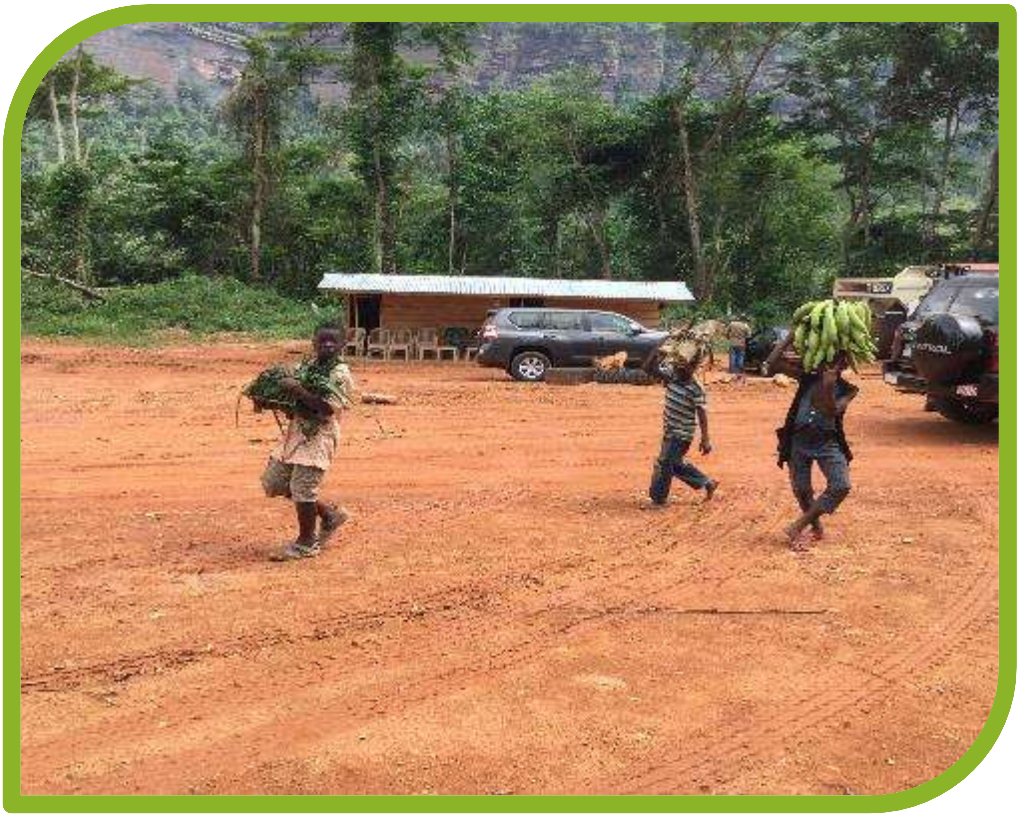
Alternative Surfacing for Steep Hill Sections in Ghana – Phase 2

Economic Analysis Report



Council for Scientific and Industrial Research (CSIR), South Africa

Building and Road Research Institute (BRRI), Ghana

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Cover photo: Construction of project road alignment and foundation.

Quality assurance and review table

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Contents

Tables and Figures

Abstract

This economic analysis has identified some key socio-economic indicators of Akwesiho, Twenedurase, and Akokobenum Nsuo communities. Akwesiho (population 1000) had an average of four persons per house, while Twenedurase (population 450) had three persons per household. Females constituted 55% of the population. Agriculture, artisan services, and petty trading were the main sources of livelihood for the indigenes. Income and expenditure levels were low, about the equivalent of GBP 2.5 per person per day. The potential benefits from the project link road between Akwesiho and Twenedurase have been discussed. Residents appreciated the link road would uplift the commercial status of the two villages significantly, and among others, generate employment for the indigenes. An initial construction cost assessment was made for all the pavement options being demonstrated on the project road. In terms of the initial construction cost, the cold mix asphalt surfacing with GBP 87.13 per metre square is the least costly option. On the other hand, the expensive option based initial construction cost is the interlocking paving block estimated at a unit cost of GBP 93.42. Thus, initial construction cost analysis alone could be misleading. Based on whole life-cycle cost analysis, the three concrete surfacing options (i.e. roller-compacted concrete, thin mesh-reinforced concrete, and interlocking concrete bloc paving) were comparable and ranked the lowest costs.

Key words

Life cycle cost, low-volume roads, steep gradients, modular paving, cold mix asphalt, roller-compacted concrete, non-reinforced concrete, thin mesh-reinforced concrete.

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Research for Community Access Partnership (ReCAP)

Safe and sustainable transport for rural communities

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Acronyms, Units and Currencies

AfCAP	African Community Access Programme
BRRI	Building and Road Research Institute, Ghana
BoQ	Bill of Quantities
CMA	Cold-Mix Asphalt
CSP	Concrete Stone Pitching
CSIR	Council for Scientific and Industrial Research, South Africa
DFID	Department for International Development (UK)
DFR	Department of Feeder Roads
DRC	Democratic Republic of Congo
GBP	Great Britain Pound
GHS	Ghana Cedi
GSS	Ghana Statistical Service
HPS	Hand Packed Stones
ICBP	Interlocking Concrete Block Paving
LVR	Low-Volume Roads
NRC	Non-Reinforced Concrete
PBCI	Prime Building Cost Index
PMU	Project Management Unit
RCC	Roller-Compacted Concrete
ReCAP	Research for Community Access Partnership
TMRC	Thin Mesh-Reinforced Concrete

Executive summary

This report presents an economic analysis of the surfacing options based on the initial construction and future maintenance costs with cost-effectiveness ranking. The report also highlights outcomes of the socio-economic survey that was conducted at the onset of the project. This survey was carried out to identify the probable socio-economic impacts due to the construction of the demonstration road which forms part of the Akwesiho-Twenedurase link road.

Socio-economic impact was identified as a key outcome from the road project especially for the residents of the immediate communities; Akwesiho and Twenedurase villages in the project catchment area as well as the farming community of Akokobenum Nsuo. The project catchment has a radial distance of 5km referenced from Ch. 1+900 along the project road. This reference point coincides with the start point of the demonstration section and a point of access road from the proposed road to Akokobenum Nsuo. The purpose was to establish the baseline socio-economic indicators of the settlements within the project catchment area and assess the impact of the project, i.e. prospects and the effects the road project could have on the population. The surveys were designed to cover basic demographic characteristics of the household (e.g. gender, age group, education level, and occupation), sources of livelihood, land use and agriculture, housing and infrastructure, education and health, and perceptions of the proposed project. Detailed results of the survey was presented in the Draft Project Report.

An initial construction cost assessment was conducted to rank the options based on the costs of construction. The construction cost encompassing a provisional sum for administrative and contractual procedures, costs for the pavement layers and an indicative cost associated with side drainage structures capable of providing the required performance over the design life. Generally, a provisional sum of GBP 11, 869 (25% of the total cost) as administrative and contractual charges is borne by all the pavement options. An average of GBP 5,046 is distributed for all the pavement options as cost for drainage systems costs catering for the lined side drains, kerb drains and cross culvert drains. The cold mix asphalt with an initial construction cost of GBP 87.13 per metre square is the least costly option. The most expensive cost-effective option is the interlocking paving block option at a unit cost of GBP 93.42.

The life cycle cost analysis considered the initial construction cost, the cost of future maintenance standards and associated activities over the analysis period and a salvage value, which is estimated as a percentage of the initial construction cost for each of the alternative option, based on empirical data and research. The life cycle cost analysis shows that all alternative surfacings types (concrete, stones and bituminous) are economically feasible and comparably more cost-effective than the control option, the double chip seal. The life-cycle costs ranged from GBP 89.20 to GBP 92.20 per square metre while the control option costs GBP 92.68 at a nominal real discount rate of 12%.

The life cycle cost analysis was subjected to a sensitivity analysis with discount rates of 8%, 10% matching the base rate of 12%. The concrete-based options (RCC, TMRC, and ICBP) which performed best in the base scenario of discount rate of 12% showed marginal but consistent and lower life cycle costs when the model was subjected to discount rates of 10% and 8% scenarios. In the case of ICBP for instance, the life cycle costs for the base (12%), 10% and 8% scenarios are GBP 91.26, GBP 91.19 and GBP 90.96 respectively. Similar trends are seen for RCC and TMRC options for the base, 10% and 8% scenarios in the range of 0.20% to 0.82% decrease of the life cycle costs for 10% and 8% scenarios over the base case. The trend of responses of life cycle costs to the sensitivity scenarios were opposite for the 'not-so-good' cost effective options, that is CMA, HPS, and CSP. The life cycle costs in the scenarios of lower discount rates (10% and 8%) yielded corresponding higher life cycle costs over the base case, 12%. For example, in the case of CMA, the life cycle cost increases from GBP 92.00 to GBP 92.47 (discount rate 10% scenario) and GBP 92.99 (discount rate 8% scenario) which translates to 0.51% and 1.07% increases, respectively for 10% and 8% discount rate scenarios over the base case of 12%.

Sensitivity analysis was conducted on the estimated cost of the maintenance activities projected over the service life for the experimented alternatives. The maintenance cost sensitivity analysis was conducted on two scenarios being10% and 25% increments over the base estimation, deemed as 100% case. Expectedly, the life cycle costs generally increases from the base case scenarios to higher values when the maintenance costs are increased by 10% and 25% of the base case. The life cycle unit costs for the control option are GBP 92.48, GBP 93.00, and GBP 93.79 for the base case, 110% and 125% scenarios of the maintenance costs.

The economic analysis has identified the key socioeconomic indicators of the immediate beneficiary communities (Akwesiho, Twenedurase, and Akokobenum Nsuo). The potential benefits associated with the project road have been assessed. Quantifying the benefits is not presented, though, as many of the potential benefits are exogenous. The level-one assessment of the cost-effectiveness of alternative pavements based on initial construction cost alone could be misleading as shown in the ranking of the cold mix asphalt. Importantly, a life cycle cost which takes into account future maintenance cost and the potential salvage (residual) values of the road assets is a better measure of the cost-effectiveness of a given surfacing option. It is found that a more holistic approach would have been factoring the associated benefits, yet due to the peculiar nature of this research work being short experimental sections (typically 85m in length for each section) defies the basic assumptions for a level-three economic assessment to be carried out.

1 Background

1.1 Background to the project

Roads in Ghana in general and particularly steep hilly sections on low-volume (feeder) roads are at risk of failure due to high annual rainfall conditions. These roads are susceptible to slope failures, erosion, and drainage-related problems that ultimately and negatively affect the rural communities in respect of provision of all year-round socioeconomic connectivity, road safety, damage to natural resources, and societal development. A prolonged rainy season, coupled with the presence of weak natural (lateritic) soils, exacerbates the problems facing the hilly sections with gradients above 12%. Based on the outcomes of AfCAP research projects on low-volume roads carried out in other sub-Saharan Africa countries like Malawi, Mozambique and Ethiopia (among others), many proven alternative surface options can be experimented and adapted for steep hilly sections on feeder roads in Ghana.

In response to the problems associated with steep hill sections on feeder roads in Ghana, the Africa Community Access Programme (AfCAP) through Cardno Emerging Markets (UK) Ltd has appointed the Council for Scientific and Industrial Research (CSIR) in partnership with Building and Road Research Institute (BRRI) to undertake the Phase 2 assignment on *Alternative surfacing for steep hill sections in Ghana*. The project investigates the suitability of road-building surfacing materials (i.e. stones, bituminous and concrete) on steep sections of feeder roads with gradients that range between 12 and 22%. Specifically, the project investigates the following five alternative surfacing materials; (1) modular paving (stones, and interlocking concrete paving), (2) roller-compacted concrete, (3) thin mesh-reinforced concrete, (4) non-reinforced concrete, and (5) cold mix asphalt. These surfacings are being demonstrated on a virgin road that links Akwesiho-Twenedurase villages in Nkawkaw District of the Eastern region of Ghana. When construction work is completed, the demonstration sections will be monitored to collect performance data for the development of guidelines and specifications for steep hill sections on feeder roads in Ghana.

