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RESEARCH ARTICLE

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OPTIMIZING ROAD SAFETY IN THE CITY OF BERTOUA, USING THE ELECTRE III METHOD

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ABSTRACT

The overall objectif of this study to optimize road safety in the development of urban roads in the city of Bertoua. To that end, we analyzed data collected by the GPS system, exploited satellite images of the Bertoua urban road network as well as the statistics on road accidents recorded in that city. The aim of these analyses was to take stock of road safety in the city. GIS tools enabled us to carry out distribution, localization as well as road security equipment distribution analyses; we also carried out the cartography of road accidents in the city so as to build up hypotheses of actions that could be implemented in order to improve road safety in developing urban roads in the city ofBertoua. An optimization analysis was conducted using the ELECTRE III multi-criteria analysis method, which enabled us to assess the various actions linked to the occurrence of road accidents in the city of Bertoua. The WSM method was used to determine the weight of each action envisaged for all criteria retained in our study. The solution to the optimization function developed through the merging of these two methods was done using the Simplex algorithm and verified by the PHP Simplexapplication.Results from our study reveal that we can reduce accidents risks by acting on the following aspects: The design of roads and car maintenance amounting to 38% reduction, and the behaviour of users and drivers aptitude to drive for 62%. All these elements put together would lead to an optimization that may go up to 95.5%, that is cutting down 114 accidents from the 119 recorded every year on average.

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INTRODUCTION

According to the World Health Organization (WHO), with only 2% of the world's total number of cars, Africa accounted for 24.1% of road casualtiesin 2016. 1.25 million personslost their lives on roads all over the world, among which 300 000 in Africa. This carnage is disproportionate compared to the road network and the number of vehicles plying the roads. Inappropriate regulations, old state of vehicles and roads, risky behaviour on the steering wheel, increase in income levels, alcoholism and corruption are some factors that come into play. Nowadays, the issue of road safety is as important as the construction of road networks. By gradually moving towards intelligent cities model, developers are now reflecting on sustainable cities,cities that include economic growth, preservation of natural resources and social equity.

This economic growth is often hampered by the reality of making available growth and communication tools,while paying special attention to the individual who lives within hisartifact. Road safety thus appears as the highest pointwhere investigations should be carried out in an urban context where city dwellers are more prone to road accidents. Africa in general and Cameroon in particular have the most increasing records of road accidents.This reality is present in most of Cameroonian cities such as Bertoua, the capital of the East Region in Cameroon. The city of Bertoua in Cameroon is no exception with a more and more increasing rate of road accidents. Due to demographic growth and high urbanization, the demand in terms of transport infrastructure is being felt.The need for road repairs, improvement of the road network is one of the major preoccupations of the State of Cameroon that launched some projects, through its devolved services and decentralized territorial collectivities in response to the issue of road infrastructures and urban public utilities in Cameroonian cities.

METHODOLOGY

General issue: How to define, manage and plan safety indicators to improve road safety conditions in the city of Bertoua

Overall objective: To design a GIS model that includes urban road network data and develop an objective function to optimize road safety in the construction of Bertoua city road networks. Data collection for this research was done in Government services. We also developed road and equipment inquiry cards,also carried out direct viewing and interviews of residents. Data included in this end-of-training dissertation are those that cover the period between 2012 during the development of the diagnosis and development prospects report for the city of Bertoua, and 2019. This dissertation was started on Monday January 8, 2019 for a period of 6 months.

Description of the working approach: In this chapter, we will have to apply a multi-criteria method of analysis for the choice of actions leading to the optimization of road safety in developing urban roads networks in the city of Bertoua. The methodology will be based on a well-known multi-criteria method of analysis known as ELECTRE III method that will enable us to compare the various actions that developers will implement in order to significantly reduce accident risks on the road network of the city of ELECTRE III Bertoua. Then, we will use another method called Weighted Sum Model (WSM) that will enable us to determine the importance of each of these actions on the criteria we used to carry out our research.Finally, we will come out with our utility function that we will solve in order to reduce the variables and the main factors that are responsible of accidents on the road network and increase road safety in the city of Bertoua.

2 Basis of the Electre III Multi-criteria method of analysis: The multi-criteria decision-making tools are being increasingly used in recent years, especially in issues relating to town planning. The ELECTRE III multi-criteria method of analysis is an analysis and decision-making method based on the designing of alternatives and actions through a partial approach of performances. For each pair of actions (ai, ak), a level of the S outclassing credibility (ai, ak) shall be determined. Tis level is situated between0and 1, and it increases as the strength of the outclassing increases. This multi-criteria method of analysis is based on a constructive approach which happens to be a decision-making tool, which helps to create a dialogue between the various stakeholders, taking into account the importance given to judgment criteria. Its principle is based on an outclassing hypothesis between actions.

