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REPORT

REVISED REPORT

Design Report: Evaluation of the Ghana Roads Activities

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ACRONYMS

AADT	Average annual daily traffic
ANN	Artificial neural network
CAPI	Computer-assisted personal interviewing
CBR	California bearing ratio
CNN	Convolutional neural network
CRM	Commercialized Road Management
DID	Difference-in-differences
DFR	Department for Feeder Roads
DHS	Demographic and Health Surveys
DMSP	Defense Meteorological Satellite Program
DN	Digital number
DNB	Day/Night Band
ERR	Economic rate of return
ESAL	Equivalent standard axle load
FWD	Falling weight deflectometer
GHA	Ghana Highway Authority
GLSS	Ghana Living Standards Survey
HDM-3	Highway Design and Maintenance Standards Model 3
HDM-4	Highway Development and Management 4
IRB	Institutional review board
IRI	International Roughness Index
KII	Key informant interviews
LTPP	Long-term Pavement Performance
M&E	Monitoring and evaluation
MiDA	Millennium Development Authority
MCC	Millennium Challenge Corporation
MPBS	Maintenance Performance Budgeting System
MRH	Ministry of Roads and Highways
NOAA	National Oceanic and Atmospheric Administration
NPP	Suomi National Polar-Orbiting Partnership
NTL	Nighttime lights
O-D	Origin-destination
OLS	Operational Linescan Sensor
PMMP	Pavement Maintenance Management Program
RDWE	Road deterioration and works effects

RED	Roads Economic Decision
RMMS	Road Maintenance and Management System
RTCS	Road traffic count survey
RUE	Road user effects
ToRs	Terms of reference
TRL	Transport Research Laboratory
VIIRS	Visible Infrared Imaging Radiometer Suite
VOCs	Vehicle operating costs

I. INTRODUCTION

While Ghana has experienced rapid economic growth (around 7 percent per year on average since 2005), there remains a stark inequality between rural and urban areas. Households in rural areas are nearly four times as likely to live in poverty as households in urban areas, and poverty rates are highest in the remote northern regions, and among agricultural workers (Cooke, Hague and McKay 2016). Rural farming populations face significant transportation costs to get their goods to market, which geographically isolates them from the economic growth in urban areas. For example, nearly 60 percent of Ghana's rural population lives two hours away from a market center, and about 10 percent live at least five hours (or more) away. Reductions in travel times and transportation costs could improve incomes for rural populations by promoting cash crop production and reducing reliance on subsistence farming (Caselli and Gollin 2012).

To address these constraints to economic growth and poverty reduction, the first Ghana compact with the Millennium Challenge Corporation (MCC) aimed to reduce poverty through economic growth led by the agriculture sector. Signed in 2006, the Ghana I compact investments started in February 2007 and ended in February 2012. The compact funded three projects designed to increase agricultural production and productivity and enhance the competitiveness of high-value cash and food crops. These were the Agriculture, Transportation, and Rural Development projects. Improvements to transportation networks were funded by the Transportation and Agriculture Projects, including: (1) upgrading a key segment of the National Highway 1 (N1) in order to reduce bottlenecks between the Kotoka International Airport and the Port of Tema, (2) improvements to segments of a secondary, or trunk road in the Afram Basin, and (3) the rehabilitation of tertiary or feeder roads in eight districts. This report will refer to these activities together as the Ghana I Roads Project ("the Roads project").

MCC contracted Mathematica Policy Research to conduct an evaluation of the Roads project that will estimate the economic rate of return (ERRs) for the completed roads projects, assess the performance of the road program in terms of roads maintenance and road users, and estimate the impact of the roads on economic growth and poverty reduction. This design report describes our approach to the Ghana roads evaluation, drawing upon our evaluation assessment and our initial design trip to Ghana.

In the next section, we summarize the high-level evaluation questions and guiding principles that we used to develop the evaluation design. We follow this with an overview of the program logic for the Ghana compact and a brief literature review to place the transportation investments in Ghana in the context of the evidence to date on the impact of roads improvement projects on key outcomes. We end this chapter with a roadmap to the rest of the design report.

A. Key research questions and guiding principles for the evaluation design

Improved roads benefit economic growth and poverty reduction by lowering vehicle operating costs (VOCs) and travel times for people using the roads resulting in lower transportation costs (Patel 2017). These reduced costs benefit the economy in a variety of ways; for example they can promote access to health and social services, trade linkages, or tourism (Bryceson et al. 2008; Escobal and Ponce 2004). Reduced transport costs can also lower costs of inputs for both agricultural and non-agricultural production, benefiting productivity and increasing household income and consumption (Khandker et al. 2009).

Because of these potentially widespread benefits, improvement of transportation infrastructure has been a high priority for many developing countries, and many countries eligible for MCC compacts have requested infrastructure investments. Over the past 10 years, MCC has made significant investments in roads projects, totaling nearly $3 billion via 18 compacts (Patel 2017). Along with investing in roads, MCC has invested in evaluations to measure the impacts of the roads projects. However, many of the early evaluations of such projects were not able to measure interim or longer-term outcomes on prices and incomes. Peer reviewers for these evaluations have emphasized that impact evaluation designs are not always based on a solid understanding of the theory of change for specific roads investments. As a leading donor in the sector, MCC continues to learn lessons from roads investments and to develop reliable ways to evaluate them, looking more closely at the intermediate objectives of the roads improvements according to the program logic.

This design report drew upon the program logic for the roads projects and MCC's learning objectives for this and future roads evaluations to develop the evaluation approach. The evaluation will reestimate the economic rate of return for the roads, and assess the performance of maintenance practices, road users, transportation costs, through the following main research questions:

1. What is the estimated economic rate of return for the completed roads projects?
2. How have maintenance practices affected the projected life of the roads?
3. Who is traveling on the roads and why? Have travel times decreased?
4. Are consumers benefiting from reduced transportation costs?

The evaluation will address these questions through a mixed-methods approach that analyzes roads engineering and road user data, administrative records, and qualitative data. In addition to the main research questions posed here, Mathematica and MCC are developing an impact evaluation design to measure the impact of the roads investments on economic activity, using new data technologies including a combination of satellite and field-level/household data collection.

In developing the design report and impact evaluation design, the Mathematica team has applied the following guiding principles to the evaluation data collection and analysis:

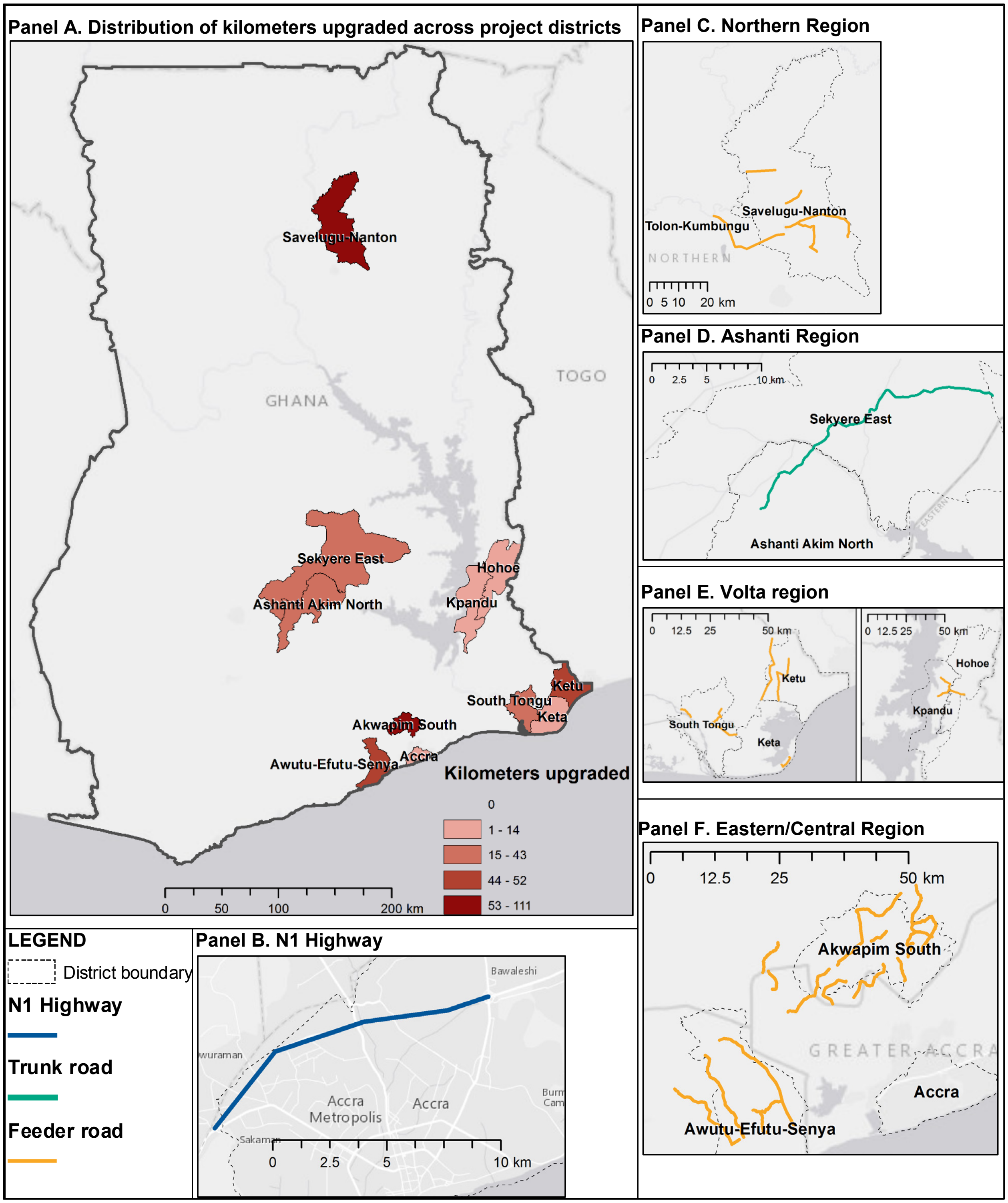
- **Clearly identify and update the theory of change for the roads investment in order to develop the analytical approach for the evaluation.** Grounding the evaluation in the current theory of change for roads projects will help identify intermediate outcomes that can help predict the longer-term impacts of the roads. As noted in the evaluation assessment memo, the expected long-term impacts were not tied to a detailed theory of change for the roads investments that specified how reduced transportation costs would affect economic growth and poverty in Ghana. For example, the roads projects were justified on the basis of increased access to markets, increased agricultural productivity, and competitiveness of cash crops on local and international markets without a complete assessment of the linkages between improved transportation networks and agricultural revenue.