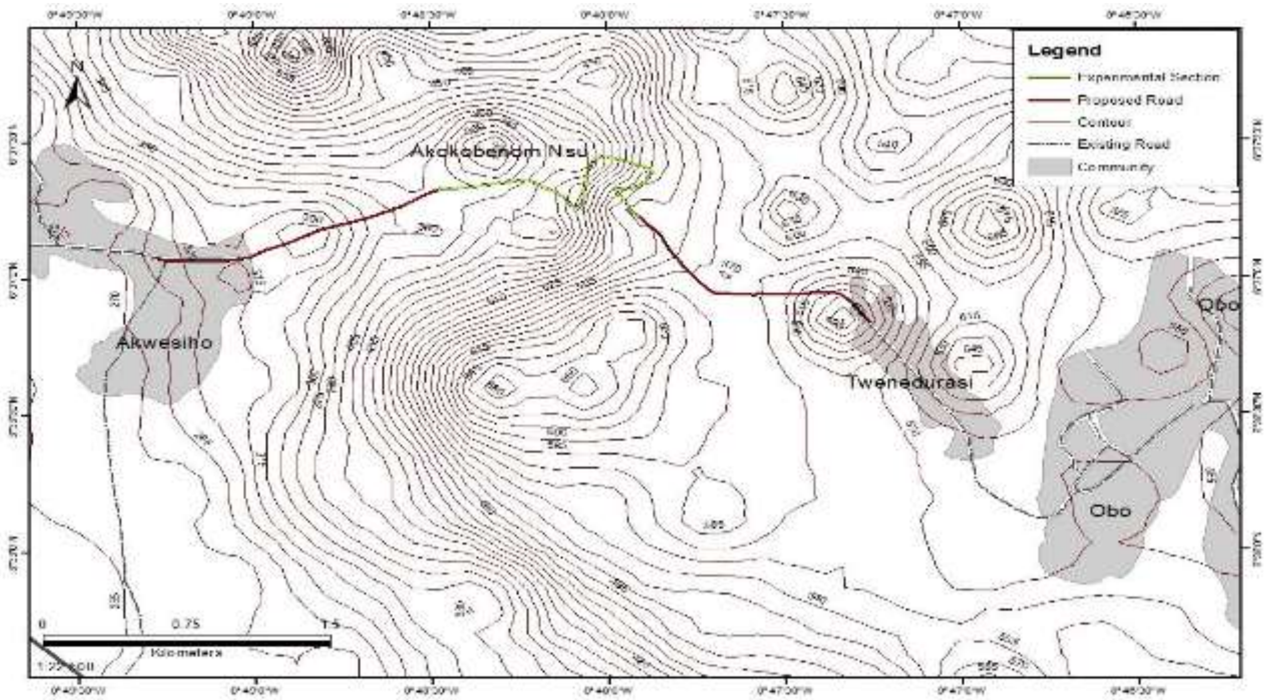
One of the main goals of the project is to provide designs that are cost-effective and allow increased community participation during construction and maintenance. Another important goal for the construction of the alternative surfacing options of this project is employment creation within the project catchment area. Consequently, cost-effective techniques that allow for the increased use of labour-based construction techniques in conjunction with light construction equipment are implemented. Thus, labour-based biased construction technique was a key consideration towards meeting one of the important goals for this project. This is expected to be accomplished without compromising on quality and standards whilst maximising utilisation of locally available materials and other resources. There is significant amount of layer works and the alternative surfacing layers that can be constructed using labour and light machinery, i.e. production of the modular units such as chiseling rock pieces to required shapes and sizes, mixing and compaction of cold-mix asphalt, labour components for roller-compacted concrete, thin mesh-reinforced concrete, and non-reinforced concrete materials. It is important to recognise that some work activities require conventional equipment inputs. For example, the compaction of the pavement formation/subgrade materials would be better handled with heavy vibratory compactors. All these activities have significant impact on the livelihoods of the indegines of the immediate beneficiary communities-Akesiho, Twenedurase, Akokobenum Nsuo,etc. Again, the road serves as a critical alternative route to and fro Kumasi to eastern region towns like Obo, Obomeng, Mpraeso and beyond.

1.2 Study area and the project road corridor

The demonstration project is being carried out in the Eastern region of Ghana. This region has a mountainous terrain (several low-volume roads are located on gradients above 12%) and high annual mean rainfall of 1,800 mm. A virgin road from Akwesiho (geo-location: 6.617906N; 0.820665W; elevation 249m) to Twenedurase (6.613102N; 0.787185W; elevation 570m) is the project road. The relief of the study area is associated with rocks of between 300 and 600 m high. The study area covers the south-western slopes of the Kwahu escarpment, a prominent series of south south-west to south-west (SSW-SW) trending hills with a maximum elevation of about 600 m above mean sea level (AMSL). The hilltops are flat to undulating and represent the eroded remnants of a former peneplain surface. The slopes are generally steep and have elevations of about 300 m to 450 m AMSL. The southwestern part is characterised by moderate relief with elevations largely in the range of 300 m to 330 m AMSL. Figure 1 shows a topographical map of the study area showing the main beneficiary communities (Akwesiho, Twenedurase, Akokobenum Nsu) and adjoining communities such as Obo and the project road.

The project road corridor is generally hilly, with occasional rise and fall. The experimental alternatives are to be demonstrated in road sections which run between the elevations 308 m to 550 m AMSL. The project road has gradients varying between 12% and 22%, which meets the 12% minimum slope criterion for the study site. The total link road length is 5.1 km with 1.6 km of steep hilly sections [ch 1+900 to ch 3+350] ear marked for the research study. The geometric and structural design standards used gave considerations for maximizing the economic returns for the investment in construction. Annex 1 is a schematic drawing showing the pavement options to be demonstrated containing information on segment location (chainage), section lengths, longitudinal slopes, etc.

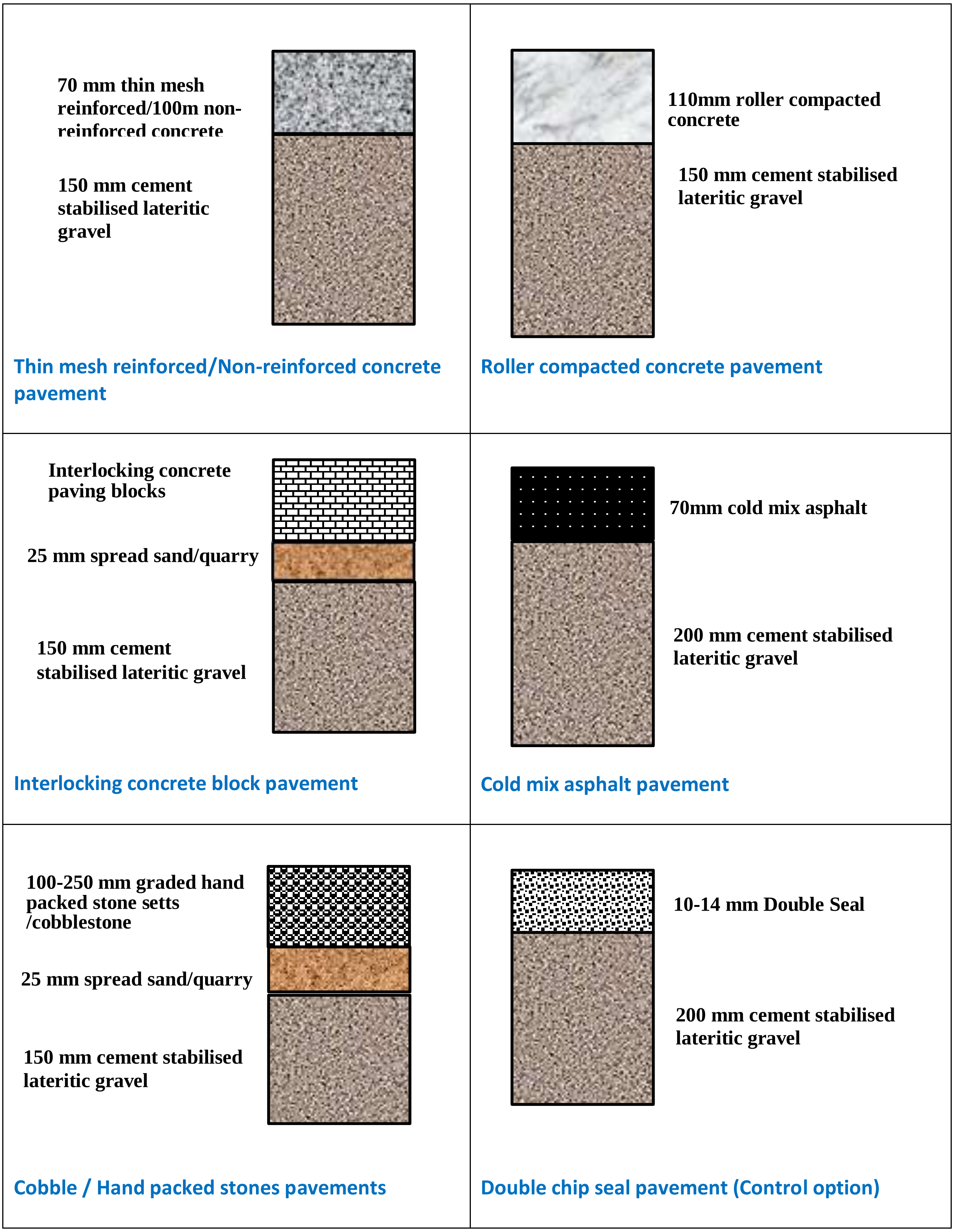
Figure 1 Topographical map of the study area showing the main beneficiary communities and project road



1.3 Project design outcomes

Following a thorough material assessment study, a comprehensive pavement design in the frame work of Environmentally Optimised Design (EOD) concept, which seeks to utilize materials within the project catchment area as much as possible, was used. The EOD concept was adopted for maximizing the economic benefits while reducing environmental impacts as many, and as much, of the road pavement materials are sourced within the project catchment area as possible. A total of 15 cost-effective pavement options have been designed for demonstration in the project catchment area. Generally, each pavement option is 85m long with a 2-lane carriageway width of 7.5 m (3.75 m per lane), and a cross-fall of 3%. The pavement options were derived from five alternative surfacing materials: the modular units comprise hand-packed stones, concrete stone pitching and interlocking block paving; the cold mix asphalt and each of the concrete and the cold mix asphalt surfacings comprise three different mix components. The modular and bituminous surfacings are designed as flexible and semi-flexible pavements supported by cement-stabilised base/subbase and subgrade pavement layers. The rigid concrete pavements (i.e. three alternative concrete surfacing) are being constructed on cement stabilised base and subgrade layers. There is a non-load bearing sand bedding layer for the modular paving surfacings. See figure 2 for schematic pavement structures for the research alternatives and the control option. Annex 1 shows a schematic drawing showing the pavement options to be demonstrated. The construction of these pavements involves the indigenes of the project catchment area who constitute a significant component of the labour resources to the project.

Figure 2 Pavement structures for the research alternatives and the control option



Thin mesh reinforced/Non-reinforced concrete pavement

Roller compacted concrete pavement

Interlocking concrete block pavement

Cold mix asphalt pavement

Cobble / Hand packed stones pavements

Double chip seal pavement (Control option)

1.4 The objective of this report

Usually, the purpose of an economic appraisal of roads is to assess and select investments with high economic returns. And mostly, the purpose of an economic appraisal is to determine what type of road, how much to invest and what economic returns to expect. The size of the investment is determined by the costs of construction and annual road maintenance. The economic returns are mainly in the form of savings in road-user costs due to the provision of a better road facility. These three costs constitute what is commonly referred to as the total (road) transport cost or the whole life cycle cost.