3 Defining Electre III parameters

Actions or alternatives : Actions or alternatives indicated as «ai»are the set of operations that may be implemented to optimize the Pγ storage problem of the said actions, from the best to the least.

Criteria : The set of criteria«j»applies to features we refer to or we use in order to choose, classify or select an action "ai". Each criterion « j »in ELECTRE III can be associated to three thresholds (indifference Q, preference P, veto V) used to define areas of preference between two actions.

qj: indifference indexto criterion j.
pj: preference indexto criterion j.
vj: veto index to criterion j.

The first two thresholds q j and p j are used to define a pseudo-criterion. Considering two actionsaiand bi belonging to a set of potential actions,and two thresholds q j and p j whereqj<pj, the following relation are defined:

a et b are indifferent when the difference between the performances of both actions is lower than the indifference threshold, that is

(a I b) implies that $g_j(a)-g_j(b) < q_j(g_j(a))$,

withgj(a) representingthee assessment of the action's performance as compared to criterion j

a is less preferred to b when the difference between the performances of both actions is situated between the indifference threshold and the preference threshold

(a Q b) implies that $q_j(g_j(a)) \leq g_j(a)-g_j(b) \leq p_j(g_j(a))$,

A is clearly preferred to b when the difference between the performances of both actions is higher than the strict preference threshold.
(a P b) implies that $g_j(a)-g_j(b) \geq p_j(g_j(a))$

In addition, when for a criterion j, action a is less good than action b, we verify if the difference between the performances of actions a and b is higher than the veto thresholdvj, that is a threshold beyond which it would be cautious to deny any credibility to the outclassing of action a by action b;therefore, the outclassing of action a by b is no longer possible, even if it is for all the other criteria:

Non (a S b) ⇔g j(a) – g j(b)≥v j(g j(a))

•The concordance index

The overall concordance index first of all indicates the importance of the affirmation “a S b”, where a and b represent two possible alternatives. Two actions will be said to be in concordance when the concordance index is high. It isexpressed as« Cik »,

$$C\,i\,k = \frac{\sum W\,j\;C\,j\;(a,b)}{\sum W\,j}$$

WhereWj: weight of criterion j

AndCj (a, b) the concordance index per criterion defined by the following relation:

For any criterion j, Cj (a, b)=0 if g j(b) - g j(a)>p j

Cj (a, b)=1 if g j(b) - g j(a)≤q j

The discordance index : Contrary to the concordance index, 02 actions are said to be in discordance when the discordance is high. The discordance index is assessed using qj preference and vj veto thresholds. It is noted Dj (a, b) and expressedas follows:
For any j criterion, Dj (a, b)=0 if g j(b)-g j(a)≤p j

Dj (a, b)=1 if g j(b)-g j(a)>v j
0<Dj (a, b) <1 if p j<g j(b)-g j(a)≤v j

Credibilitylevel: Considering the values of concordance and discordance indexes, the credibility level indicates whether the outclassing hypothesis is feasible or not. It is notedφ (a, b) and expressed as follows:

For any j criterion**, φ(a,b)=C(a,b) ifDj(a,b)>C(a,b**), where C(a,b) : overall concordance of actions, and

$$\varphi(a,b) = \frac{C(a,b)\prod(1 - Dj(a,b))}{1 - C(a,b)}$$

4 Using the ELECTRE III Method in solving the problem of the increasing number of road accidents in the city of Bertoua

In order to apply the ELECTRE III Method to our issue of road accidents on the Bertoua road network, we used the various causes and factors of road accidents. It should be noted that many causes may explain the occurrence of road accidents in urban areas as listed in graphs presented in chapter 1of this analysis under the part devoted to road security. From these graphs, one may conclude that the increase in road accidents risks is linked to the conditions of road maintenance, the behaviour of road users, their aptitudes, the design of roads, and to car design and maintenance. Within the framework of our study, an analysis is needed in order to develop a utility function of the road security aspect on the road network of the city of Bertoua. To that end, we decided to use the ELECTRE III method because generally, when we pose a multi-criteria problem, we have to find the most appropriate solution, given a certain number of criteria, and this solution may take various forms (choice, allotment, and classification). We can therefore act in four main steps:

- Draw upa list of potential actions
- Draw upa list of criteria to be taken into consideration
- Draw up a list of performances
- Aggregate performances

Listsof potential actions and criteria to be taken into account are established by indicating the opinions of the fifty people interviewed according a representative sample of various groups that use the road: drivers of heavy duty transporters (log-trucks, trucks), taxi drivers, motorbike taxi drivers, private car drivers, pedestrians, highway police unit.