- **Focus data collection activities on the variables that have the highest impact on ERR estimates, and draw lessons for future investments in roads projects.** As part of the evaluation design, we are trying to identify areas where data collection activities could be streamlined, while prioritizing those variables that are key to generating robust ERR estimates; for example, sampling road segments for some measures of road conditions, which may not be needed for every road segment or at the MCC recommended frequency. Similarly, we will rely on existing secondary data sources where data quality can be verified or for parameters to which the ERRs are not very sensitive.
- **Develop lessons from the Ghana roads evaluations to make future evaluations of infrastructure projects more efficient and useful.** In addition to the approaches above, the evaluation will aim to develop an approach for lower-cost evaluation methods to assess the impact of roads projects, such as by using satellite imaging data. In addition, we will attempt to keep track of the various lessons learned from the design of these evaluations to inform MCC's future roads evaluation efforts.

B. Overview of project activities, program logic, and beneficiaries

The Ghana Roads project funded the upgrading of segments of the N1 highway and Agogo-Dome trunk road, and the Agriculture Project funded the upgrading of feeder roads in eight districts spanning four regions of the country (Figure I.1). The logic model in Figure I.2 illustrates the causal pathways between program inputs, outputs, outcomes, and the ultimate goal of poverty reduction through economic growth, as described in compact documentation. Figure I.2 also describes the implicit assumptions in the program logic.

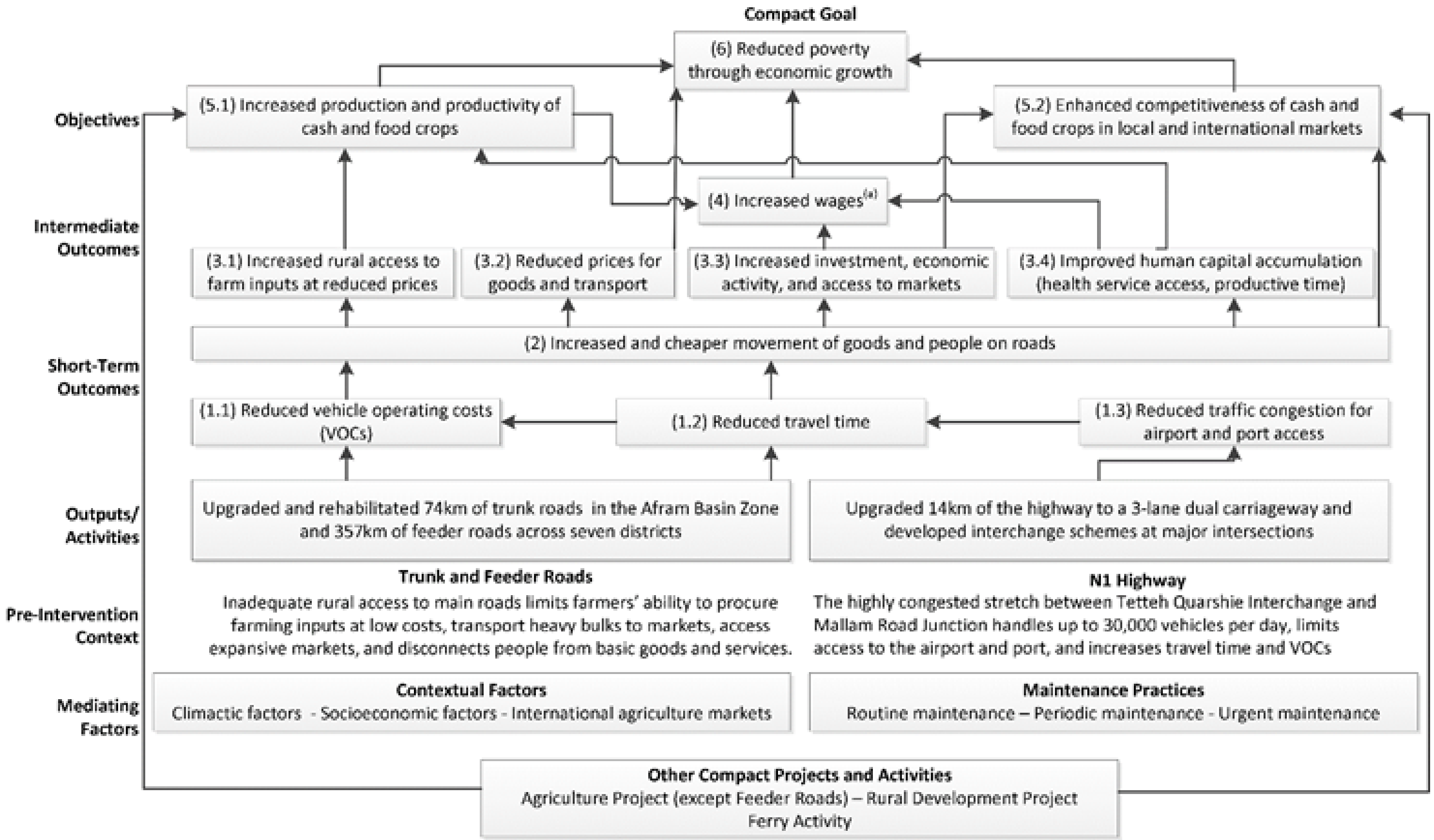
Figure I.1. Locations and distribution of upgraded roads



Sources: Mida 2012; MCC 2009; Google n.d.

Note: Some segments are located in neighboring districts to those listed, but grouped administratively with the identified districts in project documentation. Many of these districts and regions have changed since the compact was initially designed. Four feeder roads could be digitally mapped using publicly available geographic data. Locations are approximate.

Figure I.2. The program logic of the Ghana Roads Project, according to compact documentation



Sources: MCC 2006; MiDA 2008; MCC 2009; Jacobs Consultancy (2008) and BCEOM and Inter-Consult (2008); MiDA 2012.

Notes: A number of key assumptions underlie the links between the project outputs, outcomes, and overall objectives. These include (1) Upgrading the roads will permit faster travel speeds and reduce congestion on the roads, reducing travel times; (2) Upgrading the roads will reduce the cost of operating and maintaining vehicles used along improved segments; (3) Reduced VOCs and faster travel speeds will lower transportation costs; these savings will pass on to farmers through a competitive transport sector; (4) Agricultural markets will function efficiently and respond to changes in production and costs (such as inputs, transportation, etc.); and (5) Government entities will ensure adequate maintenance of the roads, which is critical for keeping the road quality at a level needed for efficient traffic movement. Outcomes would be short-lived if these assumptions do not hold up in practice.

[a] Increased wages were not explicitly included in the compact's M&E plan, but are included in ERR benefits streams and are an implicit objective necessary to link the lower-level objectives of improved human capital accumulation with the compact's goal.

1. The N1 Highway

Implemented by the Ghana Highway Authority, the N1 Highway activity entailed the expansion and upgrading of nearly 14 kilometers (kms) of the N1 Highway between the Tetteh Quarshie Interchange and the Mallam Junction from a single-lane dual carriageway (2 lanes) to a three-lane dual carriageway (6 lanes), and redesigned interchanges and intersections. The project was designed to reduce bottlenecks and travel time on the extremely busy (more than 25,000 vehicles per day prior to construction, increasing to more than 50,000 in the year following completion) segment between the Kotoka International Airport and the Port of Tema. The N1 project, the largest compact activity in terms of cost, was completed in 2012. Table I.1 below describes the planned and actual costs for the N1 Highway, as well as the other types of roads upgraded under the compact.

Table I.1. Changes in roads project implementation and costs following compact rescoping

	Anticipated kilometers to be upgraded	Actual kilometers upgraded	Anticipated total cost ($M)	Actual total cost ($M)	Anticipated cost per kilometer ($'000)	Actual cost per kilometer ($'000)
N1 Highway	13.6	13.6	$101.3	$182.1	$7,424.2	$13,348.8
Afram Basin trunk road	77.0	73.9	$25.9	$28.5	$336.4	$379.2
Feeder roads	686.0	357.5	$57.9	$70.6	$84.4	$196.9

Source: MiDA 2012.

2. Trunk Roads Activity (Afram Basin)

The Trunk Roads Activity, completed in 2012, funded the rehabilitation and upgrading of 74 km of the Agogo - Dome Trunk Road in the Afram Basin Zone, by widening and resurfacing the road with a bituminous (asphalt) surface dressing. During initial compact development, the activity targeted 230 km of the road to be upgraded, but project cost estimated from the feasibility and design stage required reducing the total number of kilometers to be upgraded. Moreover, although classified as a secondary road, the Agogo - Dome road initially had a low traffic volume (around 200 vehicles per day), and at the time of compact closeout, traffic had not grown as originally anticipated. The Roads Project also funded two ferries and related landing and terminal facilities on Lake Volta. While these ferries were initially intended for the same crossing, *Freedom and Justice* was sent to another crossing on Lake Volta. The extent to which the ferry investments complement, versus substitute for the upgraded trunk road will affect how much the expected economic benefits of both are realized.

3. Feeder Roads

The program logic anticipated that the feeder and trunk roads' contributions to agricultural productivity and growth would be complemented by other investments, including investments in irrigation, farmer training, access to agricultural credit, and post-harvest processing facilities for crops such as maize, pineapples and mangos. The due diligence process for the roads investments initially identified approximately 950 km of feeder roads in 10 districts for upgrading; this was later reduced to 686 km based on the results of feasibility studies. Continued examination of the roads projects, cost increases, and the compact rescoping that occurred in 2008 further reduced this to 40 segments, totaling 357 km across eight districts. Under the Compact, 65 percent of this total length was paved with bituminous surface dressing and an additional 35 percent was upgraded with gravel. Prior to compact implementation, these roads varied in traffic from fewer than 20 vehicles per day to more than 3,000.

The ERR estimates anticipated that the roads improvements would reduce VOCs and travel times thereby increasing traffic along the upgraded roads. While the program logic described in the investment memo and other project documents posited that increased investment, human capital accumulation and farm-gate prices would also be a direct result of improved roads, these benefit streams were not estimated independently from reduced transportation costs. The project did not include any direct maintenance-related interventions, and assumed that government entities would carry out adequate maintenance of the roads.

C. Literature review

In this section, we review the literature on impacts of roads improvement programs and similar transportation infrastructure. As described above, roads improvements benefit economic growth and poverty reduction primarily through reduced transportation costs, which can lead to other intermediate and longer-term benefits, such as improved local economic conditions and greater interregional trade and cross-border trade.

It is especially challenging to measure the impact of roads projects on income and poverty reduction when improving the movement of goods and labor affects a diverse group of people including people traveling on the roads, populations living near the road, or consumers of products transported on the road. Measuring the specific ways that roads improvements affect a broad group of beneficiaries is especially challenging because the mechanisms are complex and harder to track. For instance, institutional factors, such as the competitiveness of the transport and agriculture markets in a country, can play a considerable role in determining who benefits and to what extent. In addition, because roads improvements have small impacts on a very broad set of beneficiaries, measuring these impacts is especially challenging.

In the next section, we review the literature on the impacts of roads improvements for two groups: (1) populations located close to improved roads, and (2) other beneficiaries who use the roads or benefit from goods traveling on the roads but may not live near them.

