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International Journal of Engineering, Science and Technology
Vol. 15, No. 1, 2023, pp. 13-25

INTERNATIONAL
JOURNAL OF
ENGINEERING,
SCIENCE AND
TECHNOLOGY

www.ijest1-ng.com
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Optimisation of the choice of the sizing method for drinking water networks in the developing countries: A case of Cameroon

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Abstract

In developing countries (DC), particularly in Cameroon, the demand for drinking water is increasing. To date, the methods of design, sizing and extension of existing drinking water networks are done through the EPANET application which is a simulation software based on the Hardy-Cross method. The main objective of this study is to set up a local tool adapted to the context of D.C. allowing the design, sizing and extension of networks based on the rough model method (RMM). Thus, on the basis of a previously modelled existing network, a comparison was made between the Hardy-Cross method and the RMM (according to the criteria: costs, speed of execution, aptitude for automation, fidelity and precision) with the multi-criteria analysis tool PROMETHEE II. The results of this analysis show that the best adapted method for the design, sizing and extension of drinking water networks is the RMM. It appears that the setting up of water supply networks in DC must be done by the RMM for affordable costs, rapid execution, easy reproducibility and reliable precision.

Keywords: Cameroon, Drinking Water Networks, Sizing Method, Multi-criteria Analysis, Promethee II

DOI: http://dx.doi.org/10.4314/ijest.v15i1.2

Cite this article as:
Ntom Nkotto L.I., Manjia B.M., Wilson E.R., Sontia Metekong J.V. 2023. Optimisation of the choice of the sizing method for drinking water networks in the developing countries: A case of Cameroon. *International Journal of Engineering, Science and Technology*, Vol. 15, No. 1, pp. 13-25. doi: 10.4314/ijest.v15i1.2

Received: February 10, 2023; Accepted: March 1, 2023; Final acceptance in revised form: March 3, 2023

1. Introduction

Cameroon, like other developing countries, is experiencing a significant demographic boom, which has resulted in an ever-increasing demand for drinking water. The water distribution company is proving more and more inadequate in meeting the needs of the population (Grelle et al., 2006). Thus, the reliability of such a network depends on its capacity to meet the said demand (Djomo et al., 2008). Water distribution networks must be designed in strict compliance with the standards and regulations in force, but till date there is no rigorous operational solution to water distribution, the elements are quite variable. Distribution pressures are not constant, water needs vary according to the time of day, the materials used have different characteristics, different fittings (elbows and tees) modify the flow rate, assembly faults, and spigots (Zoungrana, 2003). All of these contribute to modification of the cross-sections of the pipes and their seating depths. However, this practice is neglected in the studies generally carried out through the EPANET application.

The generally used EPANET hydraulic simulation software only balances networks and therefore does not offer the possibility of classical, let alone optimal, sizing (Housh and Ohar, 2018). It is based on the Hardy-Cross method (Nwajuaku et al., 2017), which is based on the respect of two procedures: the sum of the inflows at a network node is equal to the sum of the outflows at the same node and the algebraic sum of the head losses in a mesh is zero. Solving these equations leads to successive corrections, which is an iterative method (Waseem, 2021). This iterative method has undergone several optimal processes to its solution namely: the approach to solving pressure losses of Wood and Charles taken up by Lejeune et al. (Todini and Rossman, 2013), where convergence characteristics of the linear theory are then improved by Wood and Rayes (Todini and Rossman, 2013), the Newton-Raphson approach (Zhang et al., 2020), the multipoint approach (Praks et al., 2018; Praks et al., 2018) which can be used as a replacement for the Newton-Raphson approach used by Hardy-Cross, the method of genetic algorithms (Khelifa, 2021). All these optimisation methods contribute to the optimal solution of the Hardy-Cross equations.

Another method for sizing drinking water networks proposed by Achour (2007) is emerging. It is a new method and approach for the calculation of turbulent flow in a pipe. It is based on the universally accepted Darcy-Weisbach and Colebrook-White relationships on the one hand, and on a rough reference model on the other hand (Bedjaoui and Achour, 2014). It does not require the use of abacuses or tables, nor the use of the William-Hazen coefficient which is replaced by the absolute roughness of the pipe. The sizing method for drinking water systems must be a routine analysis method. That is to say, a method that is simple, fast, cheap, and automatable, if possible, can be carried out by unskilled personnel (Storey et al., 2011). To this end, precision will be a global notion of the quality or analytical value of a method, and is based on the criteria of precision and accuracy. Thus, a method will be more precise when its fidelity and accuracy are greater.

The objective of this study is to provide optimised guiding data for the use of sizing methods for drinking water distribution networks in Cameroon using a multi-criteria approach. The technical choice of multi-criteria decision support is made according to the choice tree established by Lemaire (2006), which consists sequentially of answering a series of questions. In the present study, the method of improvement of the multicriteria synthesis PROMETHEE II (Preference Ranking Organization Method for Enrichment Evaluations) was chosen (Thakkar, 2021) because it allows the resolution of the problem of choice and the problem of ordering. Indeed, the use of this complete pre-order is considered simpler by the decision-maker solicited to provide an answer to the decision problem.

2. Methodology

In the course of this work, the Hardy-Cross method was used to study the network that was previously sized using the rough model method (RMM), which was done by Bedjaoui and Achour (2014). Then, the criteria for choosing the sizing method was identified and through the PROMETHEE II methodology, a preponderance was established between the rough model method and the Hardy-Cross method in the context of DC.

2.1-Presentation of the network studied

The network submitted to our study is a network that was the subject of previous work by Bedjaoui and Achour (2014). This network is composed of 3 meshes and 09 nodes with natural land elevations ranging from 56.8 to 99.3m (Figure 1). From the starting node "R" this network runs between nodes "1, 5, 6, 2, 4, 7, 3" to end at the arrival node "8".

