité par Transco.*

N◦	ROUTE	LIGNES	CAPACITES DES ROUTES
1	Échangeur - Cohydro	L1, L2, L5, L7, L8, L18, L19, L22, L23, L24, L26, L28	4 000 /heure
2	Échangeur - Sous région	L19, L10, L27, L24, L26, L5	2000 /heure
3	Sous-Région - RP Ngaba	L19, L10, L24, L27	2000 /heure
4	RP Ngaba - Cité verte (CV)	L9, L14	2 000 /heure
5	RP Ngaba - Campus	L10, L19, L24, L27	1000 /heure
6	Triangle - Campus	L14, L9	2 000 /heure
7A 7B	UPN - Cité Verte Cité Verte - Mitendi	L21, L14, L9 L21	2000 /heure 2 000/heure
8A 8B	Kapela - RP Bongolo RP Bongolo - Cohydro	L19 L19	1000 /heure 1000 /heure
9	RP Bongolo - RP Victoire	L11, L12	1000 /heure
10	UPN - Meteo	L4, L16	2000 /heure
11	Météo - DGC	L4	1 000 /heure
12	Mbudi - Kintambo	L17, L13	2000 /heure
13	Kintambo - Socimat	L4, L13	2000 /heure
14	Kintambo - Moulaert	L17, L16	1000 /heure
15	Socimat - RP Mandela	L4, L6, L13	4 000 /heure
16	UPC - RP Mandela	L3, L6, L7, L11, L12, L22, L20	3 000 /heure
17	RP Mandela - F. Publique	L7, L11, L22	2 000 /heure
18	RP Mandela - Regideso	L2, L3, L4, L6, L12, L13	4 000
19	Regideso - Hop. Gen. Kinshasa	L13, L20	1000) /heure
20	Regideso - Central Station	L4, L3, L6, L12	4 000) /heure
21	Échangeur - Quartier 1	L1, L2, L7, L8, L10, L18, L22, L23, L28	4 000 /heure
22	Quartier 1 - Kingasani	L1, L7, L8, L15, L27	4 000 /heure
23	Quartier 1 - Kimbanseke	L10, L18, L28	1000 /heure
24	Moulaert - UPC	L3, L6, L20	2 000 /heure
25	Matete - Central Station	L2	2000 /heure
26	Cohydro - Zando	L26, L24, L23	1 000 /heure
27	Cohydro - Commerce	L1	1000 /heure
28	Cohydro - Central Station	L12B	1000 /heure
29	Ngiri-ngiri - RP Huileries	L3B	(000 /heure
30	Kintambo - Meteo	L16	1000 /heure
31	UPC - Huileries	L20	4 000 /heure
32	Huileries - Regideso	L3B, L5, L12A, L20	2000 /heure
33	Kinkole - Kingasani	L15	2000 /heure
34	UPC - RP triomphal	L7,L11	3000 /heure
35	Cohydro - RP triomphal	L7, L5	3000 /heure
36	Mbudi - DGC - Kintambo	L13	1000 /heure
37	Lemba terminus – Echangeur	L5	1000 /heure
38	Bandal Tshibangu - Socimat	L6	1000 /heure
39	RP Victoire - Gambela Station	L28, L18, L8	1000) /heure
40	NgiriNgiri - Gambela Station	L17, L3, L16	1000 /heure
41	Selembao - Moulaert	L20	1000 /heure
42	RP Victoire - RP Triomphal	L12, L28, L8, L11	3000 /heure
43	Petro Congo - Quartier 1	L23, L22	1000 /heure

Moreover, let us consider flows of k distinct types of products between sources and destinations. On our network, the flow of k-type product taking the road i (arc or edge i) is noted $x_{i.j}^{(k)}$ where j represents all buses lines operating on i; and there are 32 buses lines and 43 roads. Thus, the multiflow Zi on road i is

$$Z_i=\sum_{j=1}^{j=32}\sum_{i=1}^{i=43} x_{ij}^{(k)}, \quad k = 1,2 \tag{4}$$

To calculate the multiflow Z on the entire network, we will use all roads, all types of products and all buses lines. Thus, we obtain Z using the following formula:

$$Z=\sum_{k=1}^{k=2}\sum_{i=1}^{i=43}\sum_{j=1}^{j=32} x_{ij}^{(k)} \tag{5}$$

Eq. (5) implies $x_{i.j}^{(k)} = 0$ if the product k takes not the road i or if the product k is not affected to the line Lj. It is always solved under the following constraints [9]:

$\sum_{k=1}^{2} x_{i.j}^{(k)} \leq C_{i.j}$, =1,...,43 et j=1,...32 (6a)

