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Efficient Railway Gauge Conversion with Tunnel reconstruction

Lezin Seba Minsili[1*], Michel Mbessa[1], Wolfgang Nzie[2], Rodney Chiabi Nuh Mih[3], Christian Magloire Ndjegwes[3,4]

[1] Associate Professor, Civil Engineering Department, Yaoundé National Polytechnic High College, The University of Yaoundé 1, P.O. Box 8390 Yaoundé, Cameroon, lezinsm@yahoo.com, michel.mbessa@yahoo.fr

[2] Associate Professor, Mechanical Engineering Department, ENSAI College, The University of Ngaoundéré, Adamaoua Region, Ngaoundéré, Cameroon, nziewolfgang@yahoo.fr

[3] Graduate Student, Civil Engineering Department, Yaoundé National Polytechnic High College, The University of Yaoundé 1, Yaoundé, Cameroon, rchiabi@yahoo.com

[4] Railway Engineer, Head of the Department of Railway Transport Management, The Ministry of Transport, Yaoundé, Cameroon, christiandjegwes@yahoo.fr

***** Correspondence: lezinsm@yahoo.com

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ABSTRACT

The modernization of railway networks constructed during the colonial era requires the conversion of railway gauges from the metric to the standard gauge, as well as the expansion from single-track operation to a dual-track operation in order to accommodate railway infrastructures with the traffic growth. Existing critical infrastructures such as bridges and tunnels in the existing network will also require appropriate reconstruction measures since minimum clearance requirements associated with the standard gauge are subjected to new rolling stock and maintenance facilities. The present work presents an optimal procedure to solve efficiently the problem of a tunnel reconstruction during track conversion while maintaining trains circulation during the transition period from metric to standard gauge with less traffic interruption. From a multi-criteria comparison scheme we examine different options ranging from enlarging the existing tunnel to constructing an adjacent new standard gauge dual-track tunnel with the construction of an adjacent standard gauge single-track tunnel as a neutral choice. Results show that enlarging the existing tunnel under a sustained traffic, is both technically feasible and economically viable.

***Corresponding Author:**
Lezin Seba Minsili
Yaoundé National Polytechnic High College, The University of Yaoundé
lezinsm@yahoo.com

1. INTRODUCTION

The Cameroon Railway network is a single-track system, built on the metric gauge (1000 mm) as the fruit of Cameroon's colonial heritage from Germany. With the increase in the passenger and freight traffics, there has been a growing need to modernize and expand the existing railway network to meet the growing demand. It is in this light that the KOTI Consortium et al. [1] (2012) proposed the **C**ameroon **N**ational **R**ailway **M**aster **P**lan (CNRMP) under the auspices of the Ministry of Transport of Cameroon, which contains recommendations on the modernization of the existing railway network among which is a change in the gauge of the railway network from the metric gauge (1000 mm) to the more widespread standard gauge (1435 mm) [2, 3]. In addition, the possible expansion from a single-track to dual-track operation in order to accommodate for the growth in traffic has also been considered in terms of a heavier axle load and of average trains' velocity.

In the event of a conversion from the metric to the wider standard gauge, and an expansion from single-track to dual-track operation, all the railway infrastructures on the network would require appropriate reconstruction measures in order for them to conform to the minimum clearance requirements associated with the standard gauge, and specifically railway tunnels, initially designed for a single-track metric gauge operation will have to face the space requirements associated to the standard gauge needs rolling stock geometry [4, 5].

These reconstruction measures are met with the following constraints: firstly, the current railway system operates on a single-track mode, hence there is currently no way to divert traffic to an adjacent railway track during the reconstruction process due to this drawback; secondly, the importance of the railway system to the economy of the country and the Central African sub-region, rules out any interventions that would interrupt traffic for prolonged periods of time, due to the very high social cost that would result; and thirdly, the scarcity of financial investments from the state, as the lone shareholder, as well as from investors is becoming acute due to the restraint of international partners to finance long term projects with low return [6,7, 8].

This poses the problem of how to efficiently execute tunnel reconstruction procedures while maintaining train circulation in the tunnel, minimizing construction, exploitation and maintenance costs while accommodating for future traffic growth [9, 10, 11]. In order to solve these afore mentioned problems, this work aims at proposing an optimal solution, that would satisfy the constraints that characterize the reconstruction and functional measures.

Tonon [12] presented different techniques for enlarging an existing tunnel. These techniques were classified as enlarging the tunnel using a) protective shield and b) non-shield enlargement method associated the existing lining as part of protective shield. Protective shield techniques involve the use of a steel platform covered with sound-proofing and anti-shock material, to separate the tunnel traffic from the construction activities, and also act as a working platform for the excavation activities.

Protective shield methods were seen to be more complex in their implementation [13] and require costly machinery which must generally be custom designed for the specific project; in addition to requiring a more specialized workforce that may not always be readily available in the context of a third world country. On the other hand, non-shield enlargement methods involve the use of conventional tunneling machines with little need for custom built equipment reducing the need for specialized workforce; methods which could be suitable for medium to hard rock conditions.

As such non-shield tunnel enlargement methods are more recommendable for third world countries like Cameroon where the cost of acquiring custom built machines would be prohibitively high [14, 15]. Moreover, most of the tunnels on the Cameroon railway network are built in medium to hard rock, which are suitable for the usage of non-shield methods. However, every tunneling project is a unique endeavor as different ground conditions present different challenges; and the non-shield methods reviewed in the literature must always be adapted to the physical constraints and financial context of the project area.