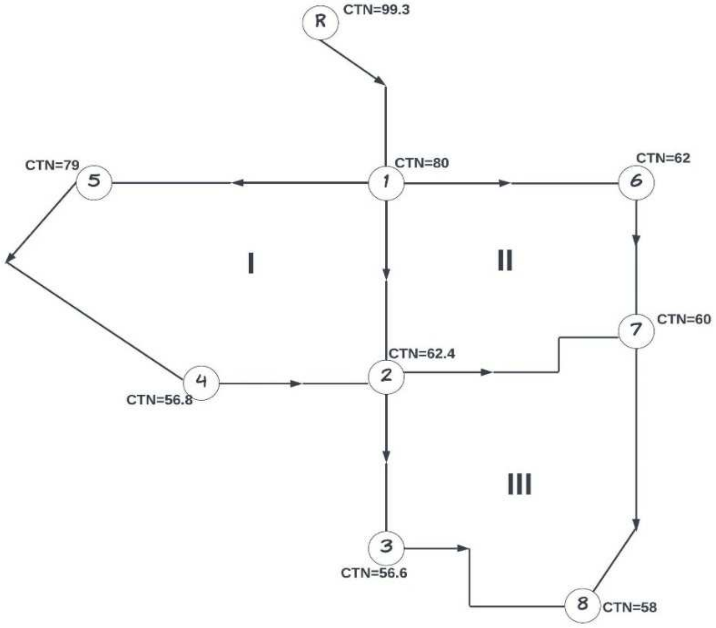

Figure 1. Diagram of the studied mesh network

Furthermore, the geometric and hydraulic parameters of the studied network are presented in Table 1.

Table1. Geometric and hydraulic parameters of the studied network (Bedjaoui and Achour, 2014)

Mesh	Section	Length (m)	Flow rate (m^3/s)	ε (m)	CTN	
I	1-2	186	0.171	0.0001	80.0	62.4
	5-1	170	0.04833	0.0001	79.0	80.0
	5-4	355	0.04833	0.0001	79.0	56.8
	4-2	25	0.03333	0.0001	56.8	62.4
II	1-6	300	0.04833	0.0001	80.0	62.0
	6-7	125	0.03133	0.0001	62.0	60.0
	7-2	357	0.02033	0.0001	60.0	62.4
	2-1	186	0.04833	0.0001	62.4	80.0
III	7-8	270	0.02100	0.0001	60.0	48.5
	7-2	357	0.02033	0.0001	60.0	62.4
	2-3	107	0.02033	0.0001	62.4	56.6
	3-8	242.5	0.00533	0.0001	56.6	48.5

In view of its properties related to pressure drop, flow, pumping costs and reinstatement, this mesh network proved to be more suitable for implementation in our context than the branched network (Table 2).

Table 2. Comparison of network types

Aspect	Branched	Mesh
Pressure losses	High	Low
Flow	Risk of dead zone at the extremities	Satisfactory
Repairs	Risk of disabling an important area depending on the point of intervention	Little risk of disabling an important area depending on the point of intervention
Pumping costs	High	Low
Repositioning	Low	High

2.2-Network design methods

The methods that have been used to study this mesh network are the Rough Model Method (RMM) and the Hardy-Cross method.

2.2.1- Rough Model Method (RMM)

It was proposed by Achour (2007). It is an iterative process reaching the equilibrium of the meshes and respecting both laws of Hardy-cross. It does not require the use of either abacuses or tables, the use of the William-Hazen coefficient now replaced by the use of the absolute roughness of the pipe. The calculation procedure is indicated in the work of Bedjaoui and Achour (2014). The results of the studies conducted by Bedjaoui and Achour (2014) are presented in Tables 3 to 6.

Table 3. Calculation of the mesh network using the new method Step: Determination of pipe diameters (Bedjaoui and Achour, 2014)

MP	MA	Sections		Q (m^3/s)	Assumed Pressures		CP		ΔHt (m)	J	$\overline{D}$ (m)	$\overline{R}$	ψ	$D_{thé}$ (m)	D_{Norm} (m)
		Start	End		PS Start	PS End	CP Start	CP End							
1		0	1	0.171	0	19	99.3	99	0.3	0.0027	0.562	3.88E+05	0.83	0.4646	0.500
	2	1	2	0.04833	19	30	99	92.4	6.6	0.0355	0.202	3.04E+05	0.78	0.1589	0.150
		1	5	-0.04833	19	19	99	98	1	0.0059	0.290	2.12E+05	0.78	0.2260	0.250
		5	4	-0.03333	19	36	98	92.8	5.2	0.0146	0.208	2.04E+05	0.79	0.1640	0.150
		4	2	-0.01833	36	30	92.8	92.4	0.4	0.016	0.161	1.45E+05	0.80	0.1285	0.150
2		1	6	0.04833	19	35	99	97	2	0.0067	0.283	2.18E+05	0.78	0.2205	0.200
		6	7	0.03133	35	35	97	95	2	0.016	0.200	2.00E+05	0.79	0.1575	0.150
	3	7	2	-0.02033	35	30	95	92.4	2.6	0.0073	0.197	1.32E+05	0.791	0.1561	0.150
	1	1	2	-0.04833	19	30	99	92.4	6.6	0.0355	0.202	3.04E+05	0.78	0.1589	0.150
3		7	8	0.021	35	34	95	92	3	0.0111	0.183	1.46E+05	0.79	0.1454	0.150
	2	7	2	0.02033	35	30	95	92.4	2.6	0.0073	0.197	1.32E+05	0.79	0.1561	0.150
		2	3	-0.02033	30	35.6	92.4	92.2	0.2	0.0019	0.258	1.00E+05	0.79	0.2046	0.200
		3	8	-0.00533	35.6	34	92.2	92	0.2	0.0008	0.178	3.82E+05	0.82	0.1460	0.150