1. Impacts on beneficiaries of improved roads

We organize the literature review starting with impacts of roads improvements on intermediate outcomes such as reduced travel times and greater access to markets and social services, followed by longer-term impacts on economic activity and income. The literature review draws on the findings of completed MCC roads evaluations, as well as other roads evaluations that used impact evaluation methods to estimate a counterfactual.

a. Travel time

MCC’s roads evaluations support the conclusion that the most immediate benefits of roads improvements come from reductions in VOCs and travel times. For example, the upgrading of secondary roads as part of MCC’s compact in Honduras slightly reduced travel time to health centers and to municipal capitals; it also reduced travel costs to hospitals, health centers, and basic markets (NORC 2013a). In Georgia, rehabilitation of a regional highway that connects the economically isolated Samtskhe-Javakheti region to the capital and the rest of the country, increased traffic and average speed of vehicles leading to decreased travel times to the capital and basic markets (NORC 2013b).[1] Similarly, the upgrading of rural roads in Armenia led to a large, over 30 percent decrease, in travel time by households to sell agricultural products, and increased use of roads by households for shopping or visiting relatives (Fortson et al. 2015). These studies employed a difference-in-differences (DID) approach to estimate impacts on travel times and other outcomes compared to a comparison group. Other studies examining the impacts of road investments also found evidence of decreased transportation costs and travel times. For example, a study that used a DID approach to examining the construction of concrete bridges and culverts for roads crossing rivers and streams, thus allowing year-round passage in Brazil, found significantly reduced travel time to population centers and increased use of public transportation (Iimi et al. 2015). A panel data study examining similar interventions in Bangladesh also decreased travel costs by more than a third (Khandker et al. 2009).

b. Access to services, markets, and use of social services

Although roads improvements can increase access to markets and social services such as schools and health centers, the empirical evidence for this is mixed, likely depending on the availability of these services in the local context. The Armenia roads evaluation found that households near rehabilitated roads reported improved market access after completion of the roads. However, the roads improvements did not have an impact on access to social services, perhaps because community members did not use the regional roads to travel to social services located nearby (Fortson et al. 2015).

In the Brazil study, researchers found mixed results on perceived access to social services. The study reported improved access in two regions, but no consistent increase in two other regions (Iimi et al. 2015). These results may be related to travel distances to the services: the average distance to the nearest hospital was 27 km in the two regions where perceived access increased, compared to 39 km in the two regions where perceived access did not. Similarly, distance to schools in communities that reported improved access was half of the distance to schools that reported no improvement, suggesting that households in the regions with closer access were able to take advantage of the roads improvements. Studies looking at the use of health care facilities also found mixed results. In particular, studies with shorter follow-up windows were less likely to see any changes in utilization. For example, the MCC-funded Honduras study did not detect increased visits to hospitals, health care facilities, or pharmacies by household members in Honduras (NORC 2013a). MCC's evaluation of the Georgia roads project also did not find impacts on the use of health care centers (NORC 2013b) within one to two years of exposure to the improved roads.

Impacts of roads on schooling follow a similar mixed pattern. Road rehabilitation in Brazil increased school attendance of girls in two regions, but attendance decreased in two other

[1] The Samtskhe-Javakheti road reduced self-reported travel times to the capital by 40 minutes and to the local markets by 44 minutes. We could not calculate the percentage changes for these reductions because the authors did not report average travel time to these destinations at baseline.

regions after one year of exposure (Iimi et al. 2015).[2] MCC's Honduras project also did not find increases in the number of children attending school (NORC 2013a). The lack of measurable impact could have resulted from an evaluation period that did not allow enough time to observe changes in household behavior caused by the improved access to services. The evaluation design and program design also may not have adequately considered how the roads would promote the use of social services such as schools or health clinics (Patel 2017).

Studies that have longer exposure windows, however, have detected improvements in school outcomes, particularly enrollment. An evaluation of a World Bank-financed rural road rehabilitation project in Vietnam using a DID approach found increases in both primary and secondary school enrollment seven years after the completion of the project (Mu and van de Walle 2011). School enrollment for both boys and girls between ages 5 and 17 also increased in Bangladesh approximately four years after the completion of the project (Khandker et al. 2009).

c. Economic activity in rural areas

Improvements in roads can connect isolated rural areas to larger roads networks and provide households an opportunity to shift away from agricultural production to the non-agricultural wage sector as a result of increased access to regional and national labor markets. MCC's evaluation in Georgia showed an increase in the number of industrial facilities located in the intervention communities near the improved roads (NORC 2013b). Another study of roads projects in Georgia, using a DID approach, found that improvement of rural roads led to increases in the number of non-agricultural small and medium enterprises, and reductions in barter trade (Lokshin and Yemtsov 2005).

The Vietnam study discussed earlier also found small increases in off-farm activities, mostly in the service sector, as a result of roads improvements (Mu and van de Walle 2011). A study, using a DID design, examined the effects of a newly built road that connected formerly inaccessible rural areas to more urban areas in the Republic of Palau and found increases in non-agricultural wage-sector employment, reduced self-employment in agriculture, and decreases in the number of immigrants sent abroad (Akee 2006). Finally, the roads improvement project in Bangladesh cited above also found increases in total labor supply of both males and females in terms of monthly employment hours (Khandker et al. 2009).[3]

In contrast, the roads improvement project in Brazil did not change the composition of labor across sectors (Iimi et al. 2015). Agriculture was the dominant sector in all four regions, which could be one reason for not observing significant changes in labor composition. MCC's projects in Honduras also did not find any impacts on employment (NORC 2013a).

[2] Girls' attendance in these two regions decreased for both the intervention and the comparison groups, but the reduction was larger in the intervention group. The authors noted that the decline in attendance is likely related to the fact that the total number of children ages 5 to 9 years has been declining in the state of Tocantins, where the study was conducted. However, that does not explain why the decrease in attendance was significantly larger among the intervention group.

[3] The study did not specify whether there were changes in the composition of labor hours across different sectors.

Increased market access through roads improvements should, in theory, affect agricultural productivity but here again, the evidence is mixed. Although the highway improvements in the MCC evaluation in Georgia project found an increase in industrial facilities along the improved road segments, there was no change in land use or cropping patterns (NORC 2013b). The study did not measure impacts on agricultural productivity in areas farther from the improved road segments. MCC's Armenia project also did not find impacts on agricultural production during the short exposure period after completion of the road (Fortson et al. 2015). On the other hand, the roads project in Bangladesh, complemented by interventions to improve secondary markets, lowered fertilizer prices by 5 percent, increased aggregate crop prices by 4 to 5 percent, and increased agricultural output by 30 to 39 percent (Khandker et al. 2009).

d. Income and consumption

Many of the studies in this literature review measured impacts on income and poverty with results varying depending on the context. For example, some studies of tertiary roads have shown that these projects improve outcomes related to income and wealth. For example, in Mexico, the upgrading of feeder roads connecting peri-urban neighborhoods to the larger roads network increased property values by 17 percent (Gonzalez-Navarro and Quintana-Domeque 2015). The roads paving program in Mexico led to increased ownership of vehicles and home appliances and increased home improvements (Gonzalez-Navarro and Quintana-Domeque 2015). Ownership of cars also increased in the Republic of Palau and Brazil (Akee 2006; Iimi et al. 2015). It is possible that these increases represent a shift in consumption, as motorized vehicles are more useful with improved road conditions.

In Peru, rural roads rehabilitation in districts with high poverty rates led to a 35 percent increase in per-capita income for households near the rehabilitated rural roads (Escobal and Ponce 2004). Roads improvement in Bangladesh led to increased household expenditure (Khandker et al. 2009), and access to all-weather roads increased consumption growth in Ethiopia (Dercon et al. 2006. A study that examined density of roads and consumption found that higher density of roads was positively correlated with higher rates of consumption (Jalan and Ravallion 2002). These studies used modeling approaches to estimating effects, as opposed to using a counterfactual approach. (The Khandker et al. [2009] and Dercon et al. [2006 studies used household fixed-effect regression models, whereas the Jalan and Ravallion [2002] study used a regression model controlling for initial conditions).

Other studies report no significant income effects in the one to two-year post completion evaluation timeline (Akee 2006; NORC 2013b; Fortson et al. 2015; Iimi et al. 2015). MCC's Nicaragua project did not find impacts on the cost and availability of a basket of basic consumer goods at the establishments selling these products, but found increases in household consumption of perishable (dairy) and fragile (eggs) goods, indicating improved access to these products from improved roads conditions (Alevy 2014).

2. Broader economic effects of infrastructure investments

Measuring the effects of improving trunk roads and highways is challenging because the impacts are more diffuse, making the identification of credible counterfactuals difficult. At the same time, recent methodological advancements are making headway in addressing the challenge. In a seminal paper exploring the impacts of building India's railroad network in the

19th and early 20th century, Donaldson (2017) analyzes a new data set from archival sources to show that the rail network reduced trade costs and interregional price gaps, increased interregional and international trade, and improved income levels. In another study, using a combination of U.S. county-level data and Geographic Information Systems (GIS) data, Donaldson and Hornbeck (2015) also found that railroad access in the U.S. had a positive impact on gross national product.

Other studies confirm that transportation costs in Africa are an important constraint to economic growth. Atkin and Donaldson (2015) investigated the cost of distance in two African countries—Ethiopia and Nigeria, where transportation costs are high because of sparse and poorly maintained road networks compared to countries with more developed networks. They find that the costs of intra-national trade are approximately four to five times larger in these two countries than in the U.S. Similarly, Storeygard (2016) studied 15 countries in sub-Saharan Africa whose largest city is a port, and found that transportation costs have important impacts on the income of cities located near these ports. With night time lights satellite data, the study uses increases in oil prices from 2002 to 2008 as a proxy for per-kilometer transport costs, and finds that cities located close to a port benefited from lower transportation costs during this period, experiencing a 7 percent increase in income compared to similar cities located farther away.

Several studies examining the impacts of the entire roads network report shifts in production and labor from the agricultural sector to the non-agricultural wage sector. For instance, Banerjee and colleagues (2012) found that although new and improved roads in China improved agricultural productivity and raised income and consumption, they also took capital and skilled labor away from rural regions through migration. A study of the effect of a national rural roads construction program in India, which connected previously unconnected villages to the regional transportation network, decreased the share of households and workers in agriculture and increased the share participating in wage labor (Asher and Novosad 2016). Gollin and Rogerson (2014) also report similar findings in a multisector multiregion model, where higher transport cost contributed to a larger agricultural workforce and a larger fraction in subsistence.

Finally, the success of roads infrastructure projects is likely to be dependent on the country contexts in which the investments are made. Inefficiencies in local and regional markets can reduce or eliminate the potential longer-run effects of infrastructure investments for the intended beneficiaries in remote locations. For example, Casaburi and Reed (2013) investigated the impacts of a rural roads rehabilitation program in Sierra Leone and found that it lowered the price of rice and cassava. The impacts were stronger in areas farther away from large urban centers and with lower productivity, likely because improved road quality decreases the cost of reaching local markets where farmers and traders conduct business.[4] However, the price effects were lower in areas with better cell phone coverage, because reductions in travel times likely were less relevant in places where farmers and traders could exchange information using the cell phone network. Atkin and Donaldson (2015) investigated the extent to which the benefits of import price reductions were passed on to consumers in two African countries—Ethiopia and Nigeria. They found that intra-national trade costs rise substantially with distance in these two

[4] Areas with higher productivity have stronger demand from traders because traders can buy more in these markets for given transportation cost. A reduction in transportation costs increases demand from traders more in the lower productivity areas.

countries, suggesting that consumers in remote locations did not benefit from reductions in international prices. Because of higher transport costs, it is less profitable to sell products in remote locations, which results in less competition in the local markets. As a result, intermediaries are able to capture a greater fraction of the benefits of price reductions, leaving little to pass on to communities in remote locations.