We examine three options in order to solve for the above mentioned challenge: (1) Enlarging the existing tunnel to a standard gauge dual-track tunnel, while maintaining traffic; (2) Constructing an adjacent standard gauge dual-track tunnel; (3) Constructing an adjacent standard gauge single-track tunnel. Then we apply a multi-criteria comparison scheme to select the optimal solution, which is thereafter sequentially optimized to attain a considerable savings in volume of materials required in the support system compared to conventional support systems. In addition, through the proposal of acquisition of an efficient loading machine, we were able to attain a fair reduction in construction time. Therefore, this work in subsequent sections will demonstrate that enlarging the existing tunnel under sustained traffic can be adopted in reconstructing a single-track railway tunnel during a gauge conversion and is both technically and economically feasible.

2. MODELING AND RESEARCH METHOD

2.1. Multi Criteria Optimization

The novelty of this work lies in the inclusion of multiple qualitative and quantitative aspects for evaluating railway tunnel and its components during construction and maintenance through a multi-criteria decision procedure. Decision making is not easy as long as the scarcity of funds does not depend on the project owner but mainly on the Public Private Partnership and on its challenges and requirements. Thus the multi-criteria optimization procedure developed in this work can be viewed as a tool to select the best compromising solution or solutions from a list of several potential alternatives by taking into consideration a set of criteria and information at hand [16,11]. In order to objectively select between the options presented above, a multi-criteria comparison selection scheme [17] was adopted in which each selection parameter was given a particular weight, and each option was given a particular score for each parameter. All scores were placed on a scale of 1 to10, and the parameters were divided into two main groups: Life-cycle costs, and operational parameters.

The lifecycle parameter also is divided into two classes namely the initial cost parameter and the maintenance requirement parameter. For the initial cost parameter, the score Sj is calculated for each option using the following equation:

$$S_j = 10 * (1 - \frac{C_j}{C_1 + C_2 + C_3}); \quad (1)$$

where c_j is the cost of option j.

For the m*aintenance requirement parameter, its weight i*s qualitatively evaluated taking into consideration the fact that the maintenance cost is a yearly expenditure which varies with the degree of exploitation of the tunnel. The Maintenance Requirement Index (**MRI**) of the tunnel is basically focused on the railway track, gutters, and tunnel lining, each with a given specific index as described previously for the tunnel reconstruction. Thus the score s_j of the index, for each option *j* of the tunnel lining maintenance index i_3, is given by the following equation based on assumptions of Triantaphyllou [7]:

$$s_j = 10 * (1 - \frac{i_{3j}}{i_{3.1} + i_{3.2} + i_{3.3}}) \quad (2)$$

Operational parameters characterize the general convenience of exploiting the tunnel during its entire operational life. The factors considered are: 1) the *future benefit* characterizing the ease with which changes can be made to the railway line with minimal impact on the railway traffic (e.g. change to dual track mode of operation, maintenance, installation of ballast-less tracks etc.); 2) the *technical feasibility* quantifying the relative ease of execution based on current advances in tunneling technology, and expertise; 3) the c*onstruction time efficiency* which the score can be extrapolated from equation 2 to obtain:

$$s_j = 10 * (1 - \frac{t_j}{t_1 + t_2 + t_3}) \quad (3)$$

where t_j is the construction duration for option j.

The scores for the future benefit and technical feasibility were arbitrarily determined based on the appreciated future operational advantages it may present and appreciated ease of execution.

2.2. Design Characteristics

The Souhe tunnel, as the subject of this study, is found in the Eseka circumscription along the Eseka – Minloh Maloume segment of the Transcam I railway axis; precisely between PK 159 + 375 to PK 161 + 395 with a length of about 2020m as shown in figures 1.a) and 1.b). This tunnel with a metric railway gauge was hand excavated out of a competent rock massif during the German colonial period [18, 16], and now exhibits a relatively benign state of degradation that would require rehabilitation in the long run.

The rock massif on site is located on the Ngovayang chain which forms part of the major tectonic unit of the Nyong Series in the southern part of Cameroon according to Ndong et al. [20]. The rock mass is predominantly amphibolite in nature, with the rock being partly weathered [21], and from tunneling point of view the rock mass could be regarded as relatively competent.

The railway segment of this study possesses three tunnels that cut across the mountainous terrain, with one of the tunnels being completely unlined, with the other two tunnels having a reinforced concrete lining. The existing tunnel present a horse-shoe profile with vertical sidewalls, and the excavation cross-section having diameter of 6,40 m and height of 7,57 m. The clear cross-section of the tunnel presents diameter of 5,60 m and height measured from top of rail level (T.O.R) of 6,27 m. The existing tunnel cross-section is illustrated in Fig 1.c).

a) aerial plane view; b) Souhe tunnel entrance; c) typical cross-section of tunnel axis

Figure 1. Existing Tunnel

The preliminary design for a new tunnel's support system was done by the empirical design approach based on the Rock Mass Rating (RMR) modeled after field estimates of uniaxial compressive strength related from EduMine [22] as the sum of the values of the following six parameters namely:

$$RMR = J_{A1} + J_{A2} + J_{A3} + J_{A4} + J_{A5} + J_{B} \quad (4)$$

With J_{A1} being the strength of intact rock material deduced from the empirical table above which gives field estimates of the rock strengths that correspond to different types of rock mass;

J_{A2} is the rock quality designation also determine from empirical tables**;**

J_{A3} is the spacing of discontinuities estimated based on qualitative observation;

J_{A4} is the condition of discontinuities obtained through qualitative observations on site;

J_{A5} is the groundwater conditions deduced by observing the state of the existing tunnel for infiltrations;