MA :Adjacent Mesh ; MP :Main Mesh ; Q :Flow rate ;PS :Assumed Pressure ; CP :Groundwater Level, ΔHt :total pressure loss ; J :Gradient of linear pressure drop, $\overline{D}$: Diameter of the rough model of a circular profile ; $\overline{R}$: Reynolds number of the flow in the rough model ; ψ :diameter correction factor ;$D_{thé}$:Calculated diameter ; D_{Norm} :Standard Diameter

Table 4:Calculation of the mesh network by applying the rough reference model method for the case where the design diameter is taken to be equal to the theoretical diameter (Bedjaoui and Achour, 2014)

MP	MA	Sections		Q (m^3/s)	$D_{thé}$ (m)	ΔHt (m)	ΔH/Q (m)	CMP (m^3/s)	CMA (m^3/s)	first correction				
		Start	End							Qcor (m^3/s)	CP		PS	
1		0	1	0.171	0.4646	0.30	1.76	0.0000	0.0000	0.1710	99.3	99	0	19
	2	1	2	0.04833	0.1589	6.61	136,68	0.0000	0.0000	0,0483	99	92,39	19	29.99
		1	5	-0.04833	0.2260	-1.00	20,73	0.0000	0.0000	-0,0483	99	98	19	19
		5	4	-0.03333	0.1640	-5.21	156,26	0.0000	0.0000	-0,0333	98	92,79	19	35.99
		4	2	-0.01833	0.1285	-0.40	21,86	0.0000	0.0000	-0,0183	92,79	92.39	35.99	29.99
						-0.01	335,53							
2		1	6	0.04833	0.2205	2.00	41,46	0.0000	0.0000	0,0483	99	97	19	35
		6	7	0.03133	0.1575	2.00	63,94	0.0000	0.0000	0,0313	97	94,99	35	34.99
	3	7	2	-0.02033	0.1561	2.61	128,19	0.0000	0.0000	0,0203	94,99	92,39	34.99	29.99
	1	1	2	-0.04833	0.1589	-6.61	136,68	0.0000	0.0000	-0,0483	99	92,39	19	29.99
						0.01	370,26							
3		7	8	0.021	0.1454	3.01	143,15	0.0000	0.0000	0,0210	94,99	91,99	34.99	33.99
	2	7	2	0.02033	0.1561	-2.61	128,19	0.0000	0.0000	-0,0203	94,99	92,39	34.99	29.99
		2	3	-0.02033	0.2046	-0.20	9.87	0.0000	0.0000	-0,0203	92,39	92,19	29.99	35.59
		3	8	-0.00533	0.1460	-0.20	37,66	0.0000	0.0000	-0,0053	92,19	91,99	35.59	33.99
						0.00	318,88							

CMP: Correction Main mesh; CMA : Correction of the adjacent mesh ; Qcor: Corrected flow rate; ΔH: sum of total pressure loss

Table 5: Calculation of the mesh network by applying the reference rough model method for the case where the design diameter is taken to be equal to the standard diameter (Iteration n°01) (Bedjaoui and Achour, 2014)

MP	MA	Sections		Q (m^3/s)	D Norm (m)	ΔHt (m)	ΔH/Q (m)	CMP (m^3/s)	CMA (m^3/s)	first correction				
		Start	End							Qcor (m^3/s)	CP		PS	
1		0	1	0.171	0.500	0,20	1,20	0,0001	0,0002	0.1710	99.3	99,10	0,00	19,10
	2	1	2	0.04833	0.150	8,88	183,71	0,0001	0.0000	0,0486	99,10	90,22	19,10	27,82
		1	5	-0.04833	0.250	-0,60	12,46	0,0001	0.0000	-0,0482	99,10	98,48	19,10	19,49
		5	4	-0.03333	0.150	-8,22	246,65	0,0001	0.0000	-0,0332	98,49	90,27	19,49	33.47
		4	2	-0.01833	0.150	-0,18	9,99	0,0001	0.0000	-0,0182	90,27	90.09	33,47	27,69
						-0,13	452,81		0,0001					
2		1	6	0.04833	0.200	3,29	68,04	-0,0002	0.0000	0,0482	99,10	95,81	19,10	33,81
		6	7	0.03133	0.150	2,57	81,95	-0,0002	0.0000	0,0312	95,81	93,24	33,81	33,24
	3	7	2	-0.02033	0.150	3,19	156,84	-0,0002	-0,0002	0,0186	93,24	90,05	33,24	27,65
	1	1	2	-0.04833	0.150	-8,88	183,71	-0,0002	-0,0001	-0,0486	99,10	90,22	19,10	27,82
						0,17	490,55		-0,0002					
3		7	8	0.021	0.150	2,57	122,19	0,0016	0.0000	0,0226	93,24	90,67	33,24	32,67
	2	7	2	0.02033	0.150	-3,19	156,84	0,0016	0,0002	-0,0186	93,24	90,05	33.24	27,65
		2	3	-0.02033	0.200	-0,22	11,06	0,0016	0.0000	-0,0187	90,05	89,83	27,65	33,23
		3	8	-0.00533	0.150	-0,18	32,98	0,0016	0.0000	-0,0037	89,83	89,65	33,23	31,65
						-1,02	323,07		0,0016					

Table 6: Calculation of the mesh network by applying the reference rough model method for the case where the design diameter is taken to be equal to the standard diameter (Iteration No. 03)(Bedjaoui and Achour, 2014)