RESULTS

Results from the study

List of potential actions : Potential actionsthat were deemed most important where classified in a table where they will be identified by lettersaij.

Table 1. Actions

Identifiers	Actions
A1	a11 : sensitize users on dangerous behaviour (pedestrians and drivers)
	a12: sanction flagrant road offences
A2	a21: check the users' ability to fly by inspecting drivers licenses.
A3	a31: carry out repair works on certain roads of the network
	a32: carry out lay out works by attributing transverse profiles to roads by taking into account the existing profile and profiles to come
	a33 : improveroadsides
A4	a41 : buildretentiondevices
	a42 : install public lighting
	a43 : put up road marking and road signs
	a44 : build new roads
A5	a51 : carry out maintenance technical checks of vehicles

Table 2.Assessment of actions' performances as compared to criteria

Actions	C1	C2	C3	Total
a11	7	3	7	17
a12	3	5	5	13
a21	9	3	7	19
a31	3	7	7	17
a32	3	7	7	17
a33	7	5	5	17
a41	7	5	3	15
a42	7	5	3	15
a43	7	7	1	15
a44	5	7	7	19
a51	9	5	1	15
Preferred orientation	+ ↗	+ ↗	+ ↗	
Importance	3	2	3	8
Indifference (q)	2	2	2	6
Preference (p)	4	3	3	10
Veto (v)				

Table3. Preference and indifference thresholds of actions as compared to the safety criterion

Actions	Performance values of actions as compared to the safety criterion	P1: Preference threshold of actions as compared to the safety criterion (p=4)	Q1: indifference threshold of actions as compared to the safety criterion (q=2)
a11	7	7*4=28	7*2=14
a12	3	3*4=12	3*2=6
a21	9	9*4=36	9*2=18
a31	3	3*4=12	3*2=6
a32	3	3*4=12	3*2=6
a33	7	7*4=28	7*2=14
a41	7	7*4=28	7*2=14
a42	7	7*4=28	7*2=14
a43	7	7*4=28	7*2=14
a44	5	5*4=20	5*2=10
a51	9	9*4=36	9*2=18

Tableau 4. Concordance of actions for the safety criterion

Actions	a11	a12	a21	a31	a32	a33	a41	a42	a43	a44	a51
a11	1	1	1	1	1	1	1	1	1	1	1
a12	0	1	0	1	1	0	0	0	0	1	0
a21	1	1	1	1	1	1	1	1	1	1	1
a31	0	1	0	1	1	0	0	0	0	1	0
a32	0	1	0	1	1	0	0	0	0	1	0
a33	1	1	1	1	1	1	1	1	1	1	1
a41	1	1	1	1	1	1	1	1	1	1	1
a42	1	1	1	1	1	1	1	1	1	1	1
a43	1	1	1	1	1	1	1	1	1	1	1
a44	1	1	0	1	1	1	1	1	1	1	0
a51	1	1	1	1	1	1	1	1	1	1	1

List of criteria to be considered and weighting operations: After having listed actions to be implemented, criteria on the basis of which we shall work must be indicated as well as how we should name the various actions and what importance should be given to each of these criteria (weighting of criteria).

Table 5. Preference and indifference thresholds for actions as compared to the performance criterion (source: road network survey, February 2019)

Actions	Performance values of actions as compared to the safety criterion	P1: Preference threshold of actions as compared to the safety criterion(p = 3)	Q1: indifference threshold of actions as compared to the safety criterion(q = 2)
a11	3	9	6
a12	5	15	10
a21	3	9	6
a31	7	21	14
a32	7	21	14
a33	5	15	10
a41	5	15	10
a42	5	15	10
a43	7	21	14
a44	7	21	14
a51	5	15	10

Table 6. Concordance of actions for the performance criterion

Actions	a11	a12	a21	a31	a32	a33	a41	a42	a43	a44	a51
a11	1	1	1	0	0	1	1	1	0	0	1
a12	1	1	1	1	1	1	1	1	1	1	1
a21	1	1	1	0	0	1	1	1	0	0	1
a31	1	1	1	1	1	1	1	1	1	1	1
a32	1	1	1	1	1	1	1	1	1	1	1
a33	1	1	1	1	1	1	1	1	1	1	1
a41	1	1	1	1	1	1	1	1	1	1	1
a42	1	1	1	1	1	1	1	1	1	1	1
a43	1	1	1	1	1	1	1	1	1	1	1
a44	1	1	1	1	1	1	1	1	1	1	1
a51	1	1	1	1	1	1	1	1	1	1	1