However, the prime objective of this report is to present an economic analysis of the research project based on the initial construction and future maintenance costs of all pavements options. This is to further rank the relative cost-effectiveness of all the pavement options. Also, this report highlights the outcomes of the socio-economic survey that was conducted at the onset of the project. This survey was carried out to identify the probable socio-economic impacts due to the construction of the demonstration road which forms part of the Akwesiho-Twenedurase road link.

The primary objectives of this economic analysis were identified as:

1. To determine the potential benefits of socio-economic impacts from the construction of the Akwesiho-Twenedurase road on which the demonstration project is part,
2. To determine a level-one cost-effectiveness appraisal of the pavement alternatives based on the initial construction cost and future maintenance costs, and rank the alternative options over the control option, and
3. Conduct sensitivity analysis for critical input parameters discount rates and maintenance costs.

2 Socio-economic Impact Assessment

2.1 Approach to the socio-economic survey

Socio-economic impact has been identified as a key outcome from the road project especially for the residents of the immediate communities; Akwesiho and Twenedurase villages in the project catchment area as well as the farming community of Akokobenum Nsuo. Thus, a household survey was chosen as the main tool to obtain information about the existing socio-economic indicators of the immediate beneficiary communities, and to assess the potential impacts of the road project. Initially, housing unit counts were conducted based on satellite images of Akwesiho and Twenedurase, the main villages in the project catchment area, see aerial photographs of the villages in Figure 3. The socio-economic survey was designed to cover a sample size of households in each village that would give a confidence level of 95%. Next, a random sampling of the houses to be surveyed was desk-marked and the survey was conducted to cover households with different socio-economic status.

For each household, respondents were carefully selected to include women and disabled persons wherever available. Household heads and opinion leaders were interviewed in both villages. In addition, a survey was conducted at a farming settlement community called Akokobenum Nsu, which is located at about 1.5 km from Akwesiho. Akokobenum Nsu (geolocation 6.624332, -0.805021) is 70 m off the Akwesiho and Twenedurase road.

The objective was to establish the baseline socio-economic indicators of the settlements within the project catchment area and assess the impact of the project, i.e. prospects and the effects the road project could have on the indigenes. The surveys were designed to cover the following issues:

- Basic demographic characteristics of the household (e.g. sex, age group, education level, occupation)
- Sources of livelihood
- Land use and agriculture
- Housing and infrastructure
- Education and health
- Perceptions of the proposed project

- **Figure 3 Aerial photographs of Akwesiho and Twenedurase communities**

Akwesiho village have about 390 housing units

Twenedurase have approximately 200 housing units

(Source: Google maps, accessed on May, 2017)

2.2 Socio-economic findings

2.2.1 Basic demographic characteristics

Akwesiho has 390 house units with an average of four persons per house, while Twenedurase has 200 units with an average occupancy of three persons per household. The house occupancy for both villages varied widely. Figure 3 shows aerial photographs of the two communities from which the housing units were desk assigned codes for the field survey. In some instances, a caretaker was the only person in a whole house, and in other cases, three families of four members each could be occupying a house. Some houses in Twenedurase (with a population of 450 persons) had similar demographic characteristics to Akwesiho with a significantly higher population of 1 000 persons. The difference in population is due not only to the difference in household units of both villages, but also to the average occupancy level in the villages. Females were observed to constitute about 55% of the population. The rest of the occupants largely represent the working class (25-65 years). Close to 50% of the middle age group (between 25-40 years) working class have moved to Nkawkaw and other bigger towns to seek greener pastures. The remaining working class members, mainly males, undertake jobs and services in nearby towns (Nkawkaw, Obo, Obomeng, etc.). For instance, youth in Akwesiho render services in mainly Nkawkaw, while Twenedurase's working adults ply their trade in Obo, Obomeng, and Nkawkaw. These dynamics of the travel pattern and route choices result from the lack of a link road between Akwesiho and Twenedurase. The females usually engage in petty trading, both in the villages and in nearby towns, Obo, Obomeng or Nkawkaw. The population of Akokobenum Nsu counted about 70 people, with an almost 50-50 distribution of gender.

2.2.2 Sources of livelihood

Like in many villages in Ghana, there were no specific market days for both villages. Agriculture, artisan services (masonry, carpentry, steel welding, etc.), and petty trading were the main sources of livelihood for the indigenes for both Akwesiho and Twenedurase. In addition, some older persons from both villages had various businesses in larger cities/towns including Nkawkaw, Kumasi and Accra. Such older persons periodically received remittances from caretakers of their businesses. At Akokobenum Nsu, inhabitants engaged in mainly cocoa and banana farming, interspersed with food crops. The community dwellers relied on buying basic needs such groceries from a few petty traders at Akwesiho. Income and expenditure levels were low, about the equivalent of two-and-a-half pounds (GBP2.5) per person per day. However, this average income/expenditure figures varied widely, depending on the person's sources of income and status.

2.2.3 Land use and agriculture

Less than half (35%) of farmers of the communities engaged in commercial farming, and the main commercial crops were cocoa and banana.Besides agriculture, land uses for other purposes were sporadic, such as for winning sand and other construction materials. Thus, the working class of the indigenes have some experience with sand and gravel mining as a job creator within the community. The use of their labour-power for the provision of sand and gravel winning for construction would help the construction phase of the project. Older adults (> 50 years) were the ones involved in both subsistence and commercial farming. Nonetheless, about 40% of adults in the middle age group also engaged in some subsistence farming. The typical size of a subsistence farm was about half an acre and mixed crops including cassava, yam, plantain, banana and vegetables were cultivated. Maize is usually cultivated in both the major (May-July) and minor (September-October) raining seasons, too. The middle age adults use their subsistence farming as an alternative source of income besides their predominantly artisan works, such as masonry, carpentry, steel welding, etc.

2.2.4 Housing and infrastructure

At the time of the survey,, about 40% of the single-storey houses in Akwesiho were constructed in mud/brick with mortar rendering on both the external and internal walls. These houses were typically over 70 years old. The rest were mainly constructed from sandcrete blocks with mortar rendering on the walls. On the other hand, many of the houses at Twenedurase are built with sandcrete blocks, with some having glazed windows. About 20% of houses at Twenedurase were 2-storey or the half-decking type, due to the hilly nature of the land. Other infrastructure included neglected and poorly maintained roads, as well as very limited physical infrastructure for basic social amenities.

2.2.5 Education and health

At Akwesiho, there was a government basic school up to Junior High School (JHS) level. The school had been the main source of formal education for pupils over the years, until (starting with 2017 academic year) Akwesiho started offering Senior High School (SHS) education in an additional secondary school. Twenedurase has one government-owned basic school up to JHS level and no SHS. To further one's education in Twenedurase, one/pupils had to continue education in Obo SHS or at others. The level of education is generally low in both villages, with many of the youth working class (25-40 years) having basic education up to Junior Secondary level. This group constitute the majority of local artisans.

Health care is basic as there is one government-run health post at both villages. The health posts were under the jurisdiction of Atibie Government Hospital. In case of serious health issues, patients were usually referred to Nkawkaw facilities or to other better-equipped health care delivery services in bigger towns.

2.2.6 Respondents' perceptions on the impact of the road project

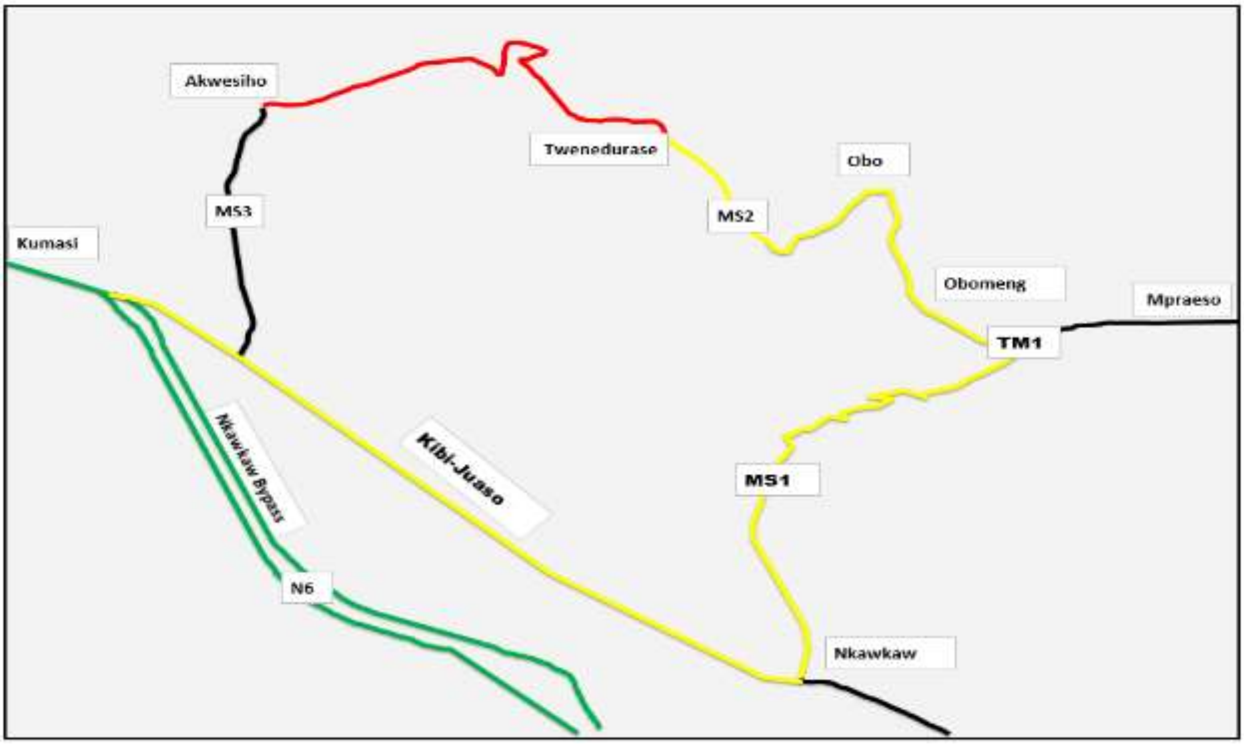
Respondents to the interviews believed getting the road that connects Akwesiho and Twenedurase would have the following benefits:

- Uplift the commercial status of the two villages significantly, as more motorists would be using the route as alternatives to the existing Nkawkaw-Obomeng/Mpraeso roads. See figure 4 showing the network in the project catchment area and external environs.
- Generate employment for the indigenes both directly and indirectly. In particular, the male youth working class, especially the artisans (25-50 years) see the construction of the road as one big opportunity to earn an income and fulfil their various aspirations. The majority of their female counterparts saw the project as a way of providing para-support services, such as menial labour services and catering services to generate an income. The youth were very eager to undergo some short skills-training course in order to be part of the project labour force during the construction phase.

- Uplift the slowly dying villages (due to the absence of a link road) and revive the villages. The elderly felt that with the link road constructed, other socio-economic activities would boost the present status of their villages which become vibrant only on funeral occasions.
- Provide easy access to both villages for the marketing of farm produce, which would usually rot due to a lack of buyers and the difficulty in accessing the villages.
- Boost access to other social amenities. Respondents generally felt that health care, in particular, would improve and thus reduce mortality once the project road is in operation.
- Offer an opportunity to travellers from Akokobenum Nsu to have shorter and easier access to Twenedurase, Obo, and beyond. It is difficult to go round through Akwesiho via Nkawkaw to climb the Obomeng hills only to access Twenedurase or Obo, when the distance is far shorter through the project link road.
- Generate revenue from tourism. One of the major rivers in Ghana, river Pra, takes its source from a point (somewhere 6.628460, -0.797531) at the summit of the scarp close to the end of the project road, and close to Twenedurase. Once the road becomes operational, that site could be developed as a tourist attraction that would generate significant traffic on the project road.