MP	MA	Sections		Q (m^3/s)	D Norm (m)	ΔHt (m)	ΔH/Q (m)	CMP (m^3/s)	CMA (m^3/s)	first correction				
		Start	End							Qcor (m^3/s)	CP		PS	
1		0	1	0.171	0.500	0,20	1,20	0,0002	0.0000	0.1710	99.3	99,10	0,00	19,10
	2	1	2	0,0515	0.150	8,78	182,71	0,0002	0.0000	0,0483	99,10	90,32	19,10	27,92
		1	5	-0,0456	0.250	-0,60	12,44	0,0002	0.0000	-0,0480	99,10	98,50	19,10	19,50
		5	4	-0,0306	0.150	-0,60	246,11	0,0002	0.0000	-0,0330	98,50	90,31	19,50	33.51
		4	2	-0,0156	0.150	-0,18	9,96	0,0002	0.0000	-0,0180	90,31	90.13	33,51	27,73
						-0,19	451,22		0,0002					
2		1	6	0,0479	0.200	3,33	68,50	0.0000	0.0000	0,0487	99,10	95,76	19,10	33,76
		6	7	0,0309	0.150	2,62	82,82	0.0000	0.0000	0,0317	95,76	93,14	33,76	33,14
	3	7	2	0,0220	0.150	2,82	147,93	0.0000	-0,0002	0,0188	93,14	90,32	33,14	27,92
	1	1	2	-0,0515	0.150	-8,78	182,71	0.0000	-0,0002	-0,0483	99,10	90,32	19,10	27,92
						0,00	481,96		0,0000					
3		7	8	0,0189	0.150	2,96	130,79	0,0002	0.0000	0,0228	93,14	90,18	33,14	32,18
	2	7	2	-0,0220	0.150	-2,82	147,93	0,0002	0.0000	-0,0188	93,14	90,32	33,14	27,92
		2	3	-0,0224	0.200	-0,19	10,28	0,0002	0.0000	-0,0185	90,32	90,12	27,92	33,52
		3	8	-0,0074	0.150	-0,09	24,48	0,0002	0.0000	-0,0035	90,12	90,03	33,52	32,03
						-0,15	313,49		0,0002					

2.2.2 Hardy Cross method

It consists in choosing, for an initial distributiondiameter in the network, the distribution of flows in the network sections in a quest to satisfy the law of nodes (1) and the law of conservation of energy in a mesh (2). When these two conditions are not satisfied, a correction of the flow rate for each mesh is applied (3)

Node equation $$\sum Q_{sor\tan ts} - \sum Q_{entrants} = 0 \quad (1)$$

Mesh equation

$$\sum h_{1ij} = 0 \quad (2)$$

Correction expression for each mesh $$\Delta Q_i = -\frac{\sum h_{1ij}}{2\sum \frac{h_{1ij}}{Q_{ij}}} \quad (3)$$

Where $\sum h_{1ij}$ the algebraic sum of the pressure drops around a mesh l and Q_{ij} means the flow rate in pipe$_{ij}$ of mesh l.

Once the flow distribution for each section is determined, a possible correction on the diameters regarding the verification of the velocity constraint is imposed. The iterative process stops when the velocity constraint is verified on all sections of the network.

The calculation process consists of:

- A provisional distribution of flows, which is the nodal flows, and a direction of flow in the network are determined in accordance with the law of nodes. Thus, the provisional diameter of the pipes can be determined using formula (4), with flow speeds between 0.9 and 1.1 m/s. But in our context, these provisional flows are known and represent the flow of each section.
- The pressure losses are calculated using the equation (5)

$$D = \left(\frac{4Q}{\pi \upsilon}\right)^{\frac{1}{2}} \quad (4)$$

with $$h_f = \frac{8\lambda L Q^2}{\pi^2 g D^5} \quad (5)$$

$$\lambda = 0.0055\left[1 + \left(\frac{2000k_s}{D} + \frac{10^6}{R_e}\right)\right] \quad (6)$$

where

R_e :the Reynolds number	k_s :the Manning-Strickler coefficient
λ : the linear pressure drop coefficient (without unit)	h_f: the linear (frictional) pressure drop in the pipe
D: the diameter of the pipe in m	L: the length of the pipe in m

In this study, a study previously carried out by RMM will be repeated, so the direction of flow will be identical to that studied and will be shown by the sign of the flow between the different sections in Table 3 thus, keeping the same geometric data. The following information is obtained: The verification of the direction of flow of the network is based on the nodal flows which must be positive and therefore the sum is that of the flow from the reservoir as verified in Table 7.

Table 7. Determination of the nodal flows of the studied network

Node	Flow rate(m^3/s)
1	0,02601
2	0.02600
3	0.01500
4	0.01500
5	0.01500
6	0.01700
7	0.03066
8	0.02633
Total	0.171

Table 8:Calculation of the mesh network using the Hardy-Cross method Step: Determination of pipe diameters

MP	MA	Sections		Q (m^3/s)	$D_{thé}$ (m)	D_{Norm}(m)
		Start	End			
1	0	0	1	0.171	0.4666	0.500
1	2	1	2	0.04833	0.2481	0.250
1	0	1	5	-0.04833	0.2481	0.250
1	0	5	4	-0.03333	0.2060	0.200
1	0	4	2	-0.01833	0.1528	0.150
2	0	1	6	0.04833	0.2481	0.250
2	0	6	7	0.03133	0.1998	0.200
2	3	7	2	-0.02033	0.1609	0.150
2	1	1	2	-0.04833	Start	0.250
3	0	7	8	0.021	0.1635	0.150
3	2	7	2	0.02033	0.1609	0.150
3	0	2	3	-0.02033	0.1609	0.150
3	0	3	8	-0.00533	0.0824	0.150

From this study, the results of the calculation of the mesh network using the Hardy-cross method are presented in the three tables below. These are Table 8, which presents these results in the case where the calculation diameter is the theoretical diameter. Table 9, where the calculation diameter is the normalized (commercial) diameter in the first iteration, and Table 10, where the calculation diameter is the normalized diameter in the third iteration. The second iteration is not presented below in order to remain consistent with the Bedjaoui and Achour (2014) presentation for a better comparison of the results between methods.