Our literature review highlights the complexity of evaluating investments in transportation projects and the need for having a clear, context-specific theory of change. Not surprisingly, studies have been more likely to find effects on the proximal outcomes, such as increased traffic, reduced travel times, and reduced VOCs. However, impacts on other intermediate and longer-term outcomes depend on the context in which these investments are made. For example, improvements in access to health and education depend on the availability of related infrastructure. The timing of the evaluation also matters, particularly for longer-term outcomes such as income and consumption, when it can take several years after a project is completed for impacts to materialize; shorter-term studies have failed to detect impacts on these outcomes. Further, tying the nature of roads improvements to the relevant beneficiary population is very important. Beneficiaries, particularly of highway or trunk roads, are likely to be dispersed across the entire transportation network and not just along the improved road segments; it is important for the evaluation designs to capture benefits where the beneficiaries are located. Studies that examined upgrading of regional highways but measured impacts only for households along the improved road segments were unlikely to find improvements in economic activity and income. Finally, improvements in roads may fail to benefit the intended beneficiaries if there are market inefficiencies, in which case complementary context-specific investments or policy changes could improve the effectiveness of roads investments.

3. Contribution of this evaluation to the literature on roads investments

This evaluation of the Roads project will contribute to the literature on the impact of infrastructure by examining factors that affect the intermediate outcomes for roads investments. The traditional impact evaluation approach of identifying treatment and comparison groups has proved to be problematic and appears not to capture the full impacts of roads, in particular trunk roads and highways. Given the potential problems with these approaches that focus on a narrow segment of the beneficiary population, developing alternative ways to assess the performance of roads projects could guide governments and funders in assessing the costs and benefits of roads investments.

ERRs, estimated using HDM-4 or RED models (described in Chapter II), are commonly used to determine which roads projects to fund. These estimates allow decision makers to compare road segments to one another in terms of anticipated benefits and to conduct sensitivity testing to look at changes in outcomes under different assumptions. HDM-4 and RED are consumer surplus models, capturing a much fuller set of impacts of the roads than the quasi-experimental approaches but without disaggregating benefits by type and beneficiary. Applying HDM-4 and RED models to an ex-post performance assessment, as we discuss in more detail in Chapter II, could benefit future decision making on roads investments by testing and updating common ex-ante assumptions about roads' cost and benefits. The evaluation will also take a closer look at maintenance practices and could help MCC consider how to incorporate assessments of maintenance practices into due diligence process and pre-implementation ERR estimates. Finally, the impact evaluation design will attempt to develop a broader set of outcome indicators using satellite data that could add to methodological tools for measuring the impacts of infrastructure projects.

D. Organization of the evaluation design report

The remaining chapters of the evaluation design report describe our approach to addressing the key research questions described earlier in this chapter. In Chapter II, we describe our approach to the HDM-4 and RED analyses and its use in calculating the ERRs for the completed project. We describe the performance assessment of roads maintenance, road users, and transportation costs in Chapter III. Chapter IV describes the impact evaluation design using satellite data and other data sources. Chapter V describes our data collection approach. Chapter VI describes our evaluation administration and presents the updated work plan.

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II. ECONOMIC ASSESSMENT

A. Motivation and research questions

The economic assessment of the roads constructed under the Ghana I compact will reestimate the ERRs for the N1 highway improvement, the upgraded Agogo-Dome trunk road, and the 40 feeder roads. This evaluation will also compare the new ERRs with the pre-implementation ERRs, and assess the main underlying assumptions used to estimate benefits. Although we will generate new ERRs for each road type using HDM-4 or RED, the direct benefit streams from all road improvements are in principle the same. These benefits are reduced travel time for road users and reduced costs for vehicle operators. Per user benefits are scaled up by the increasing volume of traffic on the improved roads. Our recalculation of the ERRs will be based on collecting new data on road users and current road conditions in order to estimate the direct benefits of road improvements. The updated ERR calculations will also use information on actual construction costs and maintenance expenses, in order to produce a comparison of predicted and realized costs and benefits.

The economic assessment will use the HDM-4 model as its framework for estimating the ERR for the N1 highway improvement and the RED model as its framework for estimating the ERRs for the trunk and feeder roads.[5] We have chosen to use different models based on the traffic volumes and type of road being evaluated. The Agogo-Dome trunk road and the 40 feeder roads are mostly low traffic volume roads serving rural areas, whereas the N1 highway is a high-volume stretch of highway running through Accra. The choice of models also matches the pre-intervention ERRs, which will allow for meaningful comparisons between ERRs. Both the HDM-4 and RED models are built on a consumer surplus approach to measuring the benefits of road improvements, but HDM-4 is more complex and requires more data. Both models assume that the economic benefits generated by an improved road can be captured by the increased volume of traffic and the declining cost of transportation, as captured by a decline in VOCs and travel times on the improved road.

HDM-4 is a program that analyzes the economic viability of road transportation projects over their lifetime by simulating pavement deterioration, road user costs, and traffic over time, and trading this off against the costs of construction and periodic and routine maintenance. At its core, HDM-4 models the interaction between road users and road deterioration. Improvements or upgrades to a road allow for smoother driving, reducing damage to vehicles and allowing for faster travel. This, in turn, increases traffic along improved roads, as traffic may be diverted from slower, poorer roads, and as economic growth generates new traffic. However, traffic and general weathering lead to deterioration in the road over time, which again impacts road users. The model also estimates the effects of regular maintenance and upgrading on road condition. Using all these data, HDM-4 calculates the economic benefit of a road by multiplying the

[5] HDM-4 is a software program used to model the engineering and economic viability of roads projects. It is based on the Highway Design and Maintenance Standards Model (HDM-3), which was originally developed by the World Bank. The current version of the model is HDM-4 version 2, which was released in August 2005. HDM-4 is considered the industry standard for project appraisal and evaluation and is the product of extensive collaboration between international donors, research groups, and practitioners. The RED software is a program developed by the World Bank to model the economic viability of rural roads with traffic volume ranging from 50 to 300 vehicles per day. The software is built in Excel.

reduction in VOCs and travel time by the traffic volume along the road. These benefits are compared to the costs of construction and any maintenance programs to arrive at an ERR for specific roads or road segments.

The HDM-4 model is very adaptable, in that its parameters can be customized to reflect the local context. This process of tailoring the model to local conditions is referred to as "calibration" and is a critical first step in using the model to estimate economic impacts. Road conditions deteriorate differently around the world, depending in part on traffic loads, traffic volumes, climate, building standards, and construction materials. Likewise, important determinants of VOCs, such as the cost of new and used vehicles, the composition of a country's vehicle fleet, and the costs of fuel, replacement parts, and maintenance labor, can vary considerably. Selecting appropriate parameters ensures that the benefit streams from reduced VOCs and travel times are accurately estimated. The process of calibrating the model entails setting many of the assumptions that need to go into estimating the direct benefit streams from road improvements. The economic assessment will involve analyzing the calibration choices used in the pre-implementation HDM-4 model and comparing these pre-implementation assumptions with assumptions based on our newly collected data.

The RED model is a simpler alternative to HDM-4 for analyzing the economic viability of transport projects with relatively low traffic volumes. The key simplification in the RED model is that it does not model the deterioration of the road surface over time and as a function of traffic volume, instead assuming that the surface condition stays constant over the period of analysis. Like the HDM-4 model, the parameters of the RED model can be calibrated to match local conditions, such as the cost of new and used vehicles, the composition of the country's vehicle fleet and the costs of fuel, replacement parts and maintenance labor. The same data required to calibrate the HDM-4 model is used to calibrate the RED model. Once calibrated, the RED model generates a relationship between the roughness of the road surface and the VOCs and travel times experienced by road users. The estimated VOC and travel time savings from a road improvement are aggregated by the net change in traffic along the improved road to determine the aggregate annual benefit of the improved road.

In addition to assessing the main assumptions underlying the ERRs for the Ghana roads investments, this evaluation will aim to develop useful lessons for future implementation and evaluation of roads activities. We will use the HDM-4 model and RED model to address a number of other important subquestions related to comparing key outcomes from the pre-implementation ERRs to actual outcomes and the expected life of the road. We outline these questions and outcomes in Table II.1.

Table II.1. Overview of research questions, key outcomes, and analytical approach

Research questions	Key outcomes	Analytical approach
1. What are the ERRs now? How do the reestimated ERRs compare to the pre-implementation ERRs for the road segments? 2. Using actual measures of traffic, axle load, and realistic assumptions about road maintenance, what is the expected remaining life of the roads? 3. How sensitive are the updated ERRs to errors in key input data, such as traffic or maintenance, and what lessons can be learned for future ERR calculation?	• Traffic (annual average daily traffic [AADT]) • Road roughness (International Roughness Index [IRI])* • Vehicle operating costs • Estimated lifetime maintenance expenditures* • Capital costs	• HDM-4 project analysis: road condition and traffic forecasting and sensitivity analysis • RED model: economic analysis and sensitivity analysis • Comparison of the key outcomes, construction costs, time savings

*Outcomes would only be estimated using the HDM-4 model for the N1 highway.

The following sections describe how we will use the HDM-4 and RED models to reestimate the ERRs for the roads activities and address the research questions described above. First, we discuss the data sources for the analysis and our approach to sampling. Then we describe our analytical approach, which includes the calibration of the HDM-4 and RED models to the Ghanaian context, conducting the economic analysis, and conducting sensitivity testing using the calibrated model.

B. Data sources

The economic assessment will draw on a broad range of primary and secondary data sources to reestimate the ERRs for the roads activities and assess the validity of the initial assumptions of the pre-implementation ERRs around growth in traffic volumes and road deterioration over time[6]. The primary and secondary data sources for our economic assessment fall under three broad categories: road condition and inventory data, road user data, and other. The ERRs for the N1 highway will be estimated using the HDM-4 model. The ERRs for the trunk and feeder roads will be estimated using the RED model, which uses a subset of the variables and data required for the HDM-4. This section first lays out the data requirements for the HDM-4 and then lays out the subset of variables required for the RED model. Table II.2, below, shows the main variable types used in the HDM-4 model and the related data sources. Appendix B includes a more detailed list of calibration and input variables within each variable type, as well as our expected data sources.