Table 7. Preference and indifference criteria thresholds for actions according to the performance criterion (source: road network survey, February 2019)

Actions	Performance values of actions as compared to the sustainability criterion	P1: Preference threshold of actions as compared to the sustainability criterion (p= 3)	Q1: indifference threshold of actions as compared to the sustainability (q=2)
a11	7	21	14
a12	5	15	10
a21	7	21	14
a31	7	21	14
a32	7	21	14
a33	5	15	10
a41	3	9	6
a42	3	9	6
a43	1	3	2
a44	7	21	14
a51	1	3	2

Table 8. Concordance of actions on the sustainability criterion

Actions	a11	a12	a21	a31	a32	a33	a41	a42	a43	a44	a51
a11	1	1	1	1	1	1	1	1	1	1	1
a12	1	1	1	1	1	1	1	1	1	1	1
a21	1	1	1	1	1	1	1	1	1	1	1
a31	1	1	1	1	1	1	1	1	1	1	1
a32	1	1	1	1	1	1	1	1	1	1	1
a33	1	1	1	1	1	1	1	1	1	1	1
a41	0	1	0	0	0	1	1	1	1	0	1
a42	0	1	0	0	0	1	1	1	1	0	1
a43	0	0	0	0	0	0	1	1	1	0	1
a44	1	1	1	1	1	1	1	1	1	1	1
a51	0	0	0	0	0	0	1	1	1	0	1

Three main criteria have been selected

- Criterion no.1 -: Safety of actions
- Criterion no.2 -: Performance of actions
- Criterion no.3 -: Sustainabilityof actions

Table 9. Criteria and their weighting (source: road network survey February 2019)

Name of criteria	Criteria	Weighting	Importance of criteria
C1	Safety	1, 3, 5, 7, 9	3
C2	Performance	1, 3, 5, 7, 9	2
C3	Sustainability	1, 3, 5, 7, 9	3

Table 9. Weight of each action determined using the WSM

Actions	A1	A2	A3	A4	A5	Total
Weight	0.033	0.007	0.16	0.24	0.01	0.45
Percentage(%)	7.33	1.54	35.60	53.33	2.2	100

Table10. Impact on each criterion

	X1	X2	X3	X4	X5
C1	0.33%	0.24%	0.73%	5.84%	0.24%
C2	1.83%	0.26%	10.37%	16.55%	0.72%
C3	1.16%	0.23%	4.6%	1.84%	0%

Describingweighting

- 1 : Not important
- 3 : Less important
- 5 : Moderately important
- 7 : Important
- 9 : Very important

Describing the weight of criteria

- 1 : Low ;
- 2 : Moderate ;
- 3 : Important.

Table of actions performances as compared to criteria

We were able to draw a table summarizing the various values of each action's for these various criteria. The following table further summarizes these weighting values per set of actions:

For any j criterion,

Grade A1= ∑ga11(Cj) + ∑ga12(Cj)= 17+13=30
Grade A2= ∑ga21(Cj)= 19
Grade A3= ∑ga31(Cj) + ∑ga32(Cj) + ∑ga33(Cj) = 17+17+17=51
Grade A4= ∑ga41(Cj) + ∑ga42(Cj) + ∑ga43(Cj) + ∑ga44(Cj)=15+15+15+19=64
Grade A5= ∑ga51(Cj)= 15

•Weighting of performances

Weighting the performances of these actions entails defining many comparison factors of these actions. Then we must compute concordance and discordance indexes, as well as the credibility index.

•Overall concordance index

$$C\,i\,k = \frac{\sum W\,j\,C\,j\,(a, b)}{\sum W\,j}$$

•Discordance index

$$D\,j\,(a, b) = \frac{\min\,(1;\ \max\,(0;\ (g\,j\,(b) - g\,j\,(a)) - P\,j\,(g\,j\,(a)}{V\,j\,g\,j\,(a) - P\,j\,g\,j\,(a))}$$

•Credibility level

φ(a,b)=C(a,b) siDj(a,b)>C(a,b) with C(a,b): overall concordance of actions

III-2- Results from the computing of preference and indifference thresholds of actions for each criterion selected

III-2-1. For criterion 1: safety

According to the performance table, safety is the criterion, p=4 and q=2

Table3:Preference and indifference thresholds of actions as compared to the safety criterion. From the preference and indifference values of each action, the actions' concordance and discordance table for the safety criterion.