Table 9:Calculation of the mesh network using the Hardy-cross method for the case where the design diameter is taken as equal to the theoretical diameter

MP	MA	Sections		First Iteration								
		Start	End	Q	V	Re	Λ	hf (m)	hf/q	Dq	dq other	dq effective
1	0	0	1	171								0.0000
1	2	1	2	48.33	1	219525.52	0.01830	0.6995	0.01447	10.2395	3.6747	6.5648
1	0	1	5	-48.33	-1	219525.52	0.01830	-0.6394	0.01323	10.2395		10.2395
1	0	5	4	-33.33	-1	182303.19	0.01912	-1.6796	0.05039	10.2395		10.2395
1	0	4	2	-18.33	-1	135194.13	0.02055	-0.1714	0.00935	10.2395		10.2395
				0	0	0.00	0.00000	-1.7908	0.08745			
2	0	1	6	48.33	1	219525.52	0.01830	1.1283	0.02335	3.6747		3.6747
2	0	6	7	31.33	1	176748.94	0.01926	0.6145	0.01961	3.6747		3.6747
2	3	7	2	-20.33	-1	142378.79	0.02029	-2.2950	0.11289	3.6747	0.1612	3.5135
2	1	1	2	-48.33	-1	219525.52	0.01830	-0.6995	0.01447	3.6747	10.2395	-6.5648
				0	0	0.00	0.00000	-1.2517	0.17032			
3	0	7	8	21	1	144705.91	0.02021	1.7011	0.08100	0.1612		0.1612
3	2	7	2	20.33	1	142378.79	0.02029	2.2950	0.11289	0.1612	3.6747	-3.5135
3	0	2	3	-20.33	-1	142378.79	0.02029	-0.6878	0.03383	0.1612		0.1612
3	0	3	8	-5.33	-1	72902.13	0.02399	-3.5994	0.67530	0.1612		0.1612
				0	0	0.00	0.00000	-0.2912	0.90303			

dq :Flow rate ;dq other : Corrective flowrate ; dq effective:Corrected flow rate

Table 10:Calculation of the mesh network using the Hardy-Cross method for the case where the design diameter is taken to be equal to the standard diameter (Iteration No. 01)

MP	MA	Sections		Sections								
		Start	End	Q	V	Re	Λ	hf (m)	hf/q	Dq	dq other	dq effective
1	0	0	1	171								0.0000
1	2	1	2	48.33	0.9846	217825.37	0.01830	0.6725	0.0139	10.9049	5.19214	5.7127
1	0	1	5	-48.33	-0.9846	217825.37	0.01830	-0.6147	0.0127	10.9049		10.9049
1	0	5	4	-33.33	-1.0609	187774.66	0.01916	-1.9512	0.0585	10.9049		10.9049
1	0	4	2	-18.33	-1.0373	137690.15	0.02058	-0.1881	0.0103	10.9049		10.9049
				0	0.0000	0.00	0.00000	-2.0814	0.0954			
2	0	1	6	48.33	0.9846	217825.37	0.01830	1.0847	0.0224	5.1921		5.1921
2	0	6	7	31.33	0.9973	176507.06	0.01926	0.6102	0.0195	5.1921		5.1921
2	3	7	2	-20.33	-1.1504	152713.63	0.02040	-3.2752	0.1611	5.1921	-6.44038	11.6325
2	1	1	2	-48.33	-0.9846	217825.37	0.01830	-0.6725	0.0139	5.1921	10.90487	-5.7127
				0	0.0000	0.00	0.00000	-2.2527	0.2169			
3	0	7	8	21	1.1884	157746.49	0.02035	2.6362	0.1255	-6.4404		-6.4404
3	2	7	2	20.33	1.1504	152713.63	0.02040	3.2752	0.1611	-6.4404	5.19214	-11.6325
3	0	2	3	-20.33	-1.1504	152713.63	0.02040	-0.9816	0.0483	-6.4404		-6.4404
3	0	3	8	-5.33	-0.3016	40037.56	0.02404	-0.1802	0.0338	-6.4404		-6.4404
				0	0.0000	0.00	0.00000	4.7495	0.3687			

Table 11:Calculation of the mesh network by application of the Hardy-Cross method for the case where the design diameter is taken to be equal to the standard diameter (Iteration n°03)

MP	MA	Sections		Sections								
		Start	Start	Q	V	Re	λ	hf (m)	hf/q	Dq	dq other	dq effective
1	0	0	1	171.00						0.00		0.00
1	2	1	2	59.88	1.2199	269894.43	0.0180	1.0151	0.0170	-0.1917	0.8148	-1.0065
1	0	1	5	-33.94	-0.6914	152955.72	0.0189	-0.3135	0.0092	-0.1917		-0.1917
1	0	5	4	-18.94	-0.6028	106687.59	0.0203	-0.6664	0.0352	-0.1917		-0.1917
1	0	4	2	-3.94	-0.2228	29574.06	0.0254	-0.0107	0.0027	-0.1917		-0.1917
				0.00	0.0000	0.00	0.0000	0.0246	0.0641			
2	0	1	6	51.17	1.0424	230625.97	0.0182	1.2102	0.0236	0.8148		0.8148
2	0	6	7	34.17	1.0877	192507.80	0.0191	0.7206	0.0211	0.8148		0.8148
2	3	7	2	-11.88	-0.6723	89241.06	0.0215	-1.1778	0.0991	0.8148	-0.5967	1.4116
2	1	1	2	-59.88	-1.2199	269894.43	0.0180	-1.0151	0.0170	0.8148	-0.1917	1.0065
				0.00	0.0000	0.00	0.0000	-0.2621	0.1608			
3	0	7	8	15.39	s0.8709	115608.25	0.0209	1.4549	0.0945	-0.5967		-0.5967
3	2	7	2	11.88	0.6723	89241.06	0.0215	1.1778	0.0991	-0.5967	0.8148	-1.4116
3	0	2	3	-25.94	-1.4679	194851.87	0.0200	-1.5697	0.0605	-0.5967		-0.5967
3	0	3	8	-10.94	-0.6191	82175.80	0.0217	-0.6849	0.0626	-0.5967		-0.5967
				0.00	0.0000	0.00	0.0000	0.3781	0.3168			

2.3.Multicriteria method PROMETHEE II

The described mesh network was studied by the RMM and the Hardy Cross method. The use of a multi-criteria selection method is necessary in order to choose the design methods for drinking water networks. The PROMETHEE II method was therefore chosen as it allows alternatives to be compared against each other on the basis of defined criteria. Five criteria were defined: the accuracy & reliability of the method, its cost, its speed of execution and its suitability for automation.