1. Data requirements for HDM-4 model

The HDM-4 model uses many input variables and allows for numerous parameters of the model to be adjusted based on the local country context. It also includes default values for the model parameters that could be appropriate depending on the purpose and use of the analysis. Making a judgment about when to use default parameters and when to adapt the parameters is a critical part of model development and affects the reliability of the model output. Our approach

[6] Secondary data used in the economic assessment will come from a number of sources, including GHA and DFR, as well as MCC project documents, feasibility studies and completion report.

will be to calibrate those parameters to which the ERRs are most sensitive and those that vary most by context or across time, such as fuel costs or vehicle prices. HDM-4 defines these variables as the Level 1 parameters, which come from a combination of existing secondary data sources or from primary data (Bennett and Paterson 2000). In addition to focusing new data collection on the variables to which the ERR is most sensitive, we will rely on existing HDM-4 models used in Ghana or similar countries that are available to us. We propose to collect the following data as part of our primary data collection:

- **Roughness** will be measured using the International Roughness Index (IRI), which is a standard measure of road smoothness.
- **Surface condition** measures characteristics of the road surface, including the number and area of potholes, rutting, raveling, and other pavement defects.
- **Deflection** measures how a road surface and its underlying structure respond to impact, and will be measured using a Falling Weight Deflectometer (FWD).
- **Modified structural number** summarizes the structural property of each layer of pavement and pavement strength. It may be derived from deflection data combined with either data from core sampling or data from the construction specifications in the as-built drawings, or if unavailable, the design drawings.
- **Axle load** measures the average weight carried on a single vehicle axle; together with the traffic volume and composition, this is used to calculate the overall traffic loading on the road.
- **Traffic** measures the volume of traffic along the roads and the composition of traffic by vehicle type.
- **Vehicle unit costs** measure the costs faced by road users for various goods and services, including maintenance, spare parts, and fuel.
- **Vehicle fleet characteristics** measure the physical characteristics of the vehicle fleet, vehicle speeds, and prices.

Table II.2. Data sources for the economic assessment, by category

Variable category	Primary data sources and illustrative variables	Secondary data sources and illustrative variables
Road condition		
Pavement characteristics	**Engineering surveys** • Roughness • Percentage of road area that is potholed • Road thickness	**As-built drawings, road agency** • Shoulder and carriageway width
Road inventory	n.a.	**Road agency** • Road segment length • Surface type
Road works and activities	n.a.	**Road agency maintenance department** • Maintenance strategy (e.g., the area of road with potholes that triggers road agency repairs)
Road users		
Road user data	**Vehicle operator surveys** • Cost of vehicle • Cost of fuel	**Transport sector reports, road agency** • Number of axles, engine speed, power
Traffic data	**Traffic counts** • Annual average daily traffic (AADT)	**Historic data collection, feasibility reports** • Traffic growth rate
Other		
Project finance data	n.a.	**MCC project documentation, road agency maintenance departments** • Interest rates • Construction costs
Climate data	n.a.	**World Meteorological Association** • Average annual rainfall

2. Data requirements for RED model

The RED model requires a subset of the data required for HDM-4. These data are: roughness, traffic, vehicle unit costs, and vehicle fleet characteristics. The RED model requires data on traffic and roughness to estimate VOC and time savings. The model is calibrated using the VOC data collected through vehicle operator surveys, transport sector reports and information from the relevant road agencies. Benefit streams, as measured by VOC and time savings will be estimated using data on road roughness and road geometry. Finally, we will use estimates of the current traffic volume and composition to estimate the growth in traffic over the period of analysis. Data on current traffic volume and composition will be collected only on a sub-sample of the 40 segments of the feeder roads. The analysis will rely on baseline measures of the annual average daily traffic (AADT) that were collected before road construction, as well as new data on traffic volume to estimate traffic growth rates.

C. Sampling approach for new data collection

We will seek to streamline the data collection requirements while prioritizing the variables that are key to generating robust ERR estimates. We will balance this against the importance of learning lessons that can inform future economic evaluations of roads. To this end, we propose different sampling approaches for collecting data on the N1 highway, the Agogo-Dome trunk road and the feeder roads that match the requirements of the HDM-4 and RED models.

The **N1 highway** is a relatively short segment of about 14 km that represents a very important component of the overall ERR across all road projects in the compact. We therefore propose to collect primary data for the variables below along the full length of the road:

- **Roughness** along the full length of the N1 highway.
- **Traffic** at two points so that any segments defined by major interchanges onto the highway are covered.
- **Axle load** at mobile weigh stations and will cover both directions of traffic.
- **Modified structural number** will be calculated along the length of the road. We will use information on road thickness and layer composition from the engineering drawings, verified using minimal core samples across all roads (pending Ghana Highway Authority [GHA] approval), to determine the California bearing ratio (CBR) of the subgrade.
- **Surface condition** along the full length of the road, using a detailed manual surface condition assessment.
- **Deflection** along the outer wheel path of the outer lane, at intervals of 500 meters. Readings in each direction of travel will be staggered so that there will be a reading every 250 meters.

In contrast to the N1, the models we propose to use to estimate ERRs for the trunk and feeder roads require fewer data inputs. These roads comprise 42 segments across seven districts, with a total length of roads exceeding 400 km.

The **Agogo-Dome trunk road,** comprised of 2 consecutive segments, is in poor condition (based on our observations during our initial visit to Ghana), indicating possible problems with its construction. Furthermore there has been little change in traffic since the completion of the road. The closeout out ERR for the road is negative, therefore we do not suggest extensive data collection. We propose to collect the following data on the Agogo-Dome trunk road:

- **Roughness** along the full length of the trunk road.
- **Traffic** at one point on the road.
- **Surface condition** on the full length of the trunk road, using a network-level windshield survey approach. This will be complemented by manual surface condition assessments on a sample of short sections along the length of the road.
- **Geotechnical** data using small pits and dynamic cone penetrometer (DCP) testing at limited points on the road.

The **feeder roads** comprise 40 separate segments over about 357 km in seven districts. Given the high cost of collecting certain types of data separately on every segment, especially for variables such as traffic counts that have large labor costs associated with data collection, we propose to collect detailed data for a sample of the 40 segments. This data will be used both for calculating ERRs using the RED model and for reporting on the general condition of the roads. To estimate ERRs for non-sampled roads, we will consider data from similar sampled roads to be representative. We propose to collect the following data on feeder roads:

- **Roughness** along the full length of all feeder road segments.
- **Traffic** on a sub-sample of roads. Before selecting the sample, road segments will be grouped by region, baseline traffic volume and surface treatment. Roads will be selected for traffic counts from within each grouping. We expect to collect data from 12 traffic count stations across the 40 roads.
- **Axle load** at up to 5 mobile weigh stations on the selected sample of roads where traffic counts are planned and in the same location as traffic counts.[7]
- **Surface condition** on the full length of the trunk road, using a network-level windshield survey approach. This will be complemented by manual surface condition assessments on a sample of short sections along the length of the road.
- **Geotechnical** data using small pits and dynamic cone penetrometer (DCP) testing at limited points on the road.

We will use data from the sample of feeder roads to estimate ERRs for all feeder roads, and will apply traffic growth and changes in traffic composition as estimates for growth rates on similar roads. Running a careful economic assessment using data from a sample of these roads will likely generate the same lessons on improvements to the pre-intervention assumptions as collecting data and conducting the analysis on the full set of feeder roads. Learning about the effect of initial traffic assumptions on estimated ERRs is important for future decisions that rely on RED models for determining which roads to build. Likewise, an analysis of traffic volumes, loading and current condition can offer lessons on whether pavement designs were appropriate for local conditions.

We will work with GHA and the Department for Feeder Roads (DFR) to establish whether up-to-date, reliable secondary sources exist that can provide information on vehicle fleet characteristics, prices, and unit costs.[8] In addition to these secondary data, we propose to collect primary data on vehicle prices and unit costs of maintenance, replacement parts, and fuel from a sample of transport companies and repair shops. Where possible, we will use primary data to validate information on road users drawn from other sources.

D. Analytical approach

In this section, we describe the process for running the HDM-4 model for the N1 highway, followed by a discussion of the RED model for trunk and feeder roads, noting differences from the HDM-4 approach.

[7] We will determine whether to measure axle loads based on estimates of heavy traffic from the traffic count surveys.

[8] Based on our initial design trip, we understand that VOC data is kept by GHA. We will work with GHA to acquire this data at which point we will assess whether the quality of data is sufficient and when the data was collected.

1. HDM-4 approach for N1 Highway evaluation

HDM-4 analysis is based on the concept of road pavement life cycle analysis, which is made up of two models that interact with each other: the road user effects (RUE) submodel and the road deterioration and works effects (RDWE) submodel (Odoki and Kerali 2000):

- **RUE** models the impacts of the road quality on road users, which are measured in terms of road user costs and other social and environmental effects.
- **RDWE** models road deterioration and condition over time; it is predicted as a function of traffic volume and congestion, road pavement type and strength, maintenance standards, and environment and climate.

A first step in using these two models is to ensure that they are appropriately calibrated to the Ghana context.

Calibrating HDM-4 models

Calibration of HDM-4 ensures that the forecasts generated by the model are as accurate as appropriate for the required application. In general, this requires high quality data so the outputs generated by the model reflect the actual conditions and benefits of the roads. GHA, with support from the University of Birmingham has conducted a level 3 calibration of the HDM-4 model for Ghana. Where relevant, we will use the existing calibrated HDM-4 model provided by GHA.

HDM-4 sets out three levels of calibration, wherein each level reflects a greater degree of customization to the local context but also a greater burden in terms of data collection and analysis. As noted earlier, we will collect new data to update some of the Level 1 calibration parameters, because the ERRs are the most sensitive to these and because the data collection effort matches MCC's expected timeline for this evaluation. Data required for Level 1 calibration can typically be collected over the course of weeks. In contrast, Levels 2 and 3 calibration require months and years of data collection, experimentation, and analysis to determine calibration parameters more accurately, and are typically used for roads planning and program purposes (Bennett and Paterson 2000). The parameters that need to be updated include data such as vehicle fleet characteristics and operating costs.

Our proposed data collection for Level 1 calibration will help us determine the values of basic input parameters, adopt default values where appropriate, and calibrate the most sensitive parameters with best estimates from desk studies or field surveys. Appendix B includes the Level 1 calibration variables and indicates whether they will come from primary or secondary sources.

The choice of calibration parameters determines the outputs of the RUE and RDWE submodels and how the submodels interact. A large number of parameters can be adjusted in both the RUE and RDWE submodels; as part of our design, we identify the level of detail needed for the analysis.

- The RUE submodel predicts VOCs, travel times, safety, and environment. Level 1 calibration of these parameters are set using best estimates, desk studies, or minimal field surveys. Appendix B provides a detailed list of the Level 1 parameters that enter the RUE submodel and where we expect to collect the necessary data. For data that change frequently over time and/or are not up-to-date, we will collect the needed information via a vehicle operator survey.