$\sum_{k=1}^{2} x_{i.j}^{(k)} - \sum_{k=1}^{2} x_{ji}^{(k)}=0, \ \forall\, i = 2,\dots,$ n-1 (6b)

$\sum_{k=1}^{2} x_{i.j}^{(k)}=\sum_{k=1}^{2} x_{j.i}^{(k)}, \quad \forall\, i = source, \forall\, j = destination$ (6c)

$x_{i.j}^{(k)} \in \boldsymbol{N}$ (6d)

Assume x(i.jk) the k-type flow from Lj line moving on the road i (1 ≤ k ≤ 2;k : integer). Noting by Z1 and Z2 respectively the total flow of type 1 and the total flow of type 2 in the network, we obtain the following fuzzy linear program

$\max Z_1 = \sum x_{i.j}^{(1)}, \quad i \in \{1, 2, 4, 10, 12, 13, 14, 18, 19, 24, 27, 28, 33\};$

$j \in \{1,2,4,5,7,8,9,10,13A,13B,14,15,16,17,18,19,24,27,28\}.$

$\text{Max } Z_2 = \sum x_{i.j}^{(2)}, \quad i \in \{16,20,38,8,28,24,21,43,1\}; j \in \{3A,3B,6A,6B,11,12A,12B,20,22,23,26\}.$

$X^{(1)}_{1.1}+X^{(1)}_{1.5}+X^{(1)}_{1.7}+X^{(1)}_{1.8}+X^{(1)}_{1.18}+X^{(1)}_{1.19}+X^{(2)}_{1.22}+X^{(2)}_{1.23}+X^{(1)}_{1.24}+X^{(2)}_{1.26}+X^{(1)}_{1.28} \leq 4.000$ (1)

$X^{(1)}_{2.19}+X^{(1)}_{2.10}+X^{(1)}_{2.27}+X^{(1)}_{2.24}+X^{(1)}_{2.26} \leq 2.000$ (2)

$X^{(1)}_{3.19}+X^{(1)}_{3.10}+X^{(1)}_{3.24}+X^{(1)}_{3.27} \leq 2.000$ (3)

$X^{(1)}_{4.9}+X^{(1)}_{4.14} \leq 1.000$ (4)

$X^{(1)}_{5.10}+X^{(1)}_{5.19}+X^{(1)}_{5.24}+X^{(1)}_{5.27} \leq 1.000$ (5)

$X^{(1)}_{6.9} \leq 1.000$ (6)

$X^{(1)}_{7.14}+X^{(1)}_{7.21}+X^{(1)}_{7.9} \leq 2.000$ (7)

$X^{(2)}_{8.11}+X^{(1)}_{8.19}+X^{(2)}_{8.12} \leq 1.000$ (8)

$X^{(2)}_{9.11}+X^{(1)}_{9.8}+X^{(1)}_{9.28}+X^{(2)}_{9.12} \leq 1.000$ (9)

$X^{(1)}_{10.4}+X^{(1)}_{10.16} \leq 2.000$ (10)

$X^{(1)}_{11.4} \leq 1.000$ (11)

$X^{(1)}_{12.17}+X^{(1)}_{12.13} \leq 1.000$ (12)

$X^{(1)}_{13.4}+X^{(1)}_{13.13}+X^{(1)}_{13.13'} \leq 2.000$ (13)

$X^{(1)}_{14.17}+X^{(1)}_{14.6}+X^{(1)}_{14.16} \leq 1.000$ (14)

$X^{(1)}_{15.2}+X^{(1)}_{15.4}+X^{(1)}_{15.13}+X^{(1)}_{15.13'} \leq 2.000$ (15)

$X^{(2)}_{16.12}+X^{(2)}_{16.22}+X^{(2)}_{16.11}+X^{(2)}_{16.3}+X^{(2)}_{16.6}+X^{(1)}_{16.7} \leq 3.000$ (16)

$X^{(1)}_{17.7}+X^{(2)}_{17.11}\ X^{(2)}_{17.22} \leq 2.000$ (17)

$X^{(1)}_{18.2}+X^{(2)}_{18.3}+X^{(1)}_{18.4}+X^{(2)}_{18.6}+X^{(1)}_{18.6'}+X^{(2)}_{18.12}+X^{(1)}_{18.13}+X^{(1)}_{18.13'} \leq 4.000$ (18)

$X^{(1)}_{19.13}+X^{(1)}_{19.13'} \leq 1.000$ (19)