2.3.1. Definition of criteria

In this study five criteria were identified: accuracy and fidelity, cost, speed of execution and automation capability

- Trueness and precision of the method

Trueness, according to ISO 3534-1, is the closeness of agreement between the mean value obtained from a large series of test results and an accepted reference value. It is usually expressed in terms of bias.

Fidelity according to ISO 3534-1 is the closeness of agreement between independent test results obtained under stipulated conditions. It depends only on random errors and has no relation to the true or specified value.

- Cost (investment and operation)

The cost here lies in the steps taken in the application of the chosen method, referring to the investment in time and expense. Decisions on investments are made taking into account the profitability and sustainability of the chosen technical option and the available or borrowed capital. For example, provide the user with a computer containing the Excel application to facilitate calculations. This criterion is conditioned by the speed of execution and the aptitude for automation which is predominant. The performance cost will be all the more important when the expenses initiated for the use of the method are lower. Nevertheless, this criterion will be considered as not beneficial to the analysis of the design methods.

- Speed

The speed of a method refers not only to the time taken to apply the method but also the ease with which the method can be applied.

- Automation capability

This is the ability to computerise a method in order to achieve an easily manageable application.

2.3.2. Parameters of the PROMETHEE II multi-criteria method

The choice of the tool permitting to compare and even rank our sizing methods was based on the PROMETHEE II quality tool, which is based on a process of comparing two by two actions according to each criterion (Thakkar, 2021). It is based on the weighting of threshold criteria and it produces a hierarchy of actions (Moalla Frikha et al, 2007).Each action is therefore compared to the others on the basis of the criteria considered. The evaluation of actions is carried out by a real function, for each criterion (Macharis et al., 2004).

Weight of criteria

We define the set $G = \{g_1, g_2,\ldots,g_n\}$ containing the evaluation of the action on the set of criteria. The importance of the criteria in the decision making is evaluated by a set of weights $W = \{w_1, w_2,\ldots,w_n\}$. These weights are determined by several methods among which are weighted analysis, weighted voting, entropy method and hierarchical criteria (Thakkar, 2021)

In our context the weighted vote was chosen as it reflects the experience of the decision-makers and their ideas.

Table 12:Weighting of criteria

	Cost	Fast to use	Ability to automate	Fidelity	Accuracy
Cost	1	0	0	1	1
Fast to use	1	1	0	1	1
Ability to automate	1	1	1	1	1
Fidelity	0	0	0	1	1
Accuracy	0	0	0	0	1
Total	3,0	2,0	1,0	4,0	5,0

For this method, the indifference, preference and veto thresholds depend on the evaluation of the action for each criterion. For an action *a*, evaluated by $g_j(\alpha)$ for criterion*j*, in this case the indifference threshold is noted $q_j(g_j(\alpha))$, the preference threshold by $P_j(g_j(\alpha))$ and the standard deviation by $\sigma_j(g_j(\alpha))$.

The thresholds can be chosen according to the performance values observed for each of the criteria. In this case study, we will propose an uncertainty of 10 and considering a criterion *j*:

- $P_j = 2\times 10\% \times \max_{i,k}(g_j(\alpha_i) - g_j(\alpha_k))$ (7)
- $q_j = 10\% \times \max_{i,k}(g_j(\alpha_i) - g_j(\alpha_k))$ (8)
- $\sigma_j = 3\times 10\% \times \max_{i,k}(g_j(\alpha_i) - g_j(\alpha_k))$ (9)

Preference function

The PROMETHEE methods are based on an extension of the notion of criterion by introducing a function expressing the decision-maker's preference for an action ai over another action a. For each criterion, the decision-maker is asked to choose one of the six forms of curves expressed in the work of Thakkar (2021) on the PROMETHEE preference function.

2.3.3. Application of the PROMETHEE II multi-criteria method

The PROMETHEE II method is implemented as follows:

- *Step 0*

A numerical scale is defined as a qualitative value of a level of satisfaction, thus representing the tiered criterion for a qualitative criterion summarised in the table below:

Table 13:PROMETHEE preference function (Tranvouez, 2016)

Level of satisfaction	Digital scale
Very Good	5
Good	4
Medium	3
Mediocre	2
Low	1

Determine the decision matrix through the relationships:
For beneficial criteria

For non-beneficial criteria

$$R_{ij} = \frac{\left[x_{ij} - \min\left(x_{ij}\right)\right]}{\left[\max\left(x_{ij}\right) - \min\left(x_{ij}\right)\right]} (i = 1,2,..., m;\ j = 1,2,..., n) \qquad (10)$$

$$R_{ij} = \frac{\left[\max(x_{ij}) - x_{ij}\right]}{\left[\max\left(x_{ij}\right) - \min\left(x_{ij}\right)\right]} (i = 1,2,..., m;\ j = 1,2,..., n) \qquad (11)$$

- *Step 1*

For each criterion, one of the six forms of curves proposed above is fixed, as well as the parameters associated with it, having previously deduced the decision matrix. Let us consider the evaluation of the preference function $F_j(\alpha_i, \alpha_k)$

$$F_j(a_i, a_k) = 0 \quad if \quad Ra_{ij} \le Ra_{kj} \rightarrow D(Ma_{ij}, Ma_{kj}) \le 0 \qquad (12)$$

$$F_j(a_i, a_k) = (Ra_{ij} - Ra_{kj}) \quad if \quad Ra_{ij} \succ Ra_{kj} \rightarrow D(Ma_{ij}, Ma_{kj}) \succ 0 \qquad (13)$$

- *Step 2*

For each pair of actions (α_i ,α_k); the preference index is calculated $P(\alpha_i, \alpha_k)$ which represents the measure of the decision maker's overall preference for the action α_i in relation to α_k , on all *n* criteria.