- The RDWE submodel predicts the road pavement strength through the modified structural number, the deterioration of the road surface over time in response to use, as well as the effect of ongoing maintenance on road condition. As with the calibration of the RUE submodel, we will primarily use the calibrated model parameters provided by GHA. We will add data derived from as-built drawings, desk studies, and literature reviews; and stated maintenance practices drawn from GHA. We will also collect primary data on the road segments on key variables needed for the evaluation, namely on roughness, surface condition, and deflection. The calibration choices for the RDWE submodel will be refined in an iterative way by comparing the pavement condition predicted by the model to the observed data collected on road roughness and pavement surface condition. We will continue to adjust our assumptions until the model predicts the observed road condition data well.

In addition to primary data collected and used as part of the calibration of the RDWE and RUE submodels, we will collect data on traffic composition and volume, which we will compare with previous estimates of traffic volume derived from feasibility studies.

HDM-4 analysis and sensitivity testing

Once calibrated, the HDM-4 model can be used to analyze a variety of scenarios for the N1 highway. The model will report predictions for the evolution of VOCs, road condition, traffic, maintenance expenditures, and other key variables over the lifetime of the N1 highway. These outputs are compared to the base case alternative, in which road improvements are not conducted, to arrive at an ERR (Morosiuk et al. 2006). We will run these analyses to predict road condition and traffic on the N1 highway, and the costs and benefits incurred over time. We will then conduct sensitivity testing to illustrate how benefit streams change depending on the underlying modeling assumptions. Finally, we will compare the ERR from our ex-post model to the pre-implementation ERR, and adjust economic variables for inflation to the same year that pre-implementation models begins.

HDM-4 generates a number of reports as part of the analysis, including important outputs that we will present in our analysis. In particular, we will predict and plot annually, for the lifetime of the road, the following outcomes:

- Traffic volume
- VOCs and travel time
- Road roughness, measured in terms of roughness (IRI)
- Cost streams, measured as expected costs of maintenance

We will compare these predicted values to the original ERR analysis conducted for the N1 highway. In addition, we will compute a new ERR based on the updated HDM-4 models. We will plot the original predictions about traffic growth, road roughness, and VOCs against the updated estimates.

Sensitivity analysis is conducted in HDM-4 by rerunning the model using different basic assumptions. For example, we might rerun the model assuming that traffic levels are 20 percent lower than predicted or that construction costs are 50 percent higher than planned. We propose to test the sensitivity of ERR to assumptions about traffic growth, maintenance, and construction costs, since these variables often change over the course of a project or differ from initial predictions. We will present the results of the sensitivity analysis as a variety of different scenarios, and report the predicted ERR, road roughness, traffic volume, and cost streams for each run of the model. We will use the sensitivity analysis to derive lessons for future applications of HDM-4 for MCC projects and potentially help the Government of Ghana in considering future roads investments.

We will compare the updated HDM-4 model to the pre-implementation HDM-4 model for the road that we received from GHA. Although we can extract information on calibration choices from the HDM-4 workspace, we do not have detailed documentation about how the calibration of the original pre-implementation HDM-4 were justified. This may create difficulties in constructing a baseline version of the HDM-4 model using our data that exactly mimics the predicted traffic, road deterioration, and rates of return reported in project documentation and ERR. Instead, we will use sensitivity analysis to compare the model outputs using “corrected” post-implementation assumptions to the pre-implementation assumptions about traffic growth, road condition, construction costs, and maintenance. We will conduct a similar sensitivity analysis to test differences in ERRs when actual construction costs are used instead of projected construction costs in the cost-benefit analysis. We will also use data on roughness and surface condition to check whether assumptions about maintenance made during the initial modelling exercise are correct. We will assess the ERR, VOCs, and IRI over time for a variety of different scenarios, including comparing actuals to pre-implementation assumptions for specific variables.

2. RED model for feeder and trunk roads:

RED is an alternative model of economic evaluation customized to the features of low traffic volume roads. The RED model uses a simplified approach relative to HDM-4 by assuming that the road condition remains at a constant level over the period of analysis. It calculates benefits such as VOC and time savings, multiplied by the flow of traffic. Similar to HDM-4, VOC and time savings are defined as function of the roughness of the road, measured as IRI, to VOCs and travel speeds. The relationship between roughness and VOC and time savings is allowed to vary by vehicle type and by the geometry of the road. The overall benefit stream from an improved road is calculated by multiplying the traffic volume by vehicle type over the period of analysis and comparing the net benefits to the cost of improvements.

Calibrating the RED model requires gathering data on vehicle operating costs, maintenance costs, costs of spare parts and characteristics of the vehicle fleet, such as vehicle utilization and hours driven per year. All of these variables will be collected as part of the HDM-4 analysis of the N1 and we propose to use the same data sources in our calibration of the RED model. VOC data is entered into the spreadsheet and used to generate a cubic polynomial relating roughness to VOCs and travel speeds for different types of vehicles.

The functional relationship between roughness and VOC and time savings are combined with estimates of the composition of traffic and estimates of future traffic growth. The RED model calculates benefits for different types of traffic generated by the project. These types are:

- **Normal traffic** representing traffic in the absence of any investment.
- **Generated traffic** caused by existing road users driving more frequently because transport costs are lower.
- **Induced traffic** caused by local economic development attracting new road users,
- **Diverted traffic** caused by existing trips being travelled along the improved road, rather than an alternative.

The assumptions made about traffic growth rates are crucial for getting good estimates of the economic benefits of road improvements from the RED model. We will undertake classified traffic counts along the sampled feeder roads in order to get accurate estimates of current traffic and compare the observed levels of traffic with assumptions made about traffic growth in the pre-implementation ERRs. For feeder roads where we do not plan to conduct traffic counts, we will use growth rates estimated from similar sampled roads, in combination with baseline traffic counts, to estimate current levels of traffic.

After calibrating and running the RED model, we will conduct sensitivity analyses and compare the outputs of the model with the pre-implementation ERRs. In addition to comparing the ERRs, we will assess the accuracy of the initial assumptions made about the average roughness of the road and the growth in traffic over the period analysis. Because we do not have access to the initial calibration assumptions[9], we will not be able to make exact comparisons between the ex post ERRs and the pre-implementation ERRs. However, we will run the calibrated ex post ERR using assumptions made at baseline, to generate a meaningful comparison of the predicted VOC and time savings over the period of analysis resulting from differences in the initial assumptions. We will look for any systematic differences across ex post and pre-implementation ERRs to draw out lessons about the importance of the initial assumptions being made.

3. Data reporting and visualization

In addition to the estimation of ERRs, we will develop itinerary diagrams to display road condition, integrating GIS data, available pre-construction data, and primary data collected for the evaluation. For the N1 highway, this will include roughness, deflection, surface condition as well as the location of count stations and axle load stations. For the trunk and feeder roads, we will show data on roughness for all roads. We will report data on surface condition and pavement characteristics for the sampled roads.

E. Risks and mitigation strategies

There are two potential risks to the proposed economic assessment, which we describe below, along with our proposed mitigation strategies.

- **Access to administrative data.** The HDM-4 model has large data requirements and we will rely on GHA and DFR to provide us with secondary data. We will continue to work closely

[9] If the data behind the initial calibrations is made available, we will use this as part of our sensitivity analysis.

with our points of contact in these agencies as well as the Millennium Development Authority (MiDA) to ensure that we receive the roads authorities' cooperation.

- **Data quality.** The HDM-4 model and the RED model rely on good quality data, especially for the most sensitive parameters. We will work with primary data collectors to ensure that data quality is a key priority, and will implement a variety of quality control protocols. Because we rely on secondary data sources for a number of variables, we will also need to establish that these data are reliable. Wherever we have primary data that relate to the secondary data, we will conduct cross-checks. We will also look for secondary data collected in other similar contexts to validate the secondary data we receive.

III. PERFORMANCE EVALUATION

A. Motivation and research questions

The performance evaluation of the Ghana Roads project will complement the economic assessment of the roads investments by addressing important elements of the program logic that are not addressed in the HDM-4 and RED models. The pre-implementation ERR estimates for the roads assumed that the maintenance resources and capacities of the roads authorities in Ghana would be sufficient to maintain adequate road conditions over the predicted lifetime of the roads. The program logic also assumed that reduced VOCs and travel time savings would especially benefit agricultural production through competitive transport and agriculture markets, leading to increased traffic related to increased agricultural productivity. If the roads are not adequately maintained, roads condition would deteriorate sooner than expected and the economic benefits would not fully materialize. Similarly, if the transport and agricultural markets are not competitive, benefits of the project may not accrue evenly to consumers and producers. To assess program logic assumptions about the roads investments and to generate lessons for future roads projects, the performance evaluation will address the remaining following three overarching research questions outlined in Chapter I:

1. What are the current maintenance practices and how do they affect the ERRs of the improved roads?
2. Who is traveling on the road, and why? What are they transporting?
3. Are there VOC savings, and are they being passed on to consumers of transportation services?

B. Roads maintenance

Effective maintenance of roads investments is critical to ensuring that they realize their full economic benefits. Lapses in maintenance or inadequate maintenance can inflict a heavy cost burden on public agencies responsible for the roads and on road users. For example, the South African National Road Agency estimated that repair costs increase by six times the initial maintenance costs when maintenance is neglected for three years. This estimate rises to 18 times the initial maintenance costs after five years without maintenance (Burningham and Stankevich 2005). At the same time, maintenance is often delayed in developing countries struggling to fill multiple funding gaps. For every kilometer of road rehabilitated in sub-Saharan Africa, an estimated three kilometers of road falls into disrepair, leading to a net loss of the overall road network (Burningham and Stankevich 2005). As the cost to repair under-maintained roads increases, the benefits of the roads to road users, who have to deal with slower speeds and higher wear and tear on their vehicles, decline rapidly.

Road maintenance covers three main types of activities: routine maintenance, periodic maintenance, and emergency maintenance. Routine maintenance of paved roads includes ensuring proper drainage and making spot repairs, such as fixing potholes or sealing cracks. Routine maintenance is typically performed at least annually. Periodic maintenance is planned work and involves more intensive roads work, such as resealing or applying asphalt overlay for paved roads. Although the timing of periodic maintenance depends on road use, climate, and the quality of the original construction, periodic maintenance is typically needed every few years

(Schroeder 1990). Emergency maintenance covers repairing roads after unexpected events such as flooding. When a road has deteriorated past the point of periodic maintenance, it will likely need to be upgraded or reconstructed (Robinson and Thagesen 2004). All roads, from highways to unpaved rural roads, will likely require each type of maintenance over the course of their lives.