For any j criterion, Cj (a, b)=0 if g j(b)-g j(a)>p j

Cj (a, b)=1 si g j(b)-g j(a)≤q j
Cj (a, b)= (p j- (g j(a)-g j(b)))/p j-q j if q j<g j(b)-g j(a)≤p j
C j (a11; a11)=1 because g j (a11) – g j (a11)=0<2 with 2= indifference criterion to the safety criterion.
C j (a11; a12) =1 car g j (a12) – g j (a11) = -4<2

After having computed the various concordance values of actions, we are able to determine the overall concordance of actions using the overall concordance formula:

$$C\,i\,k = \frac{\sum W\,j\;C\,j\;(a,b)}{\sum W\,j}$$

We have:

W =3which is the importance attributed to the safety criterion.
∑Wj= Wj1 + Wj2 +Wj3= 3+2+3=8 for any j ranging between 1 and n
∑W C j (a ; b)= 3*11+3*4+3*11+3*4+3*4+3*11+3*11+3*11+3*11+3*9+3*11= 294

The digital application of the overall concordance index formula gives the following result:

C (a, b) =294/8=36.75

C (a, b) =36.75

For any j criterion, φ(a,b)=C(a,b) siDj(a,b)>C(a,b, with C(a,b): overall concordance of actions and

$$\varphi(a,b = \frac{C(a,b).\prod\,(1-Dj(a,b)}{1-C(a,b)}$$

After having drawn the discordance table on the safety criterion, one can notice that no value D j (a; b)> C (a; b). Therefore, we can say that the credibility index is equal to the overall concordance index of actions.

Φ (a, b)=C (a, b)=36.75

We shall now move to define the same elements for the second criterion, which is performance.

III. 2.2. For criterion 2: performance

According to the performance table, the criterion for performance is p=3 and q=2

From the preference and indifference values of each action, the actions' concordance and discordance table for the performance criterion. After having obtained the various concordance values for these actions, we can then determine the overall concordance of actions. From the overall concordance formula, we now obtain:

W =2which is the importance attached to the performance criteria.

∑Wj= Wj1 + Wj2 +Wj3= 3+2+3=8 for any j ranging from 1 to n

∑W C j (a ; b)=2*7+2*11+2*7+2*11+2*11+2*11+2*11+2*11+2*11+2*11+2*11=226

The result obtained from the digital application of the overall.

C (a, b) =226/8=2.25

C (a, b) =28.25
For any j criterion, φ(a,b)=C(a,b) siDj(a,b)>C(a,b) with C(a,b): overall concordance of actions and After having drawn the discordance table on the performance criterion, we could notice that no D j value (a; b)> C (a; b). We can therefore say that the credibility index is equal to the overall concordance index of actions.

Φ (a, b) =C (a, b)=28.25

We shall now move to establishing the last criterion, which is sustainability.

III-2-3 Criterion3: sustainability

According to the performance table, the sustainability criterion is p=3 and q=2 On the basis of preference and indifference values of each action, we are now going to draw up the following concordance table on the sustainability criterion. After having calculated the various concordance values of these actions, we are now able to determine their overall concordance. Using the overall concordance formula, we have:

W =3which is the importance attributed to the sustainability criterion.

∑Wj= Wj1 + Wj2 +Wj3= 3+2+3=8 for any j ranging between 1 and n

∑W C j (a ; b)=3*11+3*11+3*11+3*11+3*11+3*11+3*5+3*5+3*4+3*11+3*4=285

The digital application of the overall concordance index produces the following result:

C (a, b) =285/8=35.625

C (a, b)=35.625

For any j criterion, φ(a,b)=C(a,b) ifDj(a,b)>C(a,b)
With C(a,b) : overall concordance of actions
φ(a,b)=C(a,b).∏ (1-Dj(a,b))/1-C(a,b).

After having drawn up the discordance table for the performance criterion, we notice that no D j value (a; b)> C (a; b). We can therefore conclude that the credibility index is equal to the overall concordance index of actions.