J_{B} is the Orientation of discontinuities arbitrarily taken to be fair for design purpose**.**

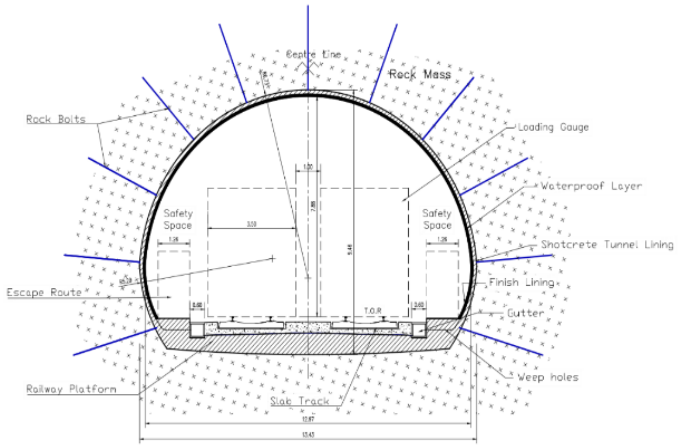
Following this expression, the field estimates of the ground characteristics gave an RMR value of 62, which can be described as good rock, with a stand-up time of one month for 13 m roof span. As such a new tunnel would require no temporary support during excavation because of its high stand-up time of one month. Recommendations from the table proposed by Bieniawski [23] suggested a permanent support system consisting of rock bolts, wire mesh, and a shotcrete lining.

A slab-track system would be suitable for the railway track bed due to the advantages it presents relative to the ballast track system such as rapid installation, and lower lifecycle cost [24]. Having presented the general characteristics of the existing tunnel, in the following the sub-sections, we would then move on to present the three options that were considered in order to resolve the challenges that were highlighted in our problem statement

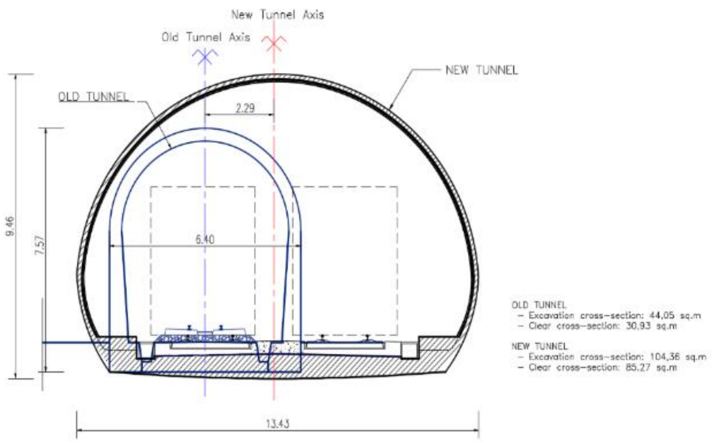
2.3. Tunnel Reconstruction Options

2.3.1. Option 1: Reconstruction and Extension of the Existing Tunnel

This option consists of the reconstruction and enlargement of the existing tunnel. The size of the tunnel shall be in such a way as to allow for a dual track operation based on the structure and geometry of the standard gauge. The tunnel is meant for both passenger and freight traffic. A sufficiently wide safety space would be provided for both inspection visits, and evacuation of passengers in case of any incident in the tunnel. Sufficient overhead allowance shall be provided for overhead lighting, signaling systems and also to provide natural ventilation. Allowance would be made for side drains that are easily accessible for cleaning. Given that the rock mass surrounding the tunnel is predominantly competent rock, vertical stresses are much more important than lateral stresses in determining the tunnel cross-section. As such the horse-shoe profile was more appropriate for the profile of this tunnel. The horse-shoe profile with curved sidewalls was selected because it offers a better resistance to lateral forces. The horse-shoe profile can be easily excavated using conventional excavation machines in a drill and blast method.



a) Cross-section of new



b) Positions of old and new tunnels

Figure 2. Tunnel reconversion cross-sections for option 1.

Based on all functional and technical constraints stated above, we obtain a horse shoe profile with the excavation cross-section with dimensions of 13.43m in diameter and 9.46 m high. We have a tunnel clear cross-section having diameter of 12.97 m and useful height measured from T.O.R of 7,88 m. The new tunnel cross-section is illustrated in figure 2.a), while figure 2.b) illustrates the relative positions of the old tunnel and the new enlarged one.

The estimate of the construction cost and the MRI were determined through an estimate of the reconstruction initial cost, and through an estimate of the reconstruction of the new tunnel on the exploitation of the existing one. For the normal weekly advance rate for a net enlarged cross-section of 60.05 m^2, we obtain an advance rate of 70 m/week, hence an average excavation time of about 15 weeks. The overall cost of the tunnel reconstruction procedures was estimated at 7 213 847 027 FCFA **(**The rate of **1.00 $ USD** is 612.483 **XAF** CFA on May 26, 2023**)**. After several calculations that are not described in detail here the overall cost of the tunnel reconstruction procedures is summarized in Table 1 below.

Table 1: Estimates of Construction cost for Option 1.