Roads maintenance is a multistage process requiring significant management and oversight. Governments need to monitor road deterioration throughout the network, ensure that there are sufficient funds for maintenance, allocate those funds effectively across the network, and, finally, manage specific maintenance projects so that they are implemented as expected. Donors supporting roads investment projects have attempted to identify and document standards and best practices for public maintenance activities (Gwilliam et al. 2009 Harral et al. 2011; Heggie 1994 Pinard 2015; Robinson and Thagesen 2004), including the following:

- Adequate, dedicated funding for maintenance generated through direct charges to road users or other sustainable revenue sources
- Political autonomy of those who oversee maintenance funds, such as through independent boards
- Prioritization of cost-saving routine and periodic maintenance activities on high-traffic roads that have the greatest effects on network-wide VOCs
- Implementation of maintenance projects by private contractors selected through competitive bidding processes
- Engagement of a variety of stakeholders in the planning, implementation, and oversight of maintenance (for example, through regional road user associations) to promote government accountability and public ownership of the roads network

Roads maintenance in Ghana is funded through the Roads Fund. The Roads Fund is financed via fuel levies, tolls, and vehicle license and other fees. The Roads Fund Secretariat oversees the Fund and is responsible for collecting revenue from these sources and managing the disbursement of funds across implementing entities under the Ministry of Roads and Highways (MRH), including GHA which is responsible for highways and trunk roads, DFR which manages feeder roads, and the Department of Urban Roads, which is responsible for urban road networks. As of 2012, these institutions were responsible for maintaining around 13,000 km of highways and trunk roads, 42,000 km of feeder roads, and 13,000 km of urban roads, respectively. Around 13 percent of these roads are paved (Pinard 2012).

In terms of the adequacy of funding, in 2015 Ghana's Deputy Minister for Roads and Highways reported that the Roads Fund could only sustain 60 percent of road maintenance needs in the country (Ghana Business News 2015). This large of a funding gap will likely translate into more costly maintenance needs in the longer term and increased vehicle operating costs for roads that require routine or periodic maintenance but are not prioritized to receive such limited resources.

Pinard (2012) previously applied the Commercialized Road management (CRM) framework, which integrates the best practices and provides a method to evaluate road management based on four core concepts: responsibility, ownership, financing, and management.

The assessment found that Ghana's road management was characterized by strong institutions, financial management, and contracting procedures. However, he also found that there was poorer quality control of roads projects, limited roads fund autonomy from the government (the Road Fund Secretariat is managed by a senior official in the MRH), and a lack of public ownership and oversight of the roads system through, for example, active road user associations. The different implementing entities use a database to track and prioritize maintenance needs. GHA uses a system called the Pavement Maintenance Management Program (PMMP) to inform decisions about allocating funds; the DFR uses a similar system, called the Maintenance Performance Budgeting System (MPBS). Pinard's analysis found that these roads management information systems were scored excellent, or good in most aspects, but the system's outputs were not considered reliable enough for planning purposes. Meetings during the evaluation design trip (in early 2017) also suggested that these databases were not up-to-date. For example, it appeared that the Agogo-Dome trunk road had not yet been logged in the system even though it was completed in January 2012.

Our assessment of maintenance practices addresses the first research question of the performance evaluation: What are the current maintenance practices and how will they affect the ERRs of the improved roads? The evaluation will use a mixed-methods approach that measures the current condition of the roads, road agencies' maintenance practices for the network, and MCC's program logic assumptions about maintenance outcomes. Table III.1 lays out more detailed subquestions for this part of the performance evaluation, as well as the data sources and key outcomes. The subquestions break down how the evaluation will assess maintenance funding and implementation using information from the HDM-4 and RED-related data collection, administrative data, and stakeholder interviews.

Table III.1. Roads maintenance subquestions, data sources, and outcomes

Research questions	Data source and type	Outcomes
1a. To what extent have government entities been able to raise adequate maintenance funding and predict funding flows?	• Roads Fund revenue and documentation—secondary • Roads Fund policy documentation—secondary • Stakeholder interviews—primary	• Roads Fund revenue and outlays
1b. To what extent do available maintenance funds meet the maintenance needs? How are these needs identified and how are funds allocated to meet those needs?	• PMMP and MPBS data—secondary • Maintenance policy documentation—secondary • Stakeholder interviews—primary	• Annual maintenance expenditures • Percentage of kilometers in the road network receiving routine/periodic maintenance per year • Percentage of kilometers in the network, by pavement condition over time • Percentage of projects prioritized by the PMMP MPBS that receive maintenance
1c. How is maintenance implemented? To what extent is it implemented according to plan? Have maintenance planning processes changed since the start of the compact?	• Stakeholder interviews—primary • PMMP and MPBS data—secondary • Maintenance policy documentation—secondary	• Planned versus actual expenditures • Percentage of maintenance projects completed on time/within budget • Comparison of maintenance of roads similar to the improved roads.

Research questions	Data source and type	Outcomes
1d. What is the ERR of the N1 highway under different maintenance scenarios and how sensitive is it to different maintenance practices?	• Road condition data (HDM-4 inputs)—primary/secondary • Sources for maintenance scenarios - Stakeholder interviews—primary - PMMP, MPBS, and Roads Fund data—secondary - Maintenance policy documentation—secondary • Axle loading data—primary	• Adjusted ERRs under different maintenance scenarios • Variance in adjusted ERRs • Percentage of large commercial vehicle axles that are overloaded • Equivalent Standard Axle Load (ESAL)

1. Data sources and outcomes

The data sources for the maintenance questions outlined above will include a combination of primary and secondary data from a number of sources. Outcomes for the performance evaluation of roads maintenance will be based on analysis of (1) administrative data, (2) interviews with maintenance officials and specialists in Ghana, (3) axle loading data, and (4) road condition engineering data collected as part of the economic assessment.

- **Official records of maintenance budgets and expenditures,** including data on Roads Fund revenue and extracts from the PMMP and MPBS databases used by GHA and DFR, respectively, and possibly regional road and transport authorities in areas where feeder roads were upgraded. We will use Roads Fund data to develop outcome measures for maintenance funding, such as annual Roads Fund revenue. We will request PMMP and MPBS data for the past five years, focusing our analysis on the period from compact end to present. We will review all secondary data received for completeness and quality. If we find that the PMMP and/or MPBS databases are indeed incomplete or out-of-date, we will rely primarily on road condition data collected as a part of the economic assessment, and supplement these data with additional key informant interviews (KIIs) or a brief stakeholder survey related to key outcomes. However, where PMMP and MPBS data is available and of reasonable quality, we will use them to develop outcomes for maintenance implementation, such as the percentage of kilometers of road in the network in need of maintenance and the percentage receiving maintenance.
- **Government and Roads Fund documents** on maintenance policies and practices: we will request and review documents such as annual maintenance plans, annual road works reports, Roads Fund performance reports, legislation governing the Roads Fund and road management agencies, strategic plans for the transport sector, guidance for road works contractors, and internal or donor-generated assessments of road management agency performance.
- **Key informant interviews (KIIs)** with staff from the roads maintenance agencies and other specialists in Ghana. These will include representatives of the MRH, GHA, DFR, the Roads Fund Secretariat, regional roads authorities, and those involved in maintenance contracting and implementation. We will develop protocols for the interviews based on recommendations from the maintenance literature on best practices in managing and maintaining national and regional roads networks. In particular, the interviews will aim to capture information on the quality and timeliness of information in the PMMP and MPBS;

how roads maintenance allocations and decisions are made, particularly in a resource constrained environment; how maintenance contracts are issued; oversight of maintenance works, including the quality control and auditing processes used for maintenance projects; and so on.

- **Axle loading data** will come from the axle load survey conducted on the N1. We will conduct up to five axle load surveys on the trunk road and the feeder roads depending on estimates of heavy traffic from the traffic counts. The survey will measure outcomes such as the weight and the number of axles of a sample of commercial freight vehicles traveling along the MCC-funded roads.
- **Road condition data.** These data will come from the primary and secondary engineering data sources used to run the HDM-4 and RED models and estimate the ERRs, as described in the previous chapter.

2. Analytical approach

Our evaluation of roads maintenance will largely consist of an assessment of maintenance funding, planning, and expenditures. We will also assess the extent to which the Ghana maintenance system is aligned with best practices for road management, and will consider differences between the N1, trunk, and feeder roads, as appropriate. Our analysis will examine the following:

- **Maintenance funding.** The Roads Funds are the primary source of funding for maintenance activities in Ghana, and adequate funding is an essential precondition for maintenance planning and implementation. We will compare revenue from the Roads Fund over time, focusing on projected and actual revenues collected since the end of the compact. We will incorporate inflation estimates to assess trends in maintenance funding in real and nominal terms. We will also track indirect measures of demand for maintenance, such as expansion of the overall roads network. These comparisons will inform whether the availability of funding over time has kept pace with demand.
- **Maintenance planning and expenditures.** Using road condition data collected for our HDM-4/RED analysis, we will assess the current condition of the roads upgraded by MCC and determine if routine and periodic maintenance has been carried out as needed. We will also analyze stakeholder perspectives on decision making around the allocation of maintenance funds, assessing how different perspectives align with information on road conditions. If available in the PMMP and MPBS data, we will attempt to assess the maintenance backlog of the roads network over time (measured in terms of the share of roads in poor, fair, or good condition), and whether the share of roads falling into poor condition or needing rehabilitation is increasing.
- **Maintenance implementation and oversight.** To assess how effectively the roads maintenance funds are used, we will start by comparing planned spending on maintenance to actual spending. KIIs will supplement the comparison and provide insights into the reasons for differences in planned and actual spending. We will compare the maintenance policies described in documents and stakeholder interviews to best practices. Based on available documentation and KIIs with maintenance officials and other stakeholders, we will also try to obtain an understanding of the contracting process, the extent to which projects

experience overruns or delays, and how maintenance authorities check programs through audits or other checks. Where possible, we will review roads that are similar to those upgraded through the compact, but that were improved less recently.

- **Axle load analysis.** The amount of pressure that large commercial vehicles exert on the road and how it is distributed across a vehicle's axles has important implications for the degree of maintenance required and the life of the road. We will analyze the axle load survey data and compute two key measures of truck overloading—the percentage of vehicles that are overloaded, and the degree of overloading in terms of weight per axle. We will compare these with policies on axle loading to see if loading policies are being enforced. Where available, we will compare reports of axle loads from the feasibility studies that MCC and MiDA commissioned prior to construction of the roads to those collected in our survey. This comparison will inform whether current use patterns are in line with the anticipated capacity of the road.
- **Road condition.** We will identify other causes of deterioration through the assessment of visual data collected from the field (e.g., photographs/video of drainage systems), and structural analysis. For the N1 highway, the structural analysis will estimate the strength and load-bearing capacity of roads using deflection data and characteristics, such as thickness and strength, of both the pavement and underlying layers. We will then estimate the remaining life of the N1 by comparing the stress and strain exerted on the pavement by the current traffic load with the findings of the structural analysis.
- **HDM-4 simulation for the N1 Highway.** HDM-4 includes assumptions about road maintenance practices, which in turn influence the predicted rate of deterioration over time. These assumptions specify maintenance work triggered by road deterioration or periodic and routine maintenance practices. The model then factors any costs incurred or maintenance into the ERRs. For the N1 Highway, we will use HDM-4 to simulate the effect of different assumptions about maintenance practices in Ghana, comparing the stated practices from the GHA and MRH with data from our analysis of the PMMP and MPBS, road agency expenditure, and backlog analysis.