Φ (a, b)=C (a, b)=35.625

3- Results from the determination of the weight of each action: In order to determine the importance of each action, the ELECTRE III method just enables us to classify the various actions (comparing actions amongst each other) without indicating the values. In order to determine the weight of each action as compared to the others, we are going to use another method, which is the « **weighted sum model** »**(WSM)**. We shall take all of actions (A1, A2, A3, A4, and A5) into consideration to easily determine these weights.
Wj

The weights are determined using formula

P(Ak/Al) =∏j.(akj/alj)

for K, L=1, 2,3,…, m

Details on the digital application of the WSM

wj1 =3; wj2 =2, wj3 =3
G1 (A1) = g1 (a11) + g1 (a12) = 7 + 3 =10
G2 (A1) = g2 (a11) + g2 (a12) = 3+8=8
G3 (A1) = g3 (a11) + g3 (a12) =7+5=12
∑G1 (A) = 7+3+9+3+3+7+7+7+7+5+9=67
∑G2 (A) = 3+5+3+7+7+5+5+5+7+7+5=59
∑G3 (A) = 7+5+7+7+7+5+3+3+1+7+1=53
P (A1) = (G1 (A1)/ ∑G1 (A))exp (wj) + (G2 (A1)/ ∑G2 (A))exp (wj)+ (G3(A1)/ ∑G3 (A))exp (wj)
P (A1) = $(10/67)^3$+ $(8/59)^2$ + $(12/53)^3$= 0.033
P (A1) = 0.033
P (A2) = $(9/67)^3$ + $(3/59)^2$ + $(7/53)^3$= 0.007
P (A2) = 0,007
P (A3) = $(13/67)^3$+ $(19/59)^2$+ $(19/53)^3$=0.24
P (A3) = 0.16

$P(A4) = (26/67)^3 + (24/59)^2 + (14/53)^3 = 0.24$
$P(A4) = 0.24$
$P(A5) = (9/67)^3 + (5/59)^2 + (1/53)^3 = 0.01$
$P(A5) = 0.01$

4 Establishing the utility function: Our utility function will be determined by the various actions earlier mentioned. It is worth making it clear that actions defined above shall be used together (A1, A2, A3, A4, and A5). We shall have actions on:

- The behaviour of users (car drivers and pedestrians)
- Users' capacity to drive.
- The design of the network's roads
- The maintenance of the road network
- Car maintenance

We must determine the impact of each action on the above-mentioned criteria. To that end we resorted to a method that has already been used previously to determine the importance of each action. In this case, we are going to determine the weight of each action A1, A2, A3, A4, and A5 on each criterion (Safety, Performance and Sustainability). Our aim is to reduce the rate of road accidents registered on the Bertoua city road network. To that end, we must act on the criteria identified earlier:

- X1: impact of users' behaviour on road accidents
- X2: impact of users' capacity to drive on road accidents
- X3: impact of road design on road accidents
- X4: impact of road maintenance on road accidents
- X5 : impact of car maintenance on road accidents

The impacts of these parameters on the criteria chosen are determined by the WSM and are listed in the table below:

The impact of users' behaviour on road accidents against the safety criterion is indicated as X1(C1)

We had $P(A1) = (10/67)^3 + (8/59)^2 + (12/53)^3 = 0.033$

X1 on C1 X1on C2 X1 on C3

$X1(C1) = (10/67)^3 = 0.003324$
$X1(C2) = (8/59)^2 = 0.0183$
$X1(C3) = (12/53)^3 = 0.0116$

De même on avait $P(A2) = (9/67)^3 + (3/59)^2 + (7/53)^3 = 0.007$

$X2(C1) = (9/67)^3 = 0.0024$
$X2(C2) = (3/59)^2 = 0.00260$
$X2(C3) = (7/53)^3 = 0.0023$

Thus, from the above percentages, we can define a utility or a performance function.

The aim of this objective function is to reduce the impacts of road accidents on the Bertoua road network (X1, X2, X3, X4 and X5) and is defined as follows:

$Z = \min(7.33X1 + 1.54X2 + 35.6X3 + 53.33X4 + 2.2X5)$, with the following constraints:
$0.33X1 + 0.24X2 + 0.73X3 + 5.84X4 + 0.24X5 \geq 67$
$1.83X1 + 0.26X2 + 10.37X3 + 16.55X4 + 0.72X5 \geq 59$
$1.16X1 + 0.23X2 + 4.6X3 + 1.84X4 \geq 53$;
$X1, X2, X3, X4, X5 \geq 0$

We shall solve this system through an optimization method called «*dual Simplex method*» because constraints correspond to the conditions of the dual-simplex method.