Cost of Enlarging the Existing Tunnel, Option 1 (in XAF CFA)[(1)]					
No	**Designation**	**Unit**	**Quantity**	**Unit Price**	**Total Cost**
I.	Site Installation and Machinery	ff	1,00	65 000 000	65 000 000
II.	Excavation Works				
	Earthworks	m3	121 301,00	2 350	285 057 350
	Explosive charges	kg	145 561,20	12 000	1 746 734 400
	Primary shotcrete lining	m3	25 431,80	71 750	1 824 731 650
	Waterproof lining	m2	47 914,40	14 000	670 801 600
	Final Shotcrete lining	m3	2 383,60	65 000	154 934 000
	Rockbolts	u	8 888,00	1 650	14 665 200
III.	Drainage				
	Ø40mm PVC pipes	ml	654,48	400	261 792
	Precast Gutters	ml	2 020,00	13 000	26 260 000
IV.	Dual Track Slab-track Railway System	km	2,02	876 038 000	1 769 596 760
V.	Labour cost (10% of (I+II+III+IV))	ff			655 804 275
	TOTAL				7 213 847 027

[(1)] The rate of **1.00 $ USD** is 612.483 **XAF** CFA on May 26, 2023. https://themoneyconverter.com/fr/usd/xaf

The **MRI** of the tunnel is calculated specifically for each option taking into account the railway track maintenance index (i_1), the gutters maintenance index (i_2), and the tunnel lining maintenance index (i_3). For the railway track maintenance index (i_1), the maintenance requirement for the track is directly proportional to the length of the track (which is the tunnel length, L). For a single track the index was taken as 1.L, and for dual track tunnels the factor 1,5L was assumed given that dual track railways cost approximately 1,5 times their single-track counterparts as mentioned earlier. Whereas, for twin tunnels we took 2L. The cost of the gutters maintenance index i_2 is directly proportional to the tunnel length, L. The cost of a single line of gutters is multiplied by the factor *nL* (where n is the number of gutters). The weight of the tunnel lining maintenance index i_3 is directly proportional to the surface area of the lining, for example it is equated to i_3 = A = P*L where A is the surface of the lining area, *P* is the perimeter of lining, and *L* the tunnel length.

The reconstruction of the new tunnel constitutes a Category A1 railway works according to the CAMRAIL's classification of operations at its Transport Department [25], Unit of Training and Human Ressouce Development. This means that the construction activities would invariably interrupt the normal flow of traffic on the railway section. Construction operations could affect the exploitation of the existing railway line in the following two ways: The Lost Time due to train delays at the tunnel site, and the revenue shortfall, that is the financial cost of the delays.

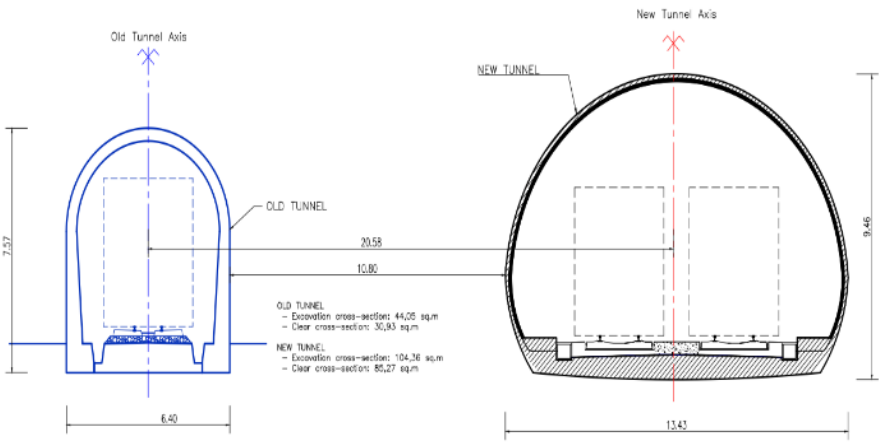
For safety reasons trains are required to slow down at the approach of a major railway worksite at least 1500 m before the site. The lost time on the Souhe tunnel worksite is evaluated below based on the railway traffic timetable at CAMRAIL between Yaoundé and Douala, a 263 km long railway section namely TRANSCAM 1, during the commercial year 2018. To simplify the analysis no distinction is made between passenger and goods traffic, and the following characteristics are adopted based on the given table: the number of trains that cross the tunnel *n*, the average course speed of trains under normal traffic conditions *V*, the Speed of traversing the worksite *v'*, the length of tunnel *l*, the security distance from worksite *d*, and the length of security zone $L = l + d$.

CAMRAIL recorded an annual turnover of US $ 113 million in 2015 [26] amounting to about 76,5 billion FCFA, that is about 209,51 million FCFA per day. Considering that about 18 train journeys are made per day on the national territory based on the Camrail traffic timetable, we obtain an average daily turnover of 11,64 million FCFA per train journey. Given that a train running the Transcam 1 at about 60 km/h would take about 4,37 hrs that is about 262 minutes, we can find the revenue shortfall $\Delta \boldsymbol{R}$ per train per day due to lost time. Thus for the total traffic of eight trains for example on that section amounts to a revenue shortfall of **3,91 million FCFA** daily due to lost time. Which for a duration of construction of 15 weeks amounts to a **total revenue shortfall of about 410,6 million FCFA.**

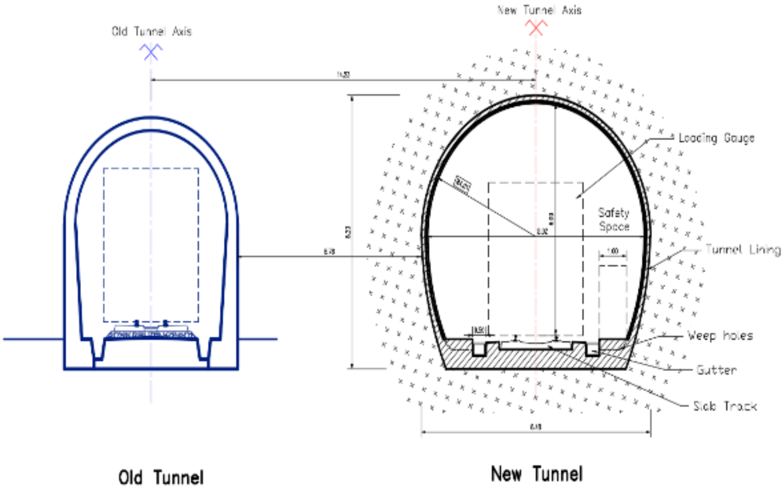
2.3.2. Option 2: Construction of a New Dual-Track Tunnel Adjacent to the Existing Tunnel