From the findings of above survey, there are huge benefits associated with the socio-economic impact of the project. Some of the benefits are intangible and not straightforward to quantify. Again, much of the benefits are not exclusive to the short sections that are being demonstrated. Thus the social-economic benefits accruing from the impact of the road project are not included in the economic analysis. Nonetheless, the results gave basis for estimating the benefits associated with the road project.

Figure 4 Network of the main roads in the project area showing the project road



(Source: adapted from Google maps; created September, 2017)

Notwithstanding, there are other consequences emanating from the project. For instance, the opinion leaders emphasised the need for resettlement of the Akokobenum Nsu farming community, since the main access to the community off the Akwesiho-Twenedurase road is currently serving as a turn-out of road surface run-off to Akokobenum Nsu. Topologically, Akokobenum Nsu lies low at about 200 m average mean sea level (AMSL). Thus, Akokobenum Nsu naturally floods during the two raining seasons. With the additional discharge of road surface runoffs, the condition of the settlement could only get worse, especially in the raining seasons.

2.3 Potential benefits from the Akwesiho-Twenedurase link road project

Obviously, there are benefits accruing from the 5.1 km Akwesiho-Twenedurase link road project. It must be noted that whereas some of the benefits may be associated with the research component of the project (i.e. the construction of demonstration sections of the alternative surfacing pavements) other benefits are as a result of the entire road link. Brief discussions of these benefits are presented as follows;

2.3.1 Employment opportunities from the construction activities

The construction techniques adopted for executing much of the construction activities presents opportunities for the indigenes with a wide spectrum of skill-levels. From the unskilled that provides ordinary labour through semi-skilled persons who provide minimal skilled construction activities such assisting with field technical work. The semi-skilled persons usually receive some form of on-the-job training which enhances their personal skills, supporting their living in post-construction periods. The wages of the unskilled trough the semi-skilled person range from GBP 6 to GBP 13 per person per workday. These are very high daily wages compared to what was noted during the economic survey at GBP 2.5 per person per workday. The work activities available for the indigenes translate into several 1000s of person-workdays. The wages received go a long way in meeting the daily needs of the residents as was noted in the socioeconomic survey. These employment opportunities come in the form of labour for the chiselling to shape stones, laying of stones, underlying pavement layer works, etc.

2.3.2 Commerce and marketing

The road link presents the opportunity for vehicular traffic in the Akweiho and Twenedurase area. As captured in the economic survey findings, agriculture forms a major source of livelihood to the indigenes. Presently, agriculture is not done to the maximum potential of the area due to poor accessibility to the communities. The road link is likely to turn the proceeds from agriculture into significantly greater levels. More of the farms produce both subsistence and commercial crops will get the needed market thereby elevating the standards of living of the indigenes.

2.3.3 Travel time savings

The link road will shorten the distance between Akwesiho and Twenedurase from 35 km (through the Kumasi-Nkawkaw highway, Obomeng, Obo) to just 5km (link road). Refer to Figure 4. The travel time savings is very huge. Related to the travel time benefit is the ease of congestion on the existing 35 km route as a result of taking away that traffic from the existing traffic. This translates into huge sums of money, as journey times are consderably reduced for the shorter Akwesiho and Twenedurase road link. Residents of communities thus can freely commute thereby enhancing the socioeconomic interactions leading to development.

2.3.4 Provision of alternative route

There is considerable traffic to and from Kumasi and Mpraeso directions. The absence of the Akwesiho and Twenedurase road link leaves motorists with no choice other than longer winding routes as displayed in Figure 4. The link road would provide a much desired alternative road to the existing long and winding route. This will ease the travel for motorists who will only transit the Akwesiho and Twenedurase communities. This alternative route will yield huge sums of savings.

2.3.5 Tourism related opportunities

The topography of the project area and its environs present huge tourism potentials. For instance, currently, a paragliding site is being constructed into a tourist attraction. This project is seeing light because of the construction of the link road. Eastern region is popularly noted for its Easter festivities which are patronized by Ghanaians from all parts of the country as well as international tourists. The link road would thus generate huge commercial activities to the surrounding communities all year round, and especially in the March April Easter seasons.

3 Economic Analysis

3.1 Approaches to the Economic Analysis and Assumptions

Life-cycle cost assessment is a common approach to determine the most cost-effective options for road construction projects. Thus, to address the first objective of this analysis, the present worth of cost (PWOC) method of life-cycle cost is used. This method discounts all future costs (sums) to the present using an appropriate discount rate. The proposed alternative pavement options were compared based on the present worth of the life-cycle costs. The main economic factors known to determine the cost of a road include the analysis period, the construction cost, the maintenance costs and the real discount rate. The empirical relationship to determine the PWOC is solved by using Equation 2.

$$\mathrm{PWOC} = \mathrm{C} + \mathrm{M}_1(1+\mathrm{r})^{-\mathrm{x}_1} + \cdots + \mathrm{M}_\mathrm{j}(1+\mathrm{r})^{-\mathrm{x}_\mathrm{j}} - \mathrm{S}(1+\mathrm{r})^{-\mathrm{z}} \quad (1)$$

where PWOC = present worth of costs; C = present cost of initial construction; $\mathrm{M_j}$ = cost of the $\mathrm{j^{th}}$ maintenance measure expressed in terms of current costs; r = real discount rate; $\mathrm{x_j}$ = number of years from the present to the $\mathrm{j^{th}}$ maintenance measure, within the analysis period (where $\mathrm{x_j}$ = 1 to z); z = analysis period; S = salvage value of pavement at the end of the analysis period expressed in terms of present values.

The following assumptions were made:

- The pavement structures selected for this study are in the same road category (i.e. low-volume roads). Road user costs for the six pavement alternatives were considered to be negligible.
- The suggested analysis period for rural access roads is 20 years and that of lightly trafficked rural roads is 30 years (Technical Recommendations for Highways—TRH4, 1996). Based on this number of years, the analysis period used in this paper is 25 years (average value) and starts from 2020.
- The salvage values were estimated to be percentage (%) values of initial costs of pavement options, based on empirical studies on performance of typical pavement options.
- All pavements options are subject to similar traffic and climate, and are assumed to have the same equivalent standard axle loads.
- The discount rate of 12% used by Ampadu et al. (2015) for the life-cycle cost analyses of eight gravel roads in Ghana were adopted for this study. The value of 12% was also used for the economic cost analysis of the World Bank/ Department for International Development (DFID) projects from six countries (Tsunokawa 2010).
- Typical maintenance measures are based on known performance of similar pavement structures/ materials to the alternative pavement structures.

3.2 Initial construction cost of the project

An initial construction cost assessment was made for the pavement options to rank the options based on the costs of construction encompassing a provisional sum for administrative and contractual procedures, sum of costs for the pavement layers and an indicative cost associated with side drainage structures capable of providing the required performance over the design life. Though side drainage varied and was being dictated by the topographical characteristics of the road corridor, an average cost per unit length was computed to standardise for the surfacing options. Again, the costs for cross culverts located at ch 2+600 and ch 2+750 were absorbed in the build up to the initial costs to ensure equity for all the options. The initial construction costs were computed based on the June 2019 Prime Building Cost Index (PBCI) in Ghana, available on the Ghana Statistical Service (GSS) website (www.stastghana.gov.gh). A typical steep road section is 85m in length and 6m in width for single carriageway. Construction work activities and current rates of local labour and equipment have been considered in the cost. Costing was mainly based on the pavement structures, as well as on variables such as materials, production, haulage distance, labour, construction and equipment. Also, being bituminous double chip seal was set as a control option for the alternative pavement options. It is assumed that provisional sums for general items and initial preparation of road formation, as well as drainage systems will be the same for all pavement options. This may not be necessarily true. However, it is expected that cost variations would be minimal.

Table 1 shows summary of the indicative initial construction costs for the pavement structures with a ranking depicting relatively cheaper options based on capital cost. The costing was done based on the initial cost estimates, and the unit costs (per square metre) for the alternative options generated. Generally, a provisional sum of GBP 11, 869 (constitutes about 25% of the total cost) which caters for the administrative and contractual charges is borne by all the pavement options. As mentioned earlier, an average of GBP 5,046 is distributed for all the pavement options as cost for drainage systems costs catering for the lined side drains, kerb drains and cross culvert drains. In terms of ranking for the initial construction cost, the cold mix asphalt with a cost of GBP 87.13 per metre square is the least costly option. It must be noted that the cost per square metre for the control surfacing option, the double chip seal option is marginally lower than that of the cold mix asphalt option. The roller compacted concrete is constructed at a cost of GBP 88.08 per square metre. Based on the initial construction cost assessment, the most expensive cost-effective option is the interlocking paving block option at a unit cost of GBP 93.42. This is as a result of the relatively high cost of production of the 30N/mm^2 compressive strength of the block units coupled with the construction of the designed pavement layers.

Table 1 Initial Construction Cost for Pavement Options

Pavement structure	Provisional Sum	Drainage Systems Cost GBP	Pavement Layers Cost GBP	Estimated Total Cost	Cost Per Sq. Metre
Cobble stone paving	11,869.44	5,046.00	28,826.91	45,742.35	89.69
Hand packed stones	11,869.44	5,046.00	29,262.08	46,177.51	90.54
Interlocking concrete block paving	11,869.44	5,046.00	30,726.68	47,642.11	93.42
Roller compacted concrete	11,869.44	5,046.00	28,007.79	44,923.23	88.08
Thin mesh reinforced concrete	11,869.44	5,046.00	28,452.92	45,368.36	88.96
Non-reinforced concrete	11,869.44	5,046.00	29,658.19	46,573.63	91.32
Cold mix asphalt	11,869.44	5,046.00	27,518.62	44,434.06	87.13
Double chip seal (Control option)	11,869.44	5,046.00	27,370.83	44,286.27	86.84

3.3 Future maintenance cost

For this economic appraisal, typical maintenance schedules for the all alternative pavements were used in the analysis. When different pavement types are compared on the basis of construction cost, the future maintenance costs should be included in the analysis to ensure that a reasonable comparison is made TRH4 (1996). The analysis period for all the surfacing options was estimated at about the average life (in years) of the typical service life of every surfacing option. Typically, a service life of 20-30 years was assumed for the stone and concrete-base options with analysis period of 25 years while the cold mix asphalt has service life of 15-20 years with analysis period of 18 years. A service life of 10-15 years and 13 years of analysis period were assumed for the control option (i.e. double chip seal).

For all the surfacing options, there will be routine maintenance schedules of relatively small value in terms of cost. The routine maintenance is carried out annually; once for the concrete-based options and twice for the bituminous surfacing options. The relatively small cost (about GBP 0.08 per square meter) for the routine maintenance carried out on a giving surfacing option is absorbed in the next structural maintenance cost for that surfacing option. For instance the total cost of routine maintenance carried out for the first two years on cold mix asphalt is carried to the eighth (8th) year structural maintenance cost. From the last structural maintenance, subsequent cost accrued from routine maintenance carried out to the end of the analysis period of a given surfacing option was deemed insignificant and neglected in the analysis. The maintenance strategies and activities with associated costs estimates are described for the surfacing options including the control option as follows.

3.3.1 Cobble stone paving

The assumption in the analysis model is that the cobble stone paving will have annual routine maintenance comprising road surface clean up, clearing off debris from drainage structures including cross culvert, if present. A critical consolidation of the routine maintenance works would be carried out on the 7th year at a cost of GBP 1.04 per square metre. The annual routine maintenance will continue until the 12th year when major structural maintenance works will be undertaken. The scope of structural maintenance works will be replacement of damaged stones and repairs of broken kerbs. It should be noted that there may be the tendency of wearing of stones due to braking from vehicles descending the steep slopes which may require replacement. The estimated cost for the 12th year structural maintenance activities is GBP 2.67 per square metre. Annual routine maintenance will continue for the next five years until the 17th year when the last structural maintenance activity is carried out. A half-depth pavement repairs will be carried out. The scope entails removal of loose stones areas, filling and re-compaction of base layer and finally replacement of the loose and damaged stones to restore the surfacing conditions. The estimated cost of the 17th year structural maintenance and consolidated routine maintenance (from 13th year through 17th) is estimated at GBP 8.16 per square metre. The cost of routine maintenance that will be carried out to the end of the service life of the cobble stone paving option is deemed relatively insignificant, and thus neglected in the economic analysis.