MINIMIZE: $7.33X1 + 1.54X2 + 35.6X3 + 53.33X4 + 2.2X5$, with the following constraints:
$0.33X1 + 0.24X2 + 0.73X3 + 5.84X4 + 0.24X5 \geq 67$
$1.83X1 + 0.26X2 + 10.37X3 + 16.55X4 + 0.72X5 \geq 59$
$1.16X1 + 0.23X2 + 4.6X3 + 1.84X4 \geq 53$;
$X1, X2, X3, X4, X5 \geq 0$

We are turning our minimization problem into a maximization problem, and we are bringing in deviation variables before starting the problem-solving operation and we obtain the following system:

MAXIMIZE: -7.33X1 - 1.54X2 - 35.6X3 - 53.33X4 - 2.2X5 + 0X6 + 0X7 + 0X8, with the following constraints:
0.33X1 + 0.24X2 + 0.73X3 + 5.84X4 + 0.24X5 + 1X6 = 67
1.83X1 + 0.26X2 + 10.37X3 + 16.55X4 + 0.72X5 + 1X7 = 59
1.16X1 + 0.23X2 + 4.6X3 + 1.84X4 + 1X8 = 53 ;
X1, X2, X3, X4, X5, X6, X7, X8 ≥ 0

By expressing deviation variables according to other variables, we obtain the following system:
X6 = 67 – (0.33X1 + 0.24X2 + 0.73X3 + 5.84X4 + 0.24X5)
X7 = 59 – (1.83X1 + 0.26X2 + 10.37X3 + 16.55X4 + 0.72X5)
X8 = 53 – (1.16X1 + 0.23X2 + 4.6X3 + 1.84X4)

Z= 7.33X1 + 1.54X2 + 35.6X3 + 53.33X4 + 2.2X5

The solution to this system is found through the addition and the subtraction of in-base and out-of-base data. We have variables X1, X2, X3, X4 and X5 which are in-base and variables X6, X7 and X8 which are out-of-base. The solution to this optimization function using the simplex method gives us the following result:

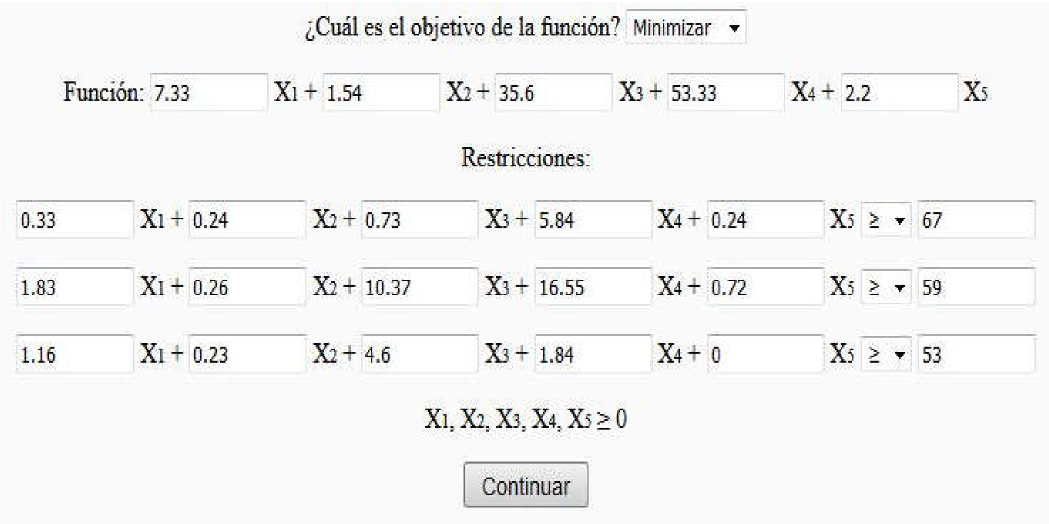

Image 11. Solving the objective function using the PHP Simplex application software