This option consists of building a new tunnel at a given distance from the existing tunnel. The new tunnel shall be built to the same specifications as the enlarged tunnel section in Option 1. The same cross-section design as Option 1 is adopted for this tunnel. The cross-section of the tunnel is presented in Fig 4. The relative positions of the old tunnel and the new tunnel is illustrated in Fig 5.

This option consists of building a new tunnel with a double track standard gauge at a given distance from the existing tunnel, and that shall be built to the same specifications as the enlarged tunnel in OPTION 1 with the same site, geologic characteristics of plan profile, characteristics of the longitudinal profile, design cross-section, support systems as shown in figure 3.a). However, the new tunnel of this option must be spaced at a minimum distance of at least 0,8 D from the existing tunnel according to Singh et al. [27], D being the largest tunnel diameter.



a) Tunnel with a new double track



b) Tunnel with a new single track

Figure 3: Relative Positions of old and new tunnel for a) option 2, and b) option 3.

The total length of railway track being 2 020 m, the following quantities of work would also be the same: number of rock bolts, volume of shotcrete lining, surface area of waterproof layer, drainage system, and railway track work. The normal weekly advance rate for excavation procedure is deduced from corresponding specific calculations. Thus for a net enlarged cross-section of 104,10 m^2 we obtain an advance construction rate of 70 m/week that leads to Table 2 outlining corresponding economic analysis in terms of the tunnel cost estimate and maintenance requirement indexes as in option 1, with an average excavation time of about 17 weeks and an approximate construction cost of 8 853 321 952 FCFA (The rate of 1.00 $ USD is 612.483 XAF CFA on May 26, 2023).

Table 2: Estimate of construction cost for Option 2.

Cost of Constructing a New Double Track Tunnel, Option 2 (in XAF CFA)[(1)]					
No	**Designation**	**Unit**	**Quantity**	**Unit Price**	**Total Cost**
I.	Site Installation and Machinery	ff	1,00	65 000 000	65 000 000
II.	Excavation Works				
	Earthworks	m3	210 282,00	2 350	494 162 700
	Explosive charges	kg	252 338,40	12 000	3 028 060 800
	Primary shotcrete lining	m3	25 431,80	71 750	1 824 731 650
	Waterproof lining	m2	47 914,40	14 000	670 801 600
	Final Shotcrete lining	m3	2 383,60	65 000	154 934 000
	Rockbolts	u	8 888,00	1 650	14 665 200
III.	Drainage				
	Ø40mm PVC pipes	ml	654,48	400	261 792
	Precast Gutters	ml	2 020,00	13 000	26 260 000
IV.	Dual Track Slab-track Railway System	km	2,02	876 038 000	1 769 596 760
V.	Labour cost (10% of (I+II+III+IV))	ff			804 847 450
	TOTAL				**8 853 321 952**

[(1)] The rate of **1.00 $ USD** is 612.483 **XAF** CFA on May 26, 2023. https://themoneyconverter.com/fr/usd/xaf

2.3.3. Option 3: Construction of a New Single-Track Tunnel Adjacent to the Old Tunnel

This option consists of construction of a new single-track tunnel with a horse-shoe profile at an axe-to-axe distance 14.23 m between the existing tunnel and the new standard one with a subsequent enlargement of the existing tunnel. The work shall be executed in two phases:

- Phase 1: Construction of New tunnel, adjacent to the existing tunnel while traffic flow is uninterrupted in the existing tunnel. Once construction is completed, the traffic is diverted to the new tunnel.
- Phase 2: Diversion of the railway traffic to the new tunnel, and enlargement of the existing tunnel to same geometry as the new tunnel.

At the end of these works, both tunnels would be fully operational and would serve the purpose of a dual track railway system. The characteristics are given below are also computed following the same procedures as described in the two previous options. In this case, the new tunnel is a single-track tunnel. The tunnel has an excavation cross-section with dimensions of 8.48m in diameter and 8,23 m high, with a clear cross-section having diameter of 8,02 m and height measured from T.O.R. to the crown of 6,99 m as illustrated in figure 3.b). The normal weekly advance rate is estimated for each cross-sectional area at:

- Phase 1: 59,54 m2; which corresponding to an advance rate of 76m/week;
- Phase 2: 15,49 m2; which corresponding to an advance rate of 76m/week.

This gives an average excavation time of about **16 weeks** for the first phase and 12 weeks for the second phase reaching a total of 28 days. Table 3 outlines corresponding economic analysis in terms of the tunnel construction cost estimate and maintenance requirement indexes as done in previous options, with an approximate construction cost of 11 101 283 431 FCFA (The rate of 1.00 $ USD is 612.483 XAF CFA on May 26, 2023).