3.3.2 Hand packed stones

For the hand packed stones, similar maintenance strategies to the cobble stone paving option will be assumed. Routine maintenance will be carried out annually until the 7th year when the maintenance works is consolidated at a cost of GBP 0.89 per square metre. While annual routine maintenance continues from the 7th year, a major structural maintenance works will be undertaken in the 12th year. The scope of structural maintenance works will be replacement of damaged stones and repairs of broken kerbs. The estimated cost for the 12th year structural maintenance activities is GBP 2.67 per square metre. Annual routine maintenance will continue for the next five years until the 17th year when the last structural maintenance activity is carried out. A half-depth pavement repairs encompassing removal of loose stones areas, filling and re-compaction of base layer and finally replacement of the loose and damaged stones will be carried out to restore the surfacing conditions. The estimated cost of the 17th year structural maintenance and consolidated routine maintenance (from 13th year through 17th) is estimated at GBP 7.42 per square metre. Again, the cost of routine maintenance that will be carried out to the end of the service life of the hand packed stones option is assumed insignificant and excluded in the economic analysis.

3.3.3 Interlock concrete block paving

Annual routine maintenance similar to the scope captured for the cobble stones and hand packed stones options will be carried out through the first 10 years at marginal costs that is consolidated into and captured for a structural maintenance activity to be undertaken in the 10th year. Replacement of all damaged concrete blocks and re-lay of loose blocks will constitute the scope of works for the structural maintenance. The cost is estimated at GBP 1.78 per square metre which includes the net sum of the routine maintenance activities (GBP 0.07 per square metre), very negligible though. Routine maintenance will continue until in the 15th year, a structural maintenance is carried out which entails fixing of any damaged concrete blocks and re-lay of loose blocks and repairs on kerb blocks at an estimated cost of GBP 2.23 per square metre. The next and last structural maintenance works will be undertaken in the 20th year which entails a half-depth pavement repair woks. The cost of the 20th year structural maintenance is estimated at GBP 8.90 per square metre. Annual routine maintenance activities will be carried out from throughout the service life of the pavement structure.

3.3.4 Roller compacted concrete

The concrete-based surfacing options (roller compacted concrete, thin mesh reinforced concrete, non-reinforced concrete) are assumed to be more robust and will require minimum structural maintenance. The main defects will be thermal and shrinkage cracks and breakages at the edges of the concrete pavements. Repairs for shrinkage and thermal cracks will be carried out in the 7th year into pavement service. The cost is estimated at GBP 2.23. Another structural maintenance consisting of crack repairs and fixing pavement broken edges will be carried out year fifteen into service life. The cost of the 15th year structural maintenance works is estimated at GBP 5.19 per square metre.

3.3.5 Thin mesh reinforced concrete

As mentioned earlier, the thin mesh reinforced concrete will assume similar maintenance strategies as the roller compacted concrete. In the 7th year of service life, repairs for shrinkage and thermal cracks will be carried out at an approximate cost of GBP 1.78 per square metre. The repair cost for the thin mesh reinforced concrete is relatively lower since it is expected that the thin mesh reinforced concrete option will show lower crack-density due the presence of reinforcement steel rods. The second and last structural maintenance works will be undertaken in the 15th year into the service of the thin mesh reinforcement concrete option. The structural maintenance works entails repair of all cracks and fixing of broken pavement edges which are estimated to cost GBP 5.19 per square metre.

3.3.6 Non-reinforced concrete

For the non-reinforced concrete, the first structural maintenance comprising repairs for shrinkage and thermal cracks will be carried out at an approximate cost of GBP 2.67 per square metre. The cost is relatively greater than for the other concrete-based options as the crack-density is expected to be higher for the non-reinforced concrete option. In the 15th year of service life, another structural maintenance works will be undertaking comprising repair of all cracks and fixing of broken pavement edges which are estimated to cost GBP 6.23 per square metre, higher than for the thin mesh reinforced concrete.

3.3.7 Cold mix asphalt

The cold mix asphalt is a typical flexible pavement which exhibits different pavement performance and structural defects from the concrete-based options. The assumed structural maintenance strategies are more frequent as they are carried out at shorter intervals. Annual routine maintenance would be carried out throughout the service life of the pavement structure. In service years 3 and 5, structural maintenance works entailing crack sealing and consolidated routine maintenance would be carried out at GBP 1.04 per square metre for both events. In the 7th year, a structural maintenance activity of crack sealing and pothole patching will be completed at an estimated cost of GBP 2.23 per square metre. Crack sealing, pothole patching would completed as preparation for reseal the pavement would be carried out at an estimated cost of GBP 6.68 per square metre during the 10th year of service life. The last structural maintenance work is expected to be executed in the 15th year comprising of crack sealing and consolidated routine maintenance at a cost of GBP 1.19 per square metre. Annual routine maintenance activities which are non-structural related at negligible cost of no more than GBP 0.06 per square metre would be carried out over the rest of the service life.

3.3.8 Double chip seal

The double chip seal is a bituminous pavement will be assumed to undergo structural maintenance strategies similar to the cold mix asphalt option. Structural maintenance works comprising crack sealing and annual routine maintenance would be carried out at GBP 1.04 per square metre during service years 3. By the 5th year, a number of potholes may have developed requiring structural maintenance activity of crack sealing and pothole patching at an estimated cost of GBP 1.63 GBP per square metre. There will be crack sealing, pothole patching completed for resealing the pavement at an estimated cost of GBP 5.93 per square metre during the 7th year of service life. Crack sealing and routine maintenance would be carried out in the 10th service year. The last structural maintenance work is expected to be executed in the 15th year comprising of crack sealing and consolidated routine maintenance at a cost of GBP 1.19 per square metre. Annual routine maintenance activities which are non-structural related at negligible cost of no more than GBP 0.06 per square metre would be carried out over the rest of the services life.

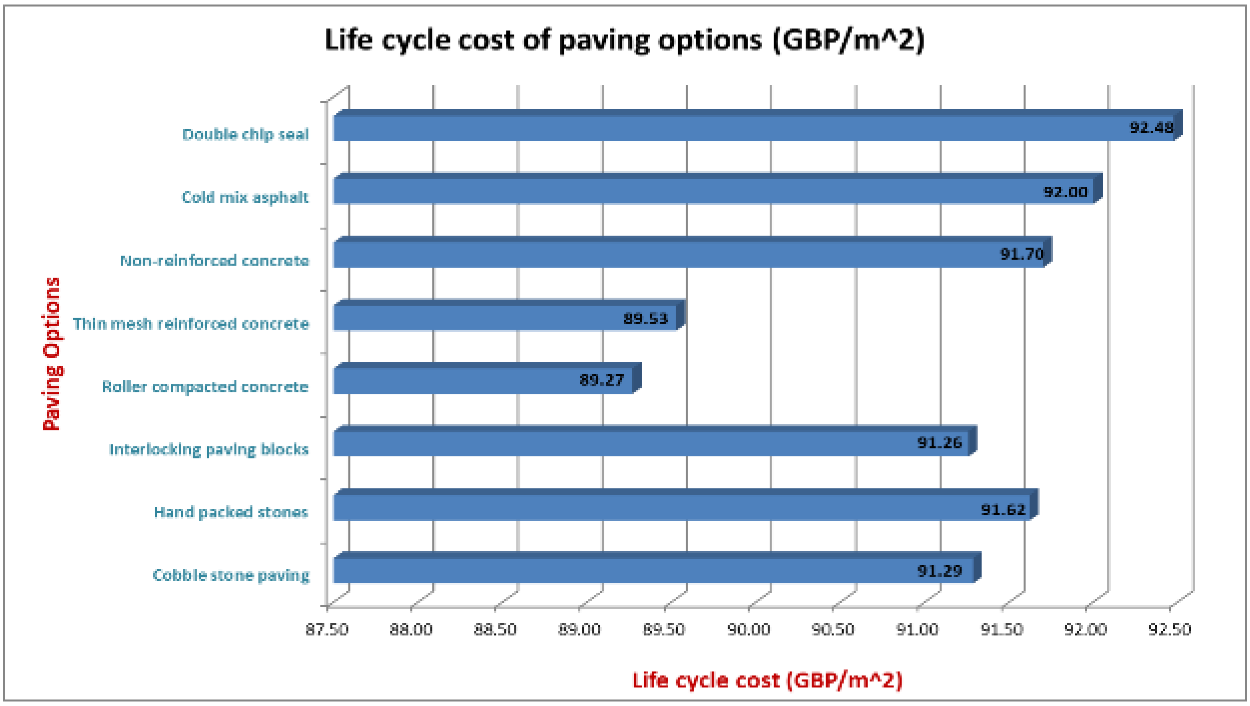
3.4 Life cost analysis

The life cycle cost analysis considered the initial construction cost, the cost of future maintenance standards and associated activities over the analysis period and a salvage value which is estimated as a percentage of the initial construction cost for each of the alternative option based on empirical data and research. The result of the present worth of cost analysis with the initial construction and future maintenance is presented in Table 2 for the alternative and control pavement options. The life cycle cost analysis shows that all alternative surfacings types (concrete, stones and bituminous) are economically feasible and comparably more cost effective than the control option, the double chip seal. The life-cycle cost of the alternative options ranged from GBP 89.20 to GBP 92.20 per square metre while the control option costs GBP 92.68 at a nominal real discount rate of 12%. Clearly all the alternative options were better cost-effective over the control option. It is worthy of note that from just the initial construction costs assessment, the control option registered the lowest cost unit of GBP 88.06. This could lead implementing agencies (in this case the DFR and Ministry of Roads and Highways) to settle on the double chip seal as the best option due to limited budget and financial constraints. Life cycle cost analysis that factors the attendant maintenance costs and residual road assets (salvage values) over the service lives of the alternative options gives better cost-effective. Analysis based on initial construction cost alone could be misleading.

The concrete-based options are generally better alternatives against the others over the control option. Nonetheless, the mass concrete option, namely non-reinforced concrete, is not a highly ranked option compared to its counterparts being roller compacted concrete which uses specialised construction technique and the thin mesh reinforcement concrete option which incorporates re-bars in the pavement design and construction.

The double chip seal (using 10mm and 14mm aggregates in emulsion bitumen) is the control option which is in the bituminous category of pavements. The alternatives under assessments are referenced to the control option. The DCS has a life cycle cost of GBP 92.48 which is the highest of all the test alternatives making all the options better cost effective alternatives. Though, the initial construction cost is lowest, GBP 88.04 per square metre, the DCS is associated with frequent structural maintenance activities estimated to cost GBP 11.57 per square metre. The DCS also has a relatively short service life of 10-15 years resulting in an analysis period of 13 years. The salvage value of the DCS is GBP 4.41 per square metre which was estimated as 4% of the initial construction cost. The results for the experimental alternatives in a ranking order of cost-effectiveness over the control option are graphically presented in Figure 5 while the details are presented in Table 2.

Figure 5 Life cycle cost of paving options expressed in unit cost of pavement (GBP/m^2)



1. Roller compacted concrete

Though with an initial construction unit cost of GBP 88.49 (ranked 2nd using the initial construction as a ranking criterion, see table 1), the roller compacted concrete would require structural maintenance costing approximately GBP 6.68 per square metre over an analysis period of 25 years and expected service life of up to 30 years. The relatively low maintenance cost coupled with high potential of residual road asset valued at GBP 17.70 per square metre (20% of initial construction cost) make the RCC the most cost-effective option of all the alternatives. The life cycle cost is GBP 89.27 per square metre which is 3.7% cost effectively translating into GBP 3.41 per square unit savings over the control option.