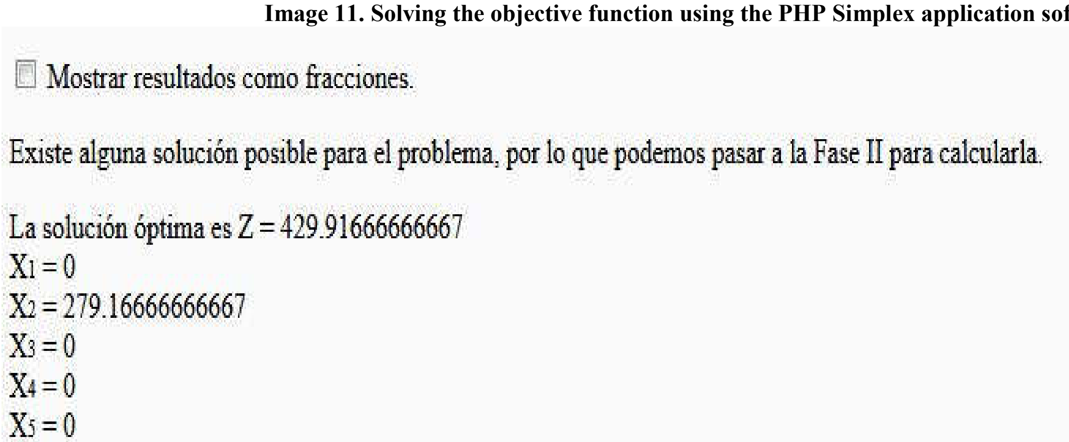

Image: solving the objective optimization function using the dual Simplex method. By dividing the value of Z by the total weight of actions, we obtain 4293.9199/0.45=955.55and 279.166667/0.45=620.37

Thus, the optimization value is:

Z=95.5%
X2=62%
(X1, X3, X4, X5)=38%

5- Interpretationof results: Our utility function illustrates the high rate of accidents recorded on urban roads of the city of Bertoua. This function was developed considering some factors that were deemed important on the basis of the multi-criteria analysis carried out earlier. Our aim was to reduce road accidents on the basis of factors such as user's behaviour, car driver's aptitude to drive, road design as well as infrastructure and car maintenance. The city of Bertoua recorded 476road accidents in 4 years, or 119 accidents per year on average**.** From our utility, we are going to find out how far we can go to reduce this figure as far as possible.

After having solved our utility function using the dual simplex method, we got the results presented below:

- (X1, X3, X4, X5) = 38% indicates that we must take actions in improving urban road networks at least up to this value through:
- Sensitization campaigns and speed limitation.
- Sensitization campaigns on the respect of personal safety and on riskybehaviour.
- Applying sanctions against offenders
- Sensitization of pedestrians and users on emergency practices.
- Carry out repair works on road ways.
- Improvingroadsides.
- Improving public lighting equipment and road signs.
- Improving cycle ways, pedestrian areas and bypasses.
- Diversifying lanes or areas for various modes of transportation.
- Improving road safetyequipment.
- Carrying out car maintenance.
- Result X2=62% represents the percentage we must use to act on the capacity of car drivers. The following actions must beimplementedat this level:
- Request and check drivers licenses;
- Check alcohol consumption on drivers;
- Introduce psychological tests on driver's license applicants to detect any possible problem.
- Vérifier l'aptitude physique des conducteurs.
- This result shows that we can attain a maximum of 95.5% reduction in road accidents on Bertoua urban roads, that is 114 accidents on the 119 recorded yearly. To this end, we must make adjustments on the various factors identified earlier.

General Conclusion

At the end of this study, it appears that optimizing road safety in the development of road networks in the city of Bertoua should be based on the mastery of the features of this network, its connected infrastructure and factors that impact road construction.Thus, in order to put in place a system for the management of road networks, it is primordial to develop a rich and coherent database. Geographic information systems help not only to set up this database, but also to give a clear picture of the real situation. It is in this perspective that the project is treated in a bid to show how the GIS are used to make timely and adequate decisions. As a matter of fact, the issue was treated based on causes of accidents linked to road networks maintenance, users' behaviour, users' capacities and car maintenance, due to time constraints, lack of means and inadequate information for the collection and storage of data linked to other causes of accidents in order to carry out more exhaustive analyses. As concerns questions we asked ourselves when identifying the problem we can answer by saying that:

- To better manage road safety conditions in the city of Bertoua, it is necessary to define road safety features, include them into a GIS model by informing related information daily in order to carry out analyses at the appropriate time.
- The Bertoua road network is particularly characterized by a main street which eases its multimodal use, with high possibilities of congestion and accidents.
- The ELECTRE III method applied in solving our problem enabled us to improve road safety by incorporating actions or alternatives into a utility function.

Recommenadations

Finally, let's make the following recommendations to improve road safety in the design and development of road networks in the city of Bertoua up to the percentages derived from the objective function's solution that was designed earlier:

- Give priority to the maintenance and improvement of road safety equipment such as public lighting, road markings and roadsigns on the network's sensitive roads, as illustrated by the map spotting sensitive roads.
- Improve the network's connectivity in order to ease traffic on the city's main road by linking roads to hubs without low Shimbel indexes, especially crowns G, I, J and W; this may lead to the creation of an East-West bypass that would link the said crowns.
- Improve public lighting as well as road markings and signs through maintenance works and the installation of new equipment within network areas with low cover in public lighting amenities.
- Promote a new management policy for road networks by introducing information systems in urban action initiatives.

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