$X^{(1)}_{20.2}+X^{(2)}_{20.3}+X^{(2)}_{20.3'}+X^{(1)}_{20.4}+X^{(2)}_{20.12}+X^{(2)}_{20.6}+X^{(2)}_{20.6'} \leq 4.000$ (20)

$$X^{(1)}_{21.1} + X^{(1)}_{21.7} + X^{(1)}_{21.8} + X^{(1)}_{21.10} + X^{(1)}_{21.18} + X^{(2)}_{21.22} + X^{(2)}_{21.23} + X^{(1)}_{21.28} \leq 4.000 \quad (21)$$

$$X^{(1)}_{22.1} + X^{(1)}_{22.7} + X^{(1)}_{22.8} + X^{(1)}_{22.15} + X^{(1)}_{22.27} \leq 4.000 \quad (22)$$

$$X^{(1)}_{23.10} + X^{(1)}_{23.18} + X^{(1)}_{23.28} \leq 1.000 \quad (23)$$

$$X^{(1)}_{25.2} \leq 2.000 \quad (24)$$

$$X^{(1)}_{26.26} + X^{(1)}_{26.24} + X^{(2)}_{26.23} \leq 1.000 \quad (25)$$

$$X^{(1)}_{27.1} \leq 1.000 \quad (26)$$

$$X^{(1)}_{28.12'} \leq 1.000 \quad (27)$$

$$X^{(1)}_{29.3'} \leq 1.000 \quad (28)$$

$$X^{(1)}_{30.4} + X^{(1)}_{30.16} \leq 1.000 \quad (29)$$

$$X^{(1)}_{31.20} + \leq 4.000 \quad (30)$$

$$X^{(1)}_{32.3'} + X^{(1)}_{32.5} + X^{(2)}_{32.12} + X^{(1)}_{32.20} \leq 2.000 \quad (31)$$

$$X^{(1)}_{33.15} \leq 2.000 \quad (32)$$

$$X^{(1)}_{34.7} + X^{(2)}_{35.11} \leq 3.000 \quad (33)$$

$$X^{(1)}_{35.5} + X^{(1)}_{35.7} \leq 3.000 \quad (34)$$

$$X^{(1)}_{36.13'} \leq 1.000 \quad (35)$$

$$X^{(1)}_{37.5} \leq 1.000 \quad (36)$$

$$X^{(2)}_{38.6'} \leq 1.000 \quad (37)$$

$$X^{(1)}_{39.16} + X^{(1)}_{39.28} + X^{(1)}_{39.8} \leq 1.000 \quad (38)$$

$$X^{(1)}_{40.16} + X^{(2)}_{40.3} + X^{(1)}_{40.17} \leq 1.000 \quad (39)$$

$$X^{(1)}_{41.20} \leq 1.000 \quad (40)$$

$$X^{(2)}_{43.11} + X^{(2)}_{43.12} \leq 000 \quad (41)$$

$$X^{(2)}_{42.11} + X^{(1)}_{42.8} + X^{(1)}_{42.28} + X^{(2)}_{42.12} \leq 3.000 \quad (42)$$

$$X^{(2)}_{43.22} + X^{(2)}_{43.23} \leq 1.000 \quad (43)$$

$X^{K}_{IJ} \geq 0 \; \forall i : 1 \leq 43 \; ; \; \forall i : 1 \leq j \leq 32 \; ; \; \forall k : 1 \leq k \leq 2$

To solve linear program above, we have used a software called « LINEAR PROGRAM SOLVER » (LIPS) under Cholesky's decomposition.

6. Results and Interprétation

We have found the following solution:

maxZ1 = 8 990

maxZ2 = 3 117

Thus, (Z1,Z2) = (8 990, 3 117)

- A considerable gap between the calculated multi flow (8 990, 3 117) and the experimental flow (390, 90), that really pass on the network. The calculated multi flow is the one that would pass if traffic is optimal on the network.
- The self propelling park n circulation of yhe Transco actuel is esteemed to 480 vehiles.
- Ttansco add its equipement of 11 627 vehicles for realizing the maximal multiflow of its network.

7. CONCLUSION

We are no doubt convinced that TRANSCO produces a service on behalf of Kinshasa people but does not cover the entire city road network. One of the essential objectives of this study was also to suggest a mathematical solution for problems of traffic jams that erode the network under study. The solution found consists in reducing the number of moving buses by requiring at the same time city transporters to buy big buses for common transportation. Personal transport will be reserved exclusively to a well controlled minority. In this paper, the calculated multi flow sets the number of buses to be reached and suggests their sharing on the whole of the network under study. Considering the importance of this to pie in the management of the city of Kinshasa, we suggest for future researchers:

1. The application of multi flow with three products (TRANSCO buses, personal buses, private buses) on the TRANCO network;
2. The application of the fuzzy multi flow on the Kinshasa city network;

The application of multi flow on the DRC road network.

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