2. Thin mesh reinforced concrete

The TMRC option is the second most cost-effective option with a unit life cycle cost of GBP 89.53. The salvage value is estimated at 20% of initial construction cost equivalent to GBP 17.79 per square metre. The TMRC is GBP 3.15 cheaper than the control option which translates into about 3.4% savings. It must be noted that, like the RCC option, the life cycle cost is lower than the initial construction cost due to lower cost of less frequent maintenance activities and a higher potential of residual road assets as salvage value at the end of the pavement service life.

3. Interlock concrete block paving

The third most cost-effective option is the ICBP, a modular alternative. The ICBP has life cycle cost of GBP 89.53 per square metre and a salvage value of GBP 18.5 (20% of initial construction cost). Unlike the typical concrete-based counterparts, the ICBP will experience three structural maintenance activities estimated to cost a total of GBP 10.83 per square metre in the course of its service life of up to 30 years. The analysis period of 25 years is considered, though. The ICBP is cheaper by GBP 1.42 which results in a 1.5% savings over the control option.

4. Cobble stone paving

The CSP is a typical modular option which is placed 4th in the ranking for cost-effectiveness over the control option. With an initial construction unit cost of GBP 89.69, the life cycle cost shoots to GBP 91.50 per square metre owing to relatively high maintenance cost of GBP 11.42 per square metre and lower pavement salvage value of GBP 10.76 (12% of initial construction cost). Nonetheless, the CSP make a unit savings of GBP 1.39, the equivalent of almost 1.5% over the control option.

5. Hand packed stones

The next alternative in contention is the HPS, another typical modular option. The HPS has a life cycle cost of GBP 91.62 per square metre higher than its initial construction unit cost of GBP 90.14. The increase is due to a pavement residual value of GBP 10.82 (12% of initial construction cost) and a total maintenance cost of GBP 10.68 per square metre. The HPS has a savings of GBP 1.06, about 1.1% cost-effective over the control option.

6. Non-reinforced concrete

The NRC is 6th on the life cycle cost scale with a unit cost of GBP 91.70. The overall maintenance cost over an analysis period of 25 years (expected service life is up to 30 years) and a salvage value of GBP 16.29 per square metre which was estimated at 18% of its initial construction unit cost of GBP 90.51. The residual value of 18% is based on empirical data of typical mass concrete pavements which is slightly lower than a reinforced counterpart, like the TMRC. The NRC is about 1.1% cost effective over the control option at a value of GBP 0.98 per square metre.

7. Cold mix asphalt

The last by cost-effectiveness ranking over the control option is the CMA with life cycle cost of GBP 92.00 which is slightly lower than that of the control option, GBP 92.68. The CMA is in the class of the control option of bituminous flexible pavements. The associated initial unit cost is significantly lower at GBP 88.14, with a marked high maintenance cost of GBP 11.57 per square metre. The structural maintenance activities are more frequent at shorter intervals. Again, the CMA has a relatively shorter service life of 10-15 years and thus an analysis period of 13 years. The residual pavement value is estimated at 5% of the initial construction unit cost yielding GBP 4.41.

Table 2 Details of life cycle cost of paving options (GBP/m^2)

	Surfacing Class	Surfacing Type	Surfacing life (years)	Analysis period (years)	Structural maintenance standard	After x years	Maintenance cost GHS/m^2	Maintenance cost GBP/m^2	Initial cost per square metre (GBP)	Salvage percent %	Salvage value (Percent of initial construction cost)	Life cycle cost (GBP/m^2)	Rank
Experimental Alternatives	Modular	Cobble stone paving	20 -30 yrs	25	Consolidated routine repairs	7	7	1.04	89.69	12.0	10.76	91.29	4
					Replace surface stones and kerbs	12	15	2.23					
					Half-depth pavement repairs	17	55	8.16					
		Hand packed stones	20 - 30 yrs	25	Consolidated routine repairs	7	7	1.04	90.14	12.0	10.82	91.62	5
					Replace surface stones and kerbs	12	15	2.23					
					Half-depth pavement repairs	17	50	7.42					
		Interlocking concrete block paving	20 -30 yrs	25	Replace damaged concrete blocks	10	8	1.19	90.77	20.0	18.15	91.26	3
					Replace surface blocks and kerbs	15	15	2.23					
					Half-depth pavement repairs	20	50	7.42					
	Concrete	Roller compacted concrete	20 -30 yrs	25	Repair shrinkage and thermal cracks	7	15	2.23	88.49	20.0	17.70	89.27	1
					Repair all cracks and broken edges	15	30	4.45					
		Thin mesh reinforced concrete	20 -30 yrs	25	Repair shrinkage and thermal cracks	7	12	1.78	88.96	20.0	17.79	89.53	2
					Repair all cracks and broken edges	15	30	4.45					
		Non-reinforced concrete	20 -30 yrs	25	Repair shrinkage and thermal cracks	7	18	2.67	90.51	18.0	16.29	91.70	6
					Repair all cracks and broken edges	15	35	5.19					
	Bituminous	Cold mix asphalt	15 - 20 yrs	18	Crack sealing and routine maintenance	3	7	1.04	88.14	5.0	4.41	92.00	7
					Crack sealing and routine maintenance	5	7	1.04					
					Crack sealing and pothole patching	7	11	1.63					
					Pothole patching and reseal	10	45	6.68					
					Crack sealing and routine maintenance	15	8	1.19					
Control	Bituminous	Double chip seal	10- 15 yrs	13	Crack sealing and routine maintenance	3	7	1.04	88.06	4.0	3.52	92.48	
					Crack sealing and pothole patching	5	11	1.63					
					Pothole patching and reseal	7	40	5.93					
					Crack sealing and routine maintenance	10	12	1.78					
					Crack sealing and routine maintenance	12	8	1.19					

Note: 1GBP = GHS 6.74 Exchange rate at 12 March 2020

3.5 Sensitivity analysis

In estimating the initial construction cost care was taking in using available construction indices released by the GSS. Other construction considerations were the prevailing economic considerations such as inflation rates, cost of essential resources including labour in the project catchment area, cost of key construction materials, for example cement, gravel, bitumen, aggregates, etc. and the cost of financial procurement, among others were undertaken during the build up to the Bill of Quantities for the demonstration project. Thus, the reliability of the estimation of the initial construction cost is high which has been corroborated with the procurement process as the construction of the demonstration project nears completion. Nonetheless, the certainty of two critical inputs considered in the life cycle cost analysis presents basis for consideration for sensitivity analysis. The input parameters and the reason for subjecting to sensitivity analysis are discussed following;

3.5.1 Sensitivity of discount rates

In partially unstable economies that typify a lower middle income country like Ghana, discount rate which is a function of the policy rate of the country (reviewed periodically, sometimes on quarterly basis) is a crucial parameter that affects the cost of resources. As indicated earlier, exempting the cost of initial construction cost which has been carefully estimated bearing in mind all volatile factors, the cost of other construction inputs could suffer negatively especially when discount rates drop from the assumed base rate of 12 precent. Thus the life cycle cost analysis was subjected to a sensitivity analysis with discount rates of 8%, 10% matching the base rate of 12%.

An Excel® spread sheet output of detailed analytic results is displayed in Table 3. The results are summarily presented graphically as depicted in Figure 6.

Figure 6 Life cycle cost of paving options for sensitivity analysis on discount rates

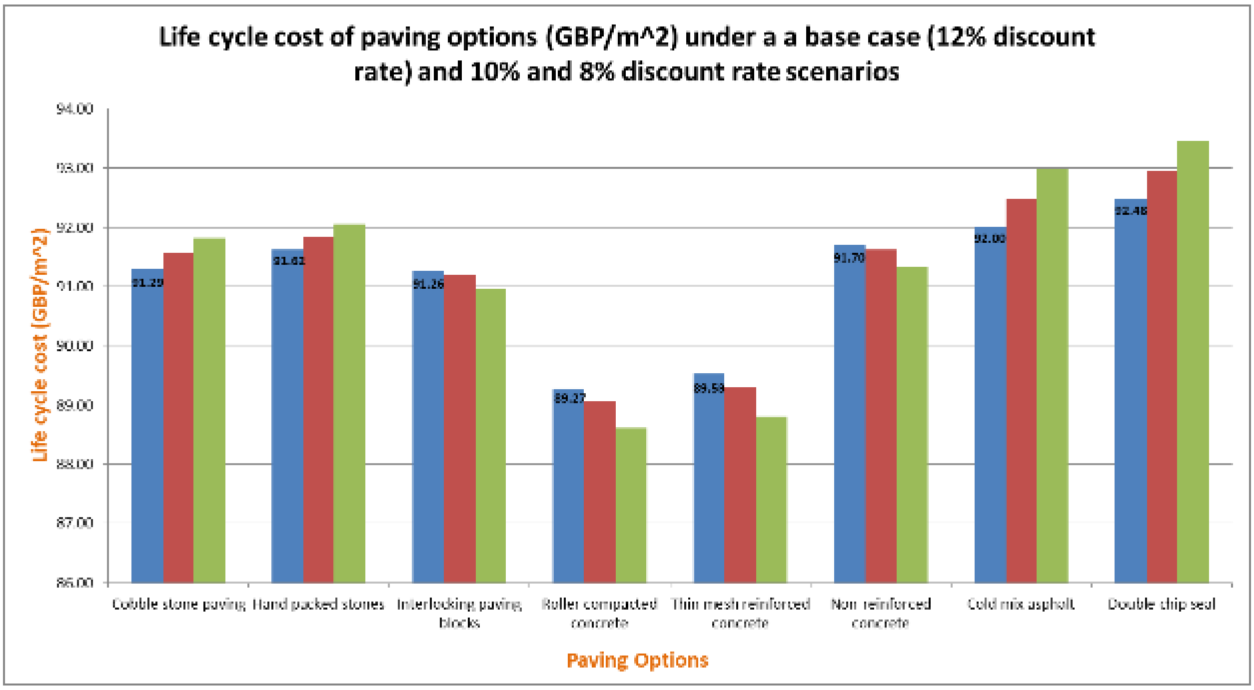


Table 3 Details of sensitivity analysis for a base case maintenance cost and 10% and 25% increase over base case scenarios

Surfacing Type	Surfacing life (years)	Analysis period (years)	Structural maintenance standard	After x years	Maintenance cost GHS/m^2	Maintenance cost GBP/m^2	Initial cost per square metre (GBP)	Salvage percent %	Salvage value (Percent of initial construction cost)	12%	10%	8%
Cobble stone paving	20 -30 yrs	25	Consolidated routine repairs	7	7	1.04	89.69	12.0	10.76	91.29	91.55	91.81
			Replace surface stones and kerbs	12	15	2.23						
			Half-depth pavement repairs	17	55	8.16						
Hand packed stones	20 - 30 yrs	25	Consolidated routine repairs	7	7	1.04	90.14	12.0	10.82	91.62	91.85	92.05
			Replace surface stones and kerbs	12	15	2.23						
			Half-depth pavement repairs	17	50	7.42						
Interlocking concrete block paving	20 -30 yrs	25	Replace damaged concrete blocks	10	8	1.19	90.77	20.0	18.15	91.26	91.19	90.96
			Replace surface blocks and kerbs	15	15	2.23						
			Half-depth pavement repairs	20	50	7.42						
Roller compacted concrete	20 -30 yrs	25	Repair shrinkage and thermal cracks	7	15	2.23	88.49	20.0	17.70	89.27	89.07	88.61
			Repair all cracks and broken edges	15	30	4.45						
Thin mesh reinforced concrete	20 -30 yrs	25	Repair shrinkage and thermal cracks	7	12	1.78	88.96	20.0	17.79	89.53	89.29	88.80
			Repair all cracks and broken edges	15	30	4.45						
Non-reinforced concrete	20 -30 yrs	25	Repair shrinkage and thermal cracks	7	18	2.67	90.51	18.0	16.29	91.70	91.62	91.32
			Repair all cracks and broken edges	15	35	5.19						
Cold mix asphalt	15 - 20 yrs	18	Crack sealing and routine maintenance	3	7	1.04	88.14	5.0	4.41	92.00	92.47	92.99
			Crack sealing and routine maintenance	5	7	1.04						
			Crack sealing and pothole patching	7	11	1.63						
			Pothole patching and reseal	10	45	6.68						
			Crack sealing and routine maintenance	15	8	1.19						
Double chip seal	10- 15 yrs	13	Crack sealing and routine maintenance	3	7	1.04	88.06	4.0	3.52	92.48	92.94	93.46
			Crack sealing and pothole patching	5	11	1.63						
			Pothole patching and reseal	7	40	5.93						
			Crack sealing and routine maintenance	10	12	1.78						
			Crack sealing and routine maintenance	12	8	1.19						