Table 3: Estimate of construction cost for Option 3

Cost of Constructing a New Single Track Tunnel, Option 3 (in XAF CFA)(1)					
No	**Designation**	**Unit**	**Quantity**	**Unit Price**	**Total Cost**
I.	Site Installation and Machinery	ff	1,00	65 000 000	65 000 000
II.	Excavation Works				
	Earthworks	m3	151 560,60	2 350	356 167 410
	Explosive charges	kg	181 872,72	12 000	2 182 472 640
	Primary shotcrete lining	m3	31 794,48	71 750	2 281 253 940
	Waterproof lining	m2	95 828,80	14 000	1 341 603 200
	Final Shotcrete lining	m3	3 838,00	65 000	249 470 000
	Rockbolts	u	14 544,00	1 650	23 997 600
III.	Drainage				
	Ø40mm PVC pipes	ml	993,84	400	397 536
	Precast Gutters	ml	4 040,00	13 000	52 520 000
IV.	Dual Track Slab-track Railway System	km	4,04	876 038 000	3 539 193 520
V.	Labour cost (10% of (I+II+III+IV)	ff			1 009 207 585
	TOTAL				11 101 283 431

(1) The rate of **1.00 $ USD** is 612.483 **XAF** CFA on May 26, 2023. https://themoneyconverter.com/fr/usd/xaf

3. RESULTS AND DISCUSSIONS

3.1. Results from Individual Options

Previous tables elaborated from each option show that option 1 has an estimated cost of construction of about 7 214 billion FCFA with an estimated total revenue shortfall due to delay of railway operations amounting to about 410.9 million FCFA (The rate of 1.00 $ USD is 612.483 XAF CFA on May 26, 2023), this is equivalent to a total social cost of about 7 625 billion FCFA. In addition, this option has a normal construction time of 15 weeks. This option also has the advantage that it maintains the existing main railway axis of the first railway line of Cameroon *Transcam 1* with no need for deviation to be constructed. In addition, provision is made for an eventual switch to a dual track operation, in such a case, the railway formation would need only an enlargement with moderate additional earthworks to be carried out, hence a relatively moderate cost of conversion.

Option 2 has an estimated cost of construction of about 8,854 billion FCFA with no revenue shortfall due to delay of railway operations, since normal traffic would not be disturbed. This option presents an estimated normal construction time of 17 weeks. It is also advantageous in that it presents an alternate route in case of a possible shutdown of the adjacent tunnel. In an eventual dual track operation, a passenger train and freight train could pass through adjacent tunnels as international safety standards do not allow their simultaneous movement in the same tunnel. However, in the event of a future dual track operation, relatively important earthworks would need to be carried out driving the cost higher. However, this option is wasteful in that the old tunnel would have to be abandoned once the new tunnel is completed, unless a triple-track operation is envisaged, in which case the old tunnel would still need to be enlarged in order to conform to the standard gauge requirements.

Option 3 has an estimated cost of construction of about 11 101 billion FCFA with no revenue shortfall due to delay of railway operations, since normal traffic would not be disturbed. However, this option has a greater maintenance requirement than option 1 and option 2 as the twin tunnels present a greater combined surface area than the single new tunnel's enlarged section of Options 1 and 2.

3.2. Weighted Comparison

The scores for each option and comparison parameters were calculated based on previous equations 1 to 4 and are summarized in **Error! Not a valid bookmark self-reference.** and the corresponding indexes in the form of radar diagram of figure 4.

Table 4: Table of weighted comparison indices

			Score of relative parameters, s_j		
		Parameter	**Option 1**	**Option 2**	**Option 3**
LIFECYCLE COSTS		Initial Cost	7,21	6,58	5,71
	Maintenance Cost	i_1	7,00	7,00	6,00
		i_2	7,50	7,50	5,00
		i_3	7,23	7,23	5,54
OPERATIONAL PARAMETERS		Future benefit	6,50	5,00	7,00
		Technical feasibility	6,00	7,00	6,50
		Construction time efficiency	7,50	7,17	5,33

From the comparison explained above and enlightened in table 4 and figure 4, we see that option 1 has a lower cost and a shorter duration than all the other alternatives. Option 2, being costlier than option 1, is also less realistic in that it involves abandoning the old tunnel hence a greater sunk cost. Meanwhile option 3 is much more expensive than all the other alternatives which offsets any comparative advantage it may present. In this light, the enlargement of the existing tunnel as presented in **option 1, as the most viable and the optimal solution** for the reconstruction of the existing tunnel, in case of a conversion from metric to standard gauge.