$$P(\alpha_i, \alpha_k) = \frac{\sum_{j=1}^{n} w_j \times F_j(\alpha_i, \alpha_j)}{\sum_{j=1}^{n} w_j} \tag{14}$$

- *Step 3*

Calculate the inflow and outflow for each action α_i

$$\Phi^+(\alpha_i) = \sum_{\alpha_k \in A; \alpha_k \neq \alpha_i} P(\alpha_i, \alpha_k) \tag{15}$$

positive flow which expresses the force of α_i : Outgoing flow;

$$\Phi^-(\alpha_i) = \sum_{\alpha_k \in A; \alpha_k \neq \alpha_i} P(\alpha_i, \alpha_k) \, (16) \tag{16}$$

negative flow which expresses the weakness of α_i : incoming flow.

- *Step 4*:

Determine the 2 total pre-orders and arrange the actions

- The first total pre-order is to arrange the actions in descending order of Φ^+
- The second total pre-order is to arrange the actions in ascending order of Φ^-
- PROMETHEE II consists of ranking stocks in descending order of net flows $\Phi(\alpha_i)$ defined as follows:

$$\Phi(\alpha_i) = \Phi^+(\alpha_i) - \Phi^-(\alpha_i) \tag{17}$$

Thus, PROMETHEE II provides a total pre-order. (Brans, 2005; Thakkar, 2021)

2.3.3.1 Assessment of criteria

In order to analyse the design methods used, the following criteria were identified:

The cost (investment and operation) of the method:

The Hardy-Cross method is essentially an iterative method.Initial diameters are set and then through iterative calculations we find the theoretical diameter. Similarly, the determination of the corrected flow rate goes through the same process so the manual determination of this data is very tedious, hence the 2 on our numerical scale. However, the determination of the theoretical diameter by RMM is done through a series of precise formulae, but the corrected flow rate also follows fewer iterations than Hardy Cross: hence the rating of 4 for this criterion.

Speed of the method

In relation to tables 5 and 9 of the numerical model studied, it can be seen that with the RMM the theoretical diameters make it possible to deduce the corrected road flows from the first iteration, which is not the case for the Hardy-cross method. Moreover, the RMM approach is also a method for optimising the sizing of drinking water networks (Bedjaoui and Achour, 2014). Thus, the references 2 to the Hardy-cross method and 4 to the RMM.

Automation capability

The existing EPANET application is based on the Hardy-cross method, which is commonly used in the D.C., while the RMM is based on a series of formulas and can be automated, studies have already been carried out on this subject but the application remains unavailable. Hence the rating of 5 for the Hardy-cross method and 4 for the RMM.

Accuracy and precision of the method (ANSES, 2015)

The method is equally more accurate, as the random part of the experimental errors that affect the results is less. The accuracy of the method will therefore be defined by two notions: repeatability when the experimental conditions are identical and reproducibility when the experimental conditions are different (Storey et al., 2011). Trueness is the average value of a number of measured values and a reference value and precision is the closeness between the measured values obtained at repeated measurements (dispersion of values). The evaluation of the accuracy of the two methods of analysis was done by analysing the pipe cross-sections summarised in Table 14.

Table 14. Theoretical and nominal network diameters according to Hardy-Cross and RMM

MP	MA	Sections		Hardy-CrossS		RMM	
		Start	End	$D_{thé}$ (m)	D_{Norm}(m)	$D_{thé}$ (m)	D_{Norm}(m)
1	0	0	1	0.466609004	0.5	0.472478	0.5
1	2	1	2	0.248063837	0.25	0.1590615	0.15
1	0	1	5	0.248063837	0.25	0.2260672	0.25
1	0	5	4	0.206002607	0.2	0.151567	0.15
1	0	4	2	0.152769371	0.15	0.1291836	0.15
2	0	1	6	0.248063837	0.25	0.2206288	0.2
2	0	6	7	0.1997263	0.2	0.1575161	0.15
2	3	7	2	0.160888035	0.15	0.1514637	0.15
2	1	1	2	0.248063837	0.25	0.1590615	0.15
3	0	7	8	0.163517676	0.15	0.142408	0.15
3	2	7	2	0.160888035	0.15	0.1514637	0.15
3	0	2	3	0.160888035	0.15	0.2047022	0.2
3	0	3	8	0.082379407	0.15	0.1514065	0.15

On observation, the RMM method presents optimal pipe cross-sections to the Hardy-cross method. Moreover, several principles and norms govern the selection of the pipe diameter in a network, among which, it is recommended to have the same pipe cross-section in order to avoid additional costs resulting from reducers, connection elements and the increase of singular pressure losses. Thus, in this study we fix as reference pipe section in each mesh. The most recurrent one in the said mesh and deduce through formula (18) the inadequacy of the two methods quantified through and summarised in Table 15.

$$Bias = \bar{y} - \mu \tag{18}$$

Table 15:Evaluation of trueness

Wrongness of the rightness		
	Basis	
	Hardy-Cross	RMM
Mesh I	-0.0375	0.025
Mesh II	-0.0375	0.0125
Mesh III	0	0.0125

Of the three meshes analysed for the first two meshes, the absolute value of the bias of the RMM is lower than that of the Hardy-Cross method, and conversely for the third mesh, the sections of the channels of the RMM are optimal compared to those of Hardy-Cross, hence the notations 4 for the RMM and 2 for Hardy-Cross in accuracy. The fidelity defect is identified by the standard deviation in Formula (19).

$$s = \sqrt{\frac{\sum (y_i - \overline{y})^2}{n-1}} \tag{19}$$

Table 16. Assessment of fidelity defects

Defects of fidelity		
	Type gap	
	Hardy-Cross	RMM
Mesh I	0.292617498	0.180277564
Mesh II	0.292617498	0.175
Mesh III	0.173205081	0.175

The standard deviations calculated for the RMM in grid cells I and II are lower than those for Hardy-Cross, and vice versa in the case of grid cell III, hence 3 for Hardy-Cross and 4 for the RMM.