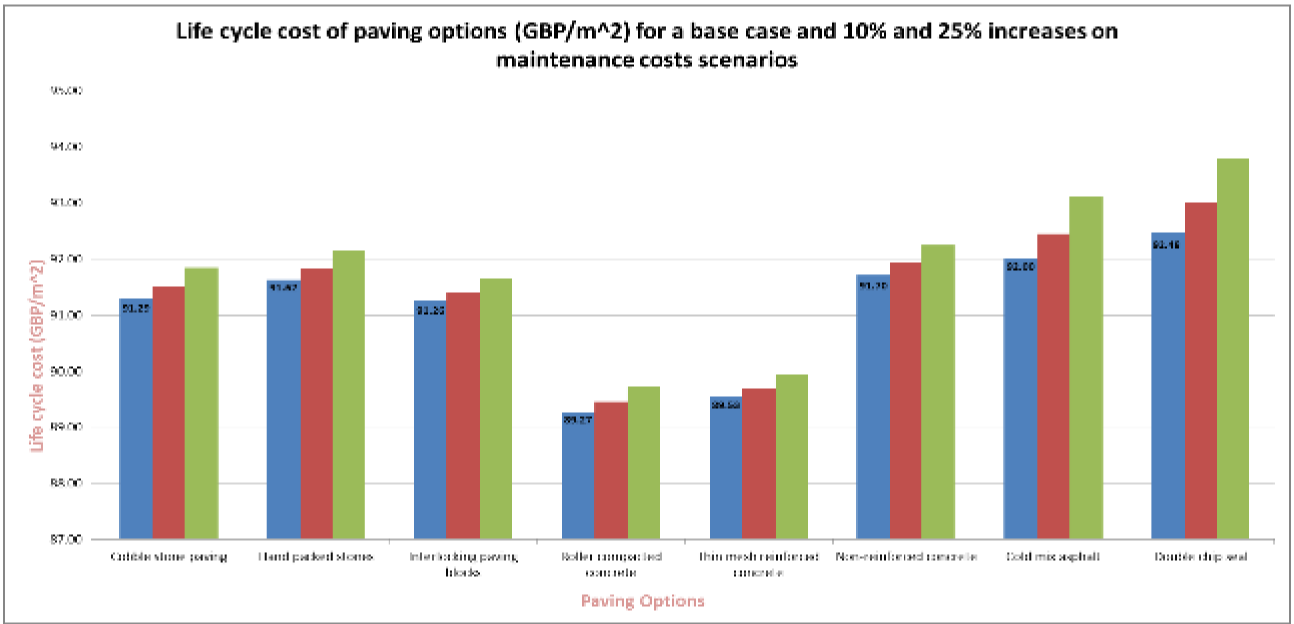
Note: 1GBP = GHS 6.74 Exchange rate at 12 March 2020

The concrete-based options (RCC, TMRC, and ICBP) which performed best in the base scenario of discount rate of 12% showed marginal but consistent and lower life cycle costs when the model was subjected to discount rates of 10% and 8% scenarios. In the case of ICBP for instance, the life cycle costs for the base (12%) ,10% and 8% scenarios are GBP 91.26, GBP 91.19 and GBP 90.96 respectively. Similar trends are seen for RCC and TMRC options for the base, 10% and 8% scenarios in the range of 0.20% to 0.82% decrease of the life cycle costs for 10% and 8% scenarios over the base case. The responses of life cycle costs to the sensitivity scenarios for the 'not-so-good' cost effective options, which is CMA, HPS, and CSP were opposite. The life cycle costs in the scenarios of lower discount rates (10% and 8%) would yield corresponding higher life cycle costs over the base case, 12%. For example, in the case of CMA, the life cycle cost increases from GBP 92.00 to GBP 92.47 (discount rate 10% scenario) and GBP 92.99 (discount rate 8% scenario) which translates to 0.51% and 1.07% increases for 10% and 8% discount rate scenarios over the base case of 12%.

3.5.2 Sensitivity of maintenance costs

Whereas the cost of the initial construction was done to ensure high levels of reliability, the cost of maintenance could suffer fluctuations especially resulting from unstable economic indicators. Consequently, sensitivity analysis has been conducted on the estimated cost of the maintenance activities projected over the service life for the experimented alternatives. The sensitivity analysis for the cost of maintenance is subjecting the base estimates for scenarios of 10% and 25% increments over the base estimation, deemed as 100% case. For the sensitivity analysis for the maintenance too, Figure 7 shows a summary results graphically while an Excel™ spread sheet output displayed in Annex 3 captures the details of the results.

Figure 7 Life cycle cost of paving options for maintenance costs sensitivity analysis



Expectedly, the life cycle costs generally increases from the base case scenarios to higher values when the maintenance costs are increased by 10% and 25% of the base case. The levels of increase are more pronounced in the less cost-effective options like the CMA, CSP, and HPS. There are about 0.48% and 1.20% increases from the base life cycle cost values respectively for the 110% and 125% scenarios. This is even clearer for the case of the control option as it is subjected to maintenance costs sensitivity analysis. The life cycle unit costs for the control option are GBP 92.48, GBP 93.00, and GBP 93.79 for the base case, 110% and 125% scenarios of the maintenance costs.

4 Conclusion

The economic analysis has identified some key socioeconomic indicators for the immediate beneficiary communities (Akwesiho, Twenedurase, and Akokobenum Nsuo). The potential benefits associated with the project road (link between Akwesiho and Twenedurase) have been assessed. Quantifying the benefits is not presented, though, as many of the identified potential benefits are exogenous. The level-one assessment of the cost-effectiveness of alternative pavements based on initial construction cost alone could be misleading as shown in the ranking of the cold mix asphalt. Importantly, a life cycle cost which takes into account future maintenance cost and the potential salvage (residual) values of the road assets is a better measure of the cost-effectiveness of a given surfacing option.

The socioeconomic survey established that Akwesiho (population about 1000) had 390 house units with an average of four persons per house, while Twenedurase (population about 450) had 200 units with an average occupancy of three persons per household. Females were observed to constitute about 55% of the population. Agriculture, artisan services (masonry, carpentry, steel welding, etc.), and petty trading were the main sources of livelihood for the indigenes for both Akwesiho and Twenedurase. The average income and expenditure levels were about the equivalent of two-and-a-half pounds (GBP2.5) per person per day. Akwesiho occupants engaged in more farming activities than those in Twenedurase. Commercial farming had a comparatively low profile, and the main commercial crops were cocoa and banana. Residents believed getting the road that connects Akwesiho and Twenedurase would uplift the commercial status of the two villages significantly, as more motorists would be using the route as alternatives to the existing Nkawkaw-Obomeng/Mpraeso roads, generating employment for the indigenes both directly and indirectly, provide easy access to both villages for the marketing of farm produce, generate revenue from tourism, among others.

An initial construction cost assessment was made of all the pavement options. In terms of ranking for the initial construction cost, the cold mix asphalt with a cost of GBP 87.13 per metre square is the least costly option. The most expensive cost-effective option is the interlocking paving block option at a unit cost of GBP 93.42. The life cycle cost analysis considered the initial construction cost, the cost of future maintenance standards and associated activities over the analysis period and a salvage value which is estimated as a percentage of the initial construction cost for each of the alternative option based on empirical data and research. The life cycle cost analysis shows that all alternative surfacings types (concrete, stones and bituminous) are economically feasible and comparably more cost effective than the control option, the double chip seal. The life-cycle costs for the alternative surfacings types ranged from GBP 89.20 to GBP 92.20 per square metre while the cost for the control option wasGBP 92.68 at a nominal real discount rate of 12%.

The life cycle cost analysis was subjected to a sensitivity analysis with variation in the discount rates of 8%, 10% and matching the base rate of 12%. The concrete-based options (RCC, TMRC, and ICBP) which performed best in the base scenario of discount rate of 12% showed marginal but consistent and lower life cycle costs when the model was subjected discount rates of 10% and 8% scenarios. In the case of ICBP for instance, the life cycle costs for the base (12%), 10% and 8% scenarios are GBP 91.26, GBP 91.19 and GBP 90.96 respectively. The cost of maintenance could suffer fluctuations especially resulting from unstable economic indicators. Consequently, sensitivity analysis was conducted on the estimated cost of the maintenance activities The sensitivity scenarios for the cost of maintenance were 10% and 25% increments over the base estimation, deemed as 100% case. Expectedly, the life cycle costs generally increases from the base case scenarios to higher values when the maintenance costs are increased by 10% and 25% of the base case. The life cycle unit costs for the control option are GBP 92.48, GBP 93.00, and GBP 93.79 for the base case, 110% and 125% scenarios of the maintenance costs respectively.

5 REFERENCES

AASHTO 1993. AASHTO Guide for Design of Pavement Structures. American Association of State Highway and Transportation Officials. Washington, D.C., USA.

Adler, H. A., 1971, Economic Appraisal of Transport Projects: A Manual with Case Studies(Bloomington: Indiana University Press).

Ampadu, S.I.K. and Addison, F.K. (2015). A comparison between the life cycle cost of gravel and of bituminous surfacing options for feeder roads in Ghana. International Journal of Pavement Engineering. DOI:10.1080/10298436.2015.1065990.

Anochie-Boateng, J.K. and Debrah, E.K. (2016). Alternative surfacing for steep hill sections in Ghana—Phase I, Final Report, ReCAP Project Activity Number: GHA2065A.

Commission Of The European Communities, 1993, Environmental Manual: Environmental Procedures and Methodology Governing Lome´ IV Development Cooperation Projects: User's Guide and Sectorial Environmental Assessment Sourcebook (Brussels: Directorate-General for Development, Forward Studies and Planning Division).

Cook J.R., Petts, R.C. and Rolt, J. (2013). Low volume rural roads-A Guide to Good Practice.

Cundill, M. A. And Withnall, S. J., 1993, Road Transport Investment Model (RTIM3). Sixth International Conference on Low-volume Roads, vol. 1 (Washington, DC: National Academy of Sciences for Transportation Research Board).

Harral, C. G. And Faiz, A., 1988, Road Deterioration in Developing Countries: Causes and Remedies. World Bank Policy Study (Washington, DC: World Bank).

Leta, N.V. and Langa, R. (2010). Use of Locally-produced materials for low-volume road paving, 1st AfCAP Practitioners Conference, 23-25 November 2010.

Morosiuk, G., Riley, M. J. And Odoki, J. B., 2002, Modelling Road Deterioration and Works Effects. The Highway Development and Management Series, vol. 6 (Paris: PIARC World Road Association).

Parsley, L. L. and Robinson, R., 1982, The TRRL Road Investment Model for Developing Countries. TRRL Laboratory Report 1057 (Crowthorne: Transport and Road Research Laboratory).

Paterson, W. D. O., 1987, Road Deterioration and Maintenance Effects: Models for Planning and Management (Washington, DC: John Hopkins University Press).