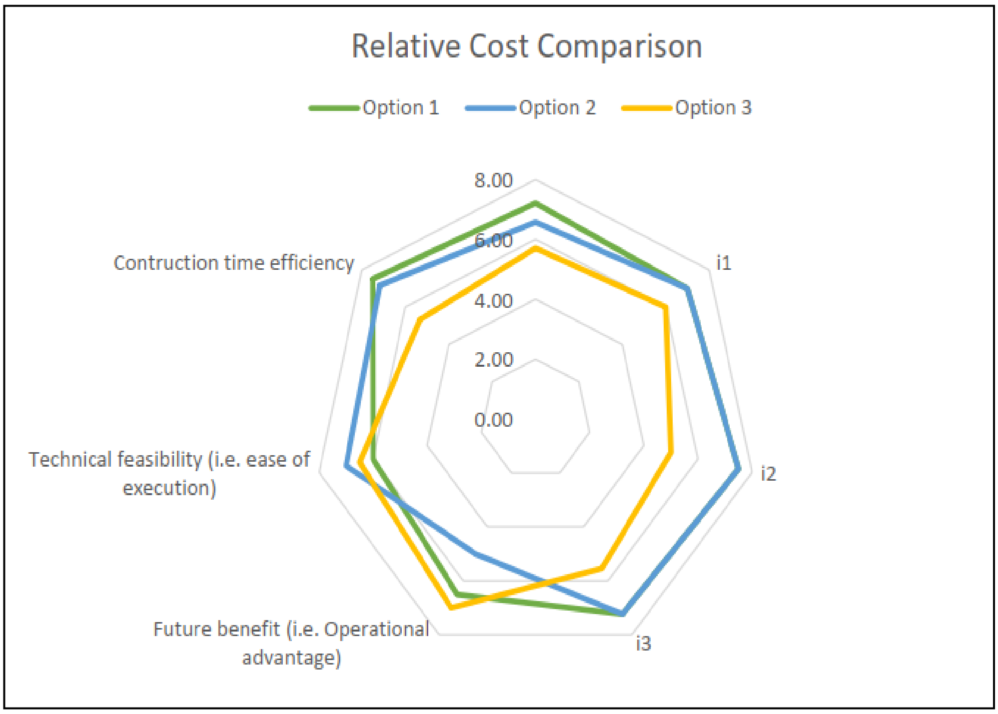


Figure 4: Options' Comparison by Radar diagram

4. CONCLUDING REMARKS

The optimization of the reconstruction of an existing railway with the modernization of its functional characteristics is not always a straightforward assignment in particular in underdeveloped countries where technical awareness and financial means are not always up-to-date. This task is even more difficult when there is little political will to renovate infrastructures such as bridges and tunnels with conversion of a metric gauge to double track standard gauge while maintaining the existing traffic demand. With existing technical documents, the present work has proved that it is possible to translate a political will to a practical project while facing the challenging of converting a single narrow gauge railway tunnel to a double standard gauge tunnel with accommodation of existing railway traffic.

The proposed methodology, in the form of a multi-criteria comparison scheme to select the optimal solution from initial three tunnel reconstruction variants, the sequential optimization was thereafter applied to attain a considerable saving in volume of materials required in the support system compared to conventional support ones. In addition, through the proposal of acquisition of an efficient loading machine, we were able to attain a fair reduction in construction time while applying it to Souhe tunnel located on the Eseka – Minloh-Maloume section of the Transnational Cameroon railway network.

This work demonstrated that the proposed optimization procedure of tunnel enlargement was practical, technically feasible and an economically viable solution. And we were able to achieve additional benefit on the overall project cost in terms of a reduction in the construction time from beginning of works to the delivery of the project of about 10%, with the same percentage being true for a reduction of the overall construction cost of the project.

As a perspective for further improvement of the findings of this works, the following points are proposed to be implemented in the near future:

1- The in-depth analysis of a solution for a cost effective and durable slab-track system, that would be suitable for the railway tunnels in Cameroon;
2- The sustainability of the solution presented in this work to various tunnels rehabilitation in the Cameroon railway network;
3- The numerical simulation of the proposed solution with geotechnical data from a real project to test actual performance of the system;
4- The reel implementation of this method on ongoing tunnelling design projects of the National Railway Master Plan.

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REFERENCES

[1] KOTI Consortium, CSE, KRNA, KORPEC. "Plan Directeur Ferroviaire National du Cameroun.," Ministère des Transports. *'The National Railway Master Plan of Cameroon from Ministry of Transports of Cameroon'*, adopted on 2012 by MINEPAT.

[2] Minsili L. S., M. J. Kisito, T. Gilbert, N. Jean, K. A. Gadam and D. P. Christian. "Requirements to the Modernization of African Railway Networks: The Standard Gauge Versus the Metric Gauge", *International Journal of Civil Engineering and Technology*, 2017 vol. 8, no. 7, pp. 925-941, 2017.

[3] Nanda Ahda Imron, Dian M. Setiawan, Ali OktavianHandoko, Erifendi Churniawan, Handoko, Ary Putra Iswanto, "An Analysis of Passengers' Safety Risk at the Infrastructure Improvement Project of Railway Station" *Journal of Railway Transportation and Technology, Vol. 2 No. 2 (2022) 1-13 p, e-ISSN: 2830-6680, https://doi.org/10.37367/jrtt.v1i2.13*

[4] Villalobos S., P. Cacciari, M. Futai, 2020. "Stability assessment around a railway tunnel using terrestrial laser scanner data and finite element analysis". *Revista Ingeniería de Construcción* RIC, Vol 35, Nº1 2020, p21-33. www.ricuc.cl

[5] Judit Gómez, Joan R. Casas, Sergi Villalba. 'Structural Health Monitoring with Distributed Optical Fiber Sensors of tunnel lining affected by nearby construction activity'. *Automation in Construction* 117 (2020) 103261, www.elsevier.com/locate/autcon

[6] Mouhamed Bayane Bouraima , Yanjun Qiu , Bekhzad Yusupov , Christian Magloire Ndjegwes. "A study on the development strategy of the railway transportation system in the West African Economic and Monetary Union (WAEMU) based on the SWOT/AHP technique", *Scientific African* (2020), doi: https://doi.org/10.1016/j.sciaf.2020.e00388

[7] Triantaphyllou E., B. Shu, Nieto Sanchez, T. Ray, 1998. 'Multicriteria Decision Making : An Operations Research Approach'. *Encyclopedia of Electrical and Electronics Engineering*, John Wiley & Sons, New York, Vol. 15 pp. 175-186 (1998).