2.2.4. Criteria Weighting Coefficients

In this study, all criteria are weighted according to their degree of importance, whether considered beneficial or not, by the weighting coefficient per criterion. The determination of the weight of a criterion was based on: the experience observed in the application of this decision support tool; the two to two comparison of each action according to the decision maker (the user of the methods) in a developing country context, the importance of the criteria through the validation guide for analytical methods (ANSES, 2015) and the guide for the evaluation of routine analytical methods, the opinion and suggestions of some actors in the field. The sum of the weights is 100%. PROMETHEE II fully ranks the alternatives from best to worst using the net flow.

3. Results and Discussions

3.1 Weight of criteria

Through the weighting of the criteria, it emerges that the most important criterion for the use of a sizing method is its accuracy & precision, then its speed of use, its cost and finally its suitability for automation. This is in line with R. Grappin's guide for the evaluation of routine analytical methods, which gives priority to the accuracy of a method and stresses that the main characteristics of the accuracy of a method are: precision, accuracy and sensitivity. The weight of each of these analysed criteria is given in Table 17.

Table 17. Weight of criteria

Criteria	Cost	Fast to use	Ability to automate	Fidelity	Accuracy
Total (%)	20,0	13,33	6,67	26,67	33,33

3.2 Performance of the criteria

Quantitative assessment criteria are the easiest to use for aggregation. Qualitative criteria are difficult to manage and require the subjective intervention of the decision-maker to score the actions on a discrete scale large enough to take into account all possible aspects of sensitivity of the decision-maker. This is the case with our numerical scale of 1 to 5, depending on the level of improvement of a criterion in the use of a method. Given the methodology used, the performance of the criteria used is summarised in Table 18. The rough model method (RMM) performs better than the Hardy-cross method with the exception of the criterion of suitability for automation. RMM is the only analytical method for calculating the normal depth in free surface channels. The other current methods are either iterative or approximate (Lakehal et al, 2014). However, software based on this method remain unavailable unlike the Hardy-Cross method which is widely popularised through the use of EPANET software.

Table 18. Performance of criteria

Criteria	Cost	Fast to use	Ability to automate	Fidelity	Accuracy
Hardy-Cross method (M1)	2	2	5	3	2
RMM method (M2)	4	4	4	4	4
Max (X_{ij})	4	4	5	4	4
Min (X_{ij})	2	2	4	3	2

3.3 Preference matrix

The calculation of each preference index shows that for all the criteria identified in the analysis of the two sizing methods, the preference threshold is between 0.4 and 0.8; the indifference threshold is between 0.2 and 0.4 and the veto threshold between 0.6 and 1.2, summarised in Table 19.

Table 19. Assessment of fidelity defects

Criteria	Cr 1	Cr 2	Cr 3	Cr 4	Cr 5
	Cost	Fast to use	Ability to automate	Fidelity	Accuracy
Weight	20	13	7	27	33
Preference threshold	0.8	0.8	0.4	0.4	0.8
Indifference threshold	0.4	0.4	0.2	0.2	0.4
Veto threshold	1.2	1.2	0.6	0.6	1.2

3.4 Flow matrix

The PROMETHEE II method is simple and understandable to the user. It provides a clear ranking. Compared to other synthetic outranking methods, each solution has a clear ranking. The results presented in Table 20 show that R.M.M tops the ranking with a net flow of 0.86 compared to the Hardy-Cross method which has a net flow of -0.860. Thus, in a developing country context, the R.M.M outperforms the Hardy-Cross method. Furthermore, it is based on measurable parameters in practice, such as road flow rate, pipe diameter, and longitudinal slope of the pipe, absolute roughness and kinematic viscosity of the flowing liquid. Furthermore, it is based on the geometric and hydraulic characteristics of a reference roughness model whose parameters are well defined and through an a dimensional correction factor, these parameters are used to deduce those of the studied pipe, in particular the normal depth (Lakehal et al, 2014).

Table 20. Assessment of fidelity defects

Actions	Hardy-Cross method	Rough model method
$\Phi+$	0.070	0.930
$\Phi-$	0.930	0.070
Φ	-0.860	0.860
Rank	2	1

4. Conclusion

The present study focused on the application of the multi-criteria selection tool for the optimisation of the choice of the sizing method for drinking water distribution networks in developing countries particularlythe case of Cameroon. Several optimisation methods were mentioned but only the Hardy-cross and Rough Model methods were retained due to their authenticity. A numerical model previously studied by the Rough Model Method (RMM) was studied by the Hardy-cross method in order to better identify the analysis criteria of a sizing method for drinking water distribution networks. The criteria were: cost, speed of use, suitability for automation, fidelity and accuracy. The multi-criteria decision-making approach used was based on the PROMETHEE II method.

The calculation of the flows and the complete ranking of the alternatives from best to worst according to their net flow were performed for each application. The global preference matrices, the inflow or outflow vectors and the net flow were calculated. The ranking of potential actions on the two sizing methods in descending order was carried out. At the end of the survey, it can be concluded that the rough model method ranks first among the sizing methods for drinking water distribution networks, allowing the best compromise between the analysis criteria for sizing water supply networks in Cameroon followed by the Hardy-cross method despite the fact that it is the most popular and widely used method (given the availability and flexibility of the EPANET application, which is based on the said method). The tool was subjected to a sensitivity analysis (by varying the weights) to test its consistency, stability and reliability. The optimised data obtained in the present study could help the hydraulic engineer in the optimal choice of sizing method for drinking water networks necessary to implement optimal drinking water networks. This is to limit both the initial investment and operating costs of the said networks in the D.C.

Acknowledgments

The authors would like to thank the authorities of the Ecole Nationale Supérieure Polytechnique de Yaoundé I (ENSPYI) for their supervision during this work.

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