Toole, Morosiuk, Petts and Done. (2002). Management guidelines for unsealed roads. [http://www.transport-links.org/transport_links/filearea/documentstore/Draft Gravel Guidelines.pdf, accessed May 4, 2016]

TRH 4 (1996). Structural Design of Flexible Pavements for Interurban and Rural Roads, South African National Roads Agency, Pretoria, South Africa.

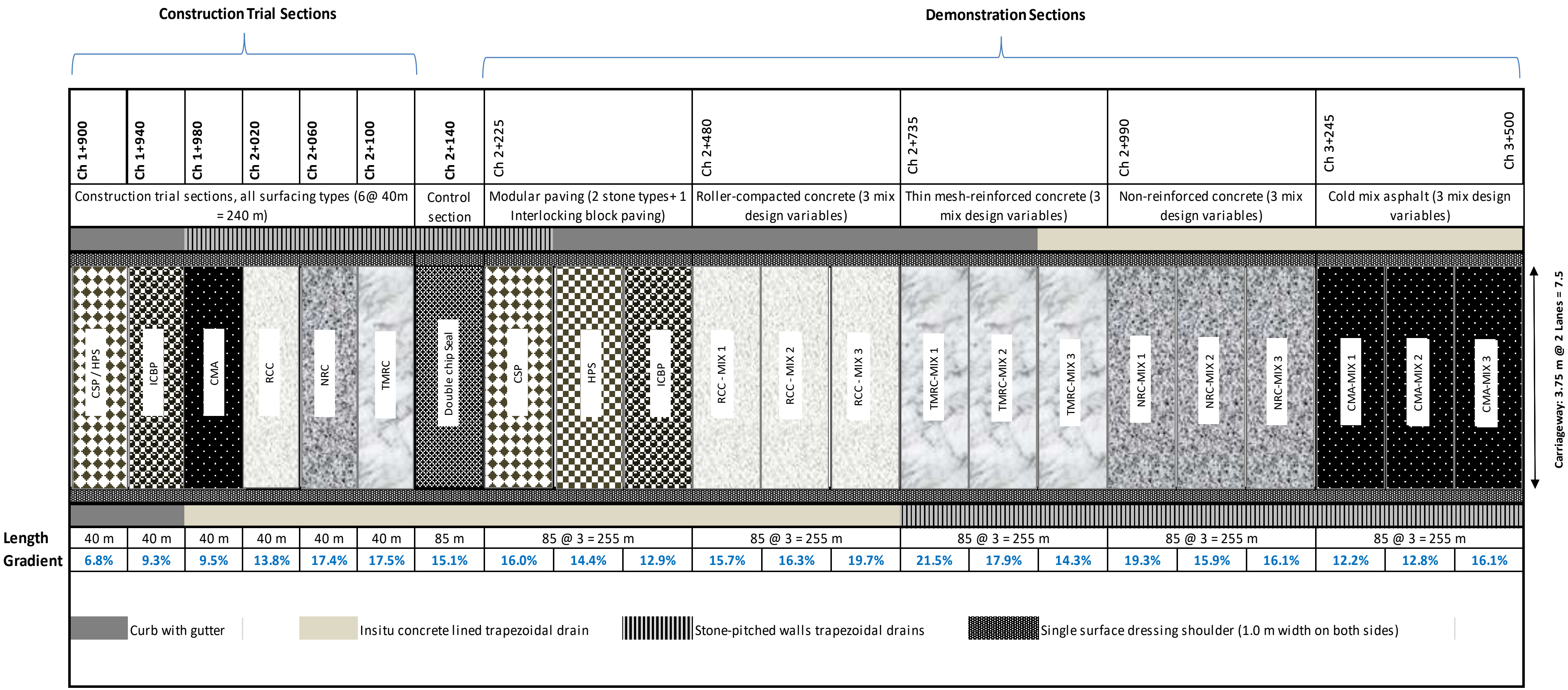
TRL, 1988, A Guide to Road Project Appraisal. Overseas Road Note 5 (Crowthorne: Transport and Road Research Laboratory).

Tsunokawa, K. (2010). Road projects cost benefit analysis: scenario analysis of the effect of varying inputs. The International Bank for Reconstruction and Development / the World Bank. www.worldbank.org

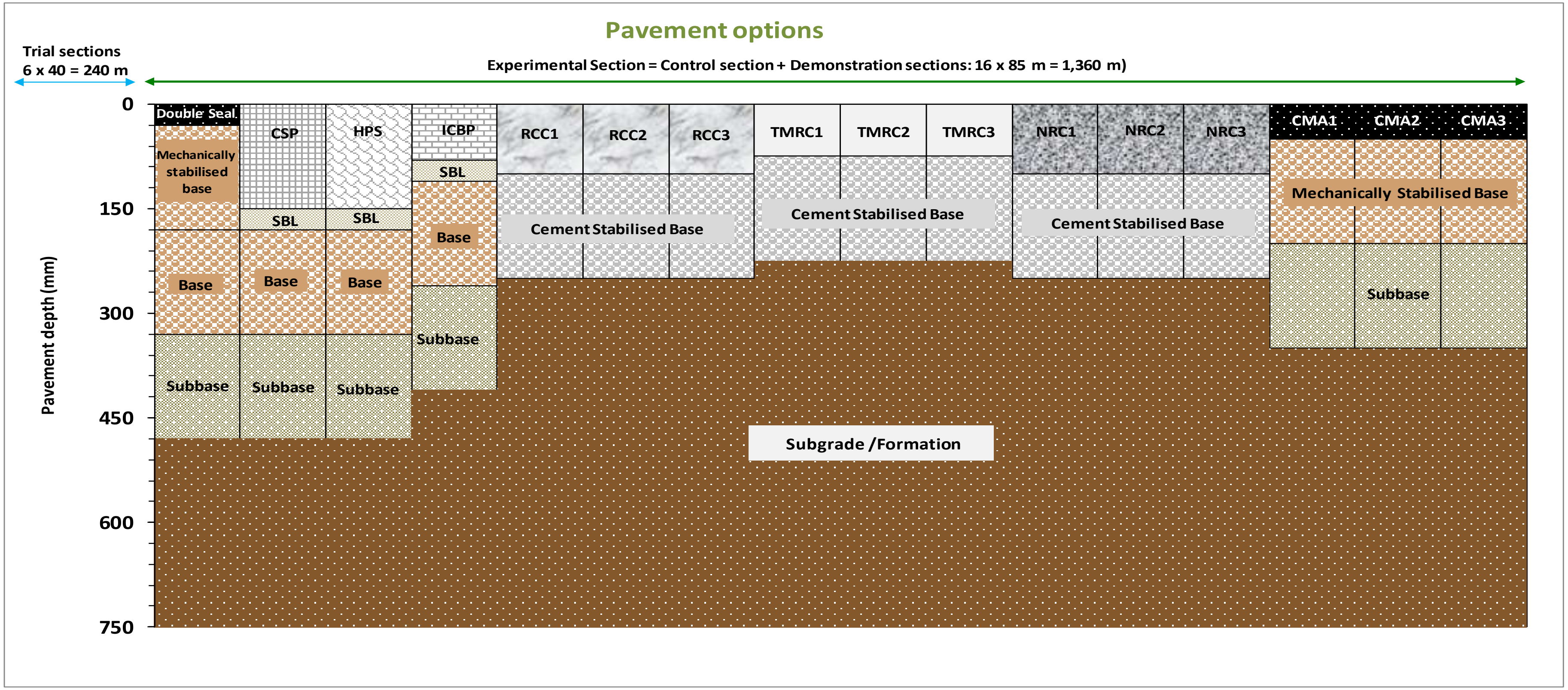
Watanatada, T., Harral, C. G., Paterson, W. D. O., Dhareshwar, A. M., Bhandari, A. and Tsunokawa K., 1987, The Highway Design and Maintenance Standards Model, vol. 1: Description of the Model (Washington, DC: John Hopkins University Press for the World Bank).

World Bank, 1997, Roads and the Environment: A Handbook. Edited by Tsunokwawa, K. and Hodan, C., World Bank Technical Paper No. 376 (Washington, DC: World Bank).

Annex 1 Layout of Trial and Experimental Sections



Annex 2 Longitudinal section of the demonstration sections (Schematic)



Notes:
1: CSP = Concrete Stone Pitching
2: HPS = Hand Packed Stone
3: SBL = Sand Bed Layer
4: ICBP = Interlocking Concrete Block Paving
5: TMRC = Thin Mesh-Reinforced Concrete
6: NRC = Non-Reinforced Concrete
7: CMA = Cold Mix Asphalt

Annex 3 Details of sensitivity analysis for a based maintenance cost and 10% and 25% increase over base case scenarios

Surfacing Type	Surfacing life (years)	Analysis period (years)	Structural maintenance standard	After x years	Maintenance cost GHS/m^2	Maintenanc e cost GBP/m^2	110% Maintenanc e cost	125% Maintenanc e cost	Initial cost per square metre (GBP)	Salvage percent %	Salvage value (Percent of initial construction cost)	Base Case 100%	110% Maintenanc e cost	125% Maintenance cost
Cobble stone paving	20 -30 yrs	25	Consolidated routine repairs	7	7	1.04	1.14	1.30	89.69	12.0	10.76	91.29	91.51	91.84
			Replace surface stones and kerbs	12	15	2.23	2.45	2.78						
			Half-depth pavement repairs	17	55	8.16	8.98	10.20						
Hand packed stones	20 - 30 yrs	25	Consolidated routine repairs	7	7	1.04	1.14	1.30	90.14	12.0	10.82	91.62	91.83	92.15
			Replace surface stones and kerbs	12	15	2.23	2.45	2.78						
			Half-depth pavement repairs	17	50	7.42	8.16	9.27						
Interlocking concrete block paving	20 -30 yrs	25	Replace damaged concrete blocks	10	8	1.19	1.31	1.48	90.77	20.0	18.15	91.26	91.41	91.65
			Replace surface blocks and kerbs	15	15	2.23	2.45	2.78						
			Half-depth pavement repairs	20	50	7.42	8.16	9.27						
Roller compacted concrete	20 -30 yrs	25	Repair shrinkage and thermal cracks	7	15	2.23	2.45	2.78	88.49	20.0	17.70	89.27	89.45	89.73
			Repair all cracks and broken edges	15	30	4.45	4.90	5.56						
Thin mesh reinforced concrete	20 -30 yrs	25	Repair shrinkage and thermal cracks	7	12	1.78	1.96	2.23	88.96	20.0	17.79	89.53	89.69	89.93
			Repair all cracks and broken edges	15	30	4.45	4.90	5.56						
Non-reinforced concrete	20 -30 yrs	25	Repair shrinkage and thermal cracks	7	18	2.67	2.94	3.34	90.51	18.0	16.29	91.70	91.92	92.24
			Repair all cracks and broken edges	15	35	5.19	5.71	6.49						
Cold mix asphalt	15 - 20 yrs	18	Crack sealing and routine maintenance	3	7	1.04	1.14	1.30	88.14	5.0	4.41	92.00	92.45	93.11
			Crack sealing and routine maintenance	5	7	1.04	1.14	1.30						
			Crack sealing and pothole patching	7	11	1.63	1.80	2.04						
			Pothole patching and reseal	10	45	6.68	7.34	8.35						
			Crack sealing and routine maintenance	15	8	1.19	1.31	1.48						
Double chip seal	10- 15 yrs	13	Crack sealing and routine maintenance	3	7	1.04	1.14	1.30	88.06	4.0	3.52	92.48	93.00	93.79
			Crack sealing and pothole patching	5	11	1.63	1.80	2.04						
			Pothole patching and reseal	7	40	5.93	6.53	7.42						
			Crack sealing and routine maintenance	10	12	1.78	1.96	2.23						
			Crack sealing and routine maintenance	12	8	1.19	1.31	1.48						