[8] Matthias Villads Hinsch Als , Mathias Bejlegaard Madsen, Rune Møller Jensen, "A data-driven bi-objective matheuristic for energy-optimising timetables in a passenger railway network", Journal of Rail Transport Planning & Management 26 (2023) 100374, www.elsevier.com/locate/jrtpm

[9] Nabil M. Al-Nasser. "The Impact of Financial Analysis in Maximizing the Firm's Value "A Case Study on the Jordanian Industrial Companies". *International Journal of Managerial Studies and Research (IJMSR)* Volume 2, Issue 6, July 2014, pp 1-9 ISSN 2349-0330 (Print) & ISSN 2349-0349 (Online). www.arcjournals.org

[10] Anaja Blessing, Emmanuel E. Onoja. "The Role of Financial Statements on Investment Decision Making: A case of United Bank for Africa". *European Journal of Business, Economics and Accountancy*, Vol. 3, No. 2, 2015. ISSN 2056-6018 Progressive Academic Publishing, UK p.12. www.idpublications.org

[11] Handoko, Firdaus Ade Kurniawan, Natriya Faisal Rachman, Rao Guangjiong, "Investigating Public Perception Toward the Level Crossing Without Railway Gate Crossing (Case Study: at JPL 297 and 294 Lamongan)". *Journal of Railway Transportation and Technology* Vol. 1 No. 1 (2022) 37-45 p-ISSN:2830-0491 e-ISSN:2830-6680 37-45 https://doi.org/10.37367/jrtt.v1i1.7

[12] Tonon F. "Methods for Enlarging Transportation Tunnels while Keeping Tunnels Fully Operational", *Periodical on Structural Design and Construction*, Vol. 15, Issue 4 (November 2010). **https://doi.org/10.1061/(ASCE)SC.1943-5576.0000035**

[13] Smith CDM. "Heroes Tunnel Alternative Construction Options Study". Final Report, *Connecticut Department of Transportation*, New Haven, November 2014. https://www.heroestunnelproject.com/HTAbout.php

[14] Libasse SOW. "Ballasted Railways in Senegal - Characterization of Bandia Limestone and Diack Basalt for Use as Ballast Materials". *International Journal of Applied Engineering Research*, ISSN 0973-4562 Volume 14, Number 15 (2019), pp. 3396-3405. © Research India Publications. http://www.ripublication.com

[15] Kampas G., J.A. Knappett, M.J. Brown, I. Anastasopoulos, N. Nikitas, R. Fuentes. "Implications of volume loss on the seismic response of tunnels in coarsegrained soils". *Tunnelling and Underground Space Technology* 95 (2020) 103127. www.elsevier.com/locate/tust

[16] Rajagopalan, N., Brancart S., De Regel S., Paduart A., Temmerman N.D., Debacker W. "Multi-Criteria Decision Analysis Using Life Cycle Assessment and Life Cycle Costing in Circular Building Design: A Case Study for Wall Partitioning Systems in the Circular Retrofit Lab". *Sustainability* 2021, 13, 5124. https://doi.org/10.3390/su13095124

[17] Hodgett, R. E. "Comparison of Multi-Criteria Decision-Making Methods for Equipment Selection". *The International Journal of Advanced Manufacturing Technology*, 2016, 85 (5-8). pp. 1145-1157. ISSN 0268-3768 https://doi.org/10.1007/s00170-015-7993-2

[18] UNESCO, 'Les Tunnels ferroviare de Njock', 2nd February 2018. Accessed 21 September 2019. Available online : https://whc.unesco.org/en/tentativelists/6327/ .

[19] Google Maps. The railway network at Eseka. Accessed on July 19, 2019. Available: https://maps,google.com/ .

[20] Ndong B. F., M. S. Ntomba and O. J. Mvondo. "Deformation et Metamorphisme dans la Partie Centrale de la Chaine de Ngovayang (Sud-Cameroun)', *Afrique Science* 08(3) (2012) 42 – 50, ISSN 1813-548X, http://www.afriquescience.info

[21] Owona S., G. A. Alexandre, D. Youmen and L. Ratschbacher. "Geologic control of morphotectonic units from the Edea-Eseka Line", REV. CAMES - VOL. 01.2013, *Research Gate*, December 2013. https://www.researchgate.net/publication/272794488

[22] EduMine. "Rock Mass Rating (RMR) Design Tables". Retrieved from EduMine - Professional Development and Training for Mining and the Geosciences on august 2020: http://www.edumine.com/tools/rock-mass-rating-rmr-design-tables

[23] Bhawani Singh, R.K. Coel. "Rock Mass Classification: A Practical Approach in Civil Engineering". 1999 Elsevier Science Ltd. All rights reserved, p. 47-60. http://faculty.tafreshu.ac.ir/file/download/course/1583681774-rock-mass-classification.pdf

[24] Avramovic N., 2010. ‘Comparison of ballasted and ballastless tracks: Ballast and concrete railway superstructure’, VDM Verlag Dr. Müller 2010, ISBN-10: 3639271386, 108 pages.

[25] CAMRAIL. “Cameroun Railway : Guide Horraires et Tarrifs”. Retrieved on september 17, 2019 from CAMRAIL website: http://www.camrail.net/en/

[26] Singh, R., Singh, T. N., & Bajpai, R. K. “The Investigation of Twin Tunnel Stability: Effect of Spacing and Diameter”. *Journal of the Geological Society of India, 2018 vol. 91*(5), 563-568.

[27] World Bank. “Railway Reform: Toolkit for Improving Rail Sector Performance, Case Study: Camrail”. 2nd Edition 2017. *Transport and ICT Global Practice*, International Bank for Reconstruction and Development / The World Bank 1818 H Street NW, Washington DC 20433. : http://www.worldbank.org/transport