  As we test the sensitivity of the HDM-4 model, we will define a set of maintenance scenarios based on observed road conditions and maintenance requirements over the last five years. These scenarios could include (1) a fully funded, "best case" scenario where all maintenance can be completed; (2) a "realistic" maintenance scenario, reflecting actual maintenance as indicated in administrative maintenance records; and (3) a "worst case" scenario that might occur if the taxes and levies underwriting the Roads Fund were cut substantially. We will use these different maintenance scenarios to modify the maintenance-related inputs to the Maintenance Standards in our HDM-4 model, rerun the model, and report the ERRs that result.

Finally, the output of these analyses will help the evaluation team identify potential lessons for future roads performance assessments and for developing assumptions about maintenance in the due diligence process of MCC roads investments.

C. Road users

This component of the performance evaluation will address the second main research question: Who is traveling on the road and why? What are they transporting? Are there VOC savings, and are they being passed on to consumers of transportation services? The program logic assumes that cheaper and increased movement of people and goods as a result of project activities will lead to greater economic activity and growth, especially in the agricultural sector, via greater access to markets. Roads improvements that facilitate transportation and goods to markets that are cheaper and more efficient benefit both producers and consumers. In particular, the program logic expected that expanded access to agricultural markets would generate greater aggregate sales for cash crop producers as more buyers are incentivized to access markets.

The performance assessment for this question will involve using data on traffic volume and traffic composition from pre-implementation feasibility studies. It will also use data collected for the economic analysis and from road users on their travel purpose and patterns through the expanded vehicle intercept survey. In addition, we will conduct focus groups in communities along improved and unimproved roads to discuss changes in transportation since completion of the roads activities. We will select comparison trunk and feeder roads from the roads that were selected for upgrading, but were dropped during project re-scoping.

These data will allow us to compare the present-day traffic with assumptions about economic activity and market access that the roads investments were intended to produce. As feasible, we will assess changes in traffic composition and volume by comparing the new traffic counts to those collected prior to implementation and at the end of the compact. Data from the expanded vehicle intercept survey will allow us to conduct a descriptive analysis of who is using the road and how, including information on the origin and destination of individual travelers and their trips, purpose, and frequency. In addition, the information acquired from the focus groups discussions provide perspectives on how transportation options and roads use have evolved since the completion of the roads. Below, we describe the main outcomes and data sources for this aspect of the evaluation, as well as the analytical approach we will use.

Table III.2 lists the outcomes and data sources for the road users assessment and links the outcomes to the research subquestions.

Table III.2. Traffic and road users research questions, data sources, and outcomes

Research questions	Data source and type	Key outcomes
2a. How many and what types of vehicles are traveling on project road segments?	• Classified traffic counts on improved roads— primary • Traffic counts from the feasibility study—secondary	• Traffic counts • Traffic composition • Estimate of AADT
2b. Who are the road users, where are they traveling, and why are they using project road segments? Have travel patterns changed since the roads were improved? Are there differences in transportation options between improved and unimproved roads?	• Expanded vehicle intercept survey on improved roads—primary • Focus group discussions with communities near improved and unimproved roads	• Road user demographic characteristics • Origin • Origin activity categories • Destination • Trip purpose categories • Travel direction • Trip frequency categories

Research questions	Data source and type	Key outcomes
2c. How long does it take road users to move along key routes? What alternative routes or modes of transportation do road users use?	• Expanded vehicle intercept survey on improved roads—primary • Focus group discussions with communities near improved and unimproved roads • HDM-4 and RED estimates of time savings	• Time per unit distance traveled • Alternative routes • Alternative modes of transportation categories
2d. What are freight carriers (trucks) transporting? How many passengers and what kinds of goods are passenger transportation services carrying? What is the capacity for each?	• Expanded vehicle intercept survey on improved roads—primary	**Freight carriers:** • Cargo type • Vehicle capacity • Number of crew **Passenger transportation services:** • Number of passengers, seats • Number of crew
2e. Where are passengers in commercial vehicles traveling, and what are they paying for transport?	• Expanded vehicle intercept survey on improved roads—primary	• Passenger origin and destination • Fare charged (GH¢)

1. Data sources and outcomes

The outcomes data related to road users will come from three sources: (1) traffic counts, (2) expanded vehicle intercept surveys, and (3) focus group discussions.

- **Traffic count data,** an important input to the ERR analysis, will also inform the performance evaluation. Traffic counts provide data on traffic volume and traffic composition that will enable the performance evaluation to assess how many people and vehicles are currently using the improved road segments.
  - **Traffic volume.** Data on volume of traffic on upgraded project roads will come from the primary classified traffic counts. We will convert traffic counts into standard volume measures including estimates of Average Daily Traffic (the average number of vehicles passing a specific point during a 24-hour period) and AADT (the total volume of vehicle traffic of a road segment for a year divided by 365 days). Total volume in the calculation of AADT is typically estimated using seasonal adjustment factors. The traffic counts will take into account market days and seasonality considerations. They will also disaggregate traffic by time of day and day of the week (for example, weekday versus weekend), and will indicate directional movement of traffic volume.
  - **Traffic composition.** The traffic count survey will assign a class to each vehicle using the categories from the road traffic count survey (RTCS) of the pre-implementation feasibility studies to facilitate any potential pre-post analyses of traffic composition. Vehicles in the RTCS were disaggregated into motorized and nonmotorized vehicles; motorized vehicles were further disaggregated into passenger and goods vehicles. Passenger vehicle categories include cars, utility vehicles, two-wheel vehicles, and buses. Goods vehicle categories include light trucks, medium trucks, heavy trucks, semi/full trailers, and tractors. Bicycles and carts make up the two main nonmotorized categories.

- The **Expanded Vehicle Intercept Survey** will interview drivers and/or passengers of commercial and private vehicles traveling on the N1, trunk road, and sampled feeder roads. It will also capture pedestrians and non-vehicular use of the road on the feeder and trunk roads. The survey will include two modules as described below:
  - **Origin-destination (O-D) module** will collect details on the origin and destination of each respondent's trip, including the trip purpose, such as travel to home, work, school, leisure, or commercial activities. The survey will also collect data on travel direction, trip frequency, travel time between the trip's origin and the interview point, and basic driver and vehicle characteristics.[10]
  - **Road users module** will collect data on an expanded set of questions about the road users, including information on cargo, costs, alternative routes, and household or business travel patterns. For trucks and other freight vehicles, we will gather information such as cargo type. For passenger vehicles, we will gather information on the number of passengers, capacity, and passenger destination and fares charged. We will also gather descriptive information from road users to obtain their perspectives and opinions about the road and their travel options and how they use them.
  - We will pre-test the road users module to understand the level of detail we can collect from drivers and passengers over various periods of stoppage time (we understand that up to 10 minutes is a tolerable amount of time for a vehicle intercept survey in Ghana, but this will need to be confirmed during pre-testing). We will use this information to determine the optimal length of both modules given the information we hope to obtain from the survey.
- **Focus group discussions** will be conducted in select communities along the improved roads as well as along comparison roads segments selected from the set of roads that were identified but not selected for improvement after the compact rescoping process. The discussions will involve interviewing community members about transportation in their area since the upgrading of project roads. In particular, we are interested in learning respondents' perceptions of changes to transportation availability and options, transportation use and costs, access to markets and social services, and travel times to access markets and services. We will use data from the feasibility studies and compact rescoping to guide the selection of communities within which to conduct the focus group discussions, and classify responses into subgroups such as where focus group participants live (for example, close to a commercial center or more remote).

2. Sampling for the expanded vehicle intercept survey

The expanded vehicle intercept survey will be carried out on three days per road, including both a market and nonmarket day. On the N1, we will randomly sample approximately 1,000 vehicles. This translates into approximately 0.5 percent of all traffic moving in both directions along the road. We anticipate that our proposed sample size on the N1 will allow us to estimate O-D outcomes, including the share of inter- and intraregional traffic, with a sampling error of 2.5 percent or less (see Appendix C for methodology).

[10] Details on the categories of information collected are included in Chapter V.

On high-traffic feeder roads (more than 1,000 vehicles per day), we will aim to sample 20 percent of all vehicles traveling along the road. This proportion of traffic falls between the 10 percent rate that is considered adequate for descriptive studies and the 50 percent that is recommended for surveys used to predict future travel patterns; a 20 percent survey rate has also been used for previous traffic surveys in Ghana (Hajek 1977; Damsere-Derry et al. 2016). For the trunk road and most feeder roads with a lower traffic volume, we plan to sample a larger proportion of vehicles.

We will use data from traffic counts and survey pre-tests, and consult with our data collection partner to finalize our selection of traffic stations, survey days and durations, and sampling rates to ensure that our final sample will permit us to estimate O-D and other key outcomes with adequate precision. The interview rate will be expanded to daily totals using the volumetric count totals.

3. Analytical approach

The analytical approach to using information from the various data related to road use will involve developing several comparisons related to understanding the movement of goods and people on the road segments and how the roads improvements may have contributed to it. These comparisons include the following:

- **Pre-post analysis of traffic volume and composition.** As described in Chapter V, where possible, we will conduct traffic counts in similar locations as the counts conducted for the feasibility studies. This will allow us to examine changes in traffic volume and composition over time. Although these comparisons would not determine the impact of the project on traffic volume or composition, we would be able to measure whether traffic volume has significantly increased since the Roads project was completed.
- **Origin-destination matrix.** Using data from the vehicle intercept surveys, we will construct O-D matrices for various roads to analyze current road usage patterns. An O-D matrix illustrates travel patterns and demands by mapping trip origins and/or destinations located within a region (see the example in Table III.3). In practice, it would start with local market towns, moving up through regional centers and then to the greater Accra area, and then to international destinations, indicating the routes that are the most heavily used. These travel patterns within and across subregions can reveal information about the types of economic activity in the region. For example, if there are increases over time in travel on a project road originating in the interior of the region and ending outside a district contiguous to an international border, it could suggest that international trade was facilitated by the project. The O-D matrix also allows for an analysis of trip length and intra- and interzonal traffic patterns.

Table III.3. Illustrative O-D matrix

	Destination				
Origin	Within region	Accra	Other regions	International	Total
Within region (%)	16	14	27	0	57
Accra (%)	15	NA	0	0	15
Other regions (%)	23	0	1	0	24
International (%)	0	2	0	2	4
Total (%)	54	16	28	2	100

Note: Frequency counts are illustrative, and not based on historical O-D data from Ghana.

- **Descriptive analyses of road users.** Using data from the expanded vehicle intercept survey, we will conduct descriptive analyses of road users, for example, of how they are using the road, and what they are transporting. To understand economic activity of road users, we will use the O-D data to estimate the percentage of traffic devoted to agricultural production, travel to social services, other productive activities such as wage labor, and leisure activities, and the frequencies with which these types of trips are made. We will also describe results from qualitative questions about alternative routes and road users' opinions about transportation options and changes in road user travel patterns since the improvements of the roads. The analysis will look at direction of travel on project roads, alternate routes and modes of transportation, and (as applicable) cargo and passenger capacities and freight charges and fare costs. These will be presented in graphical illustrations, disaggregated by key subgroups such as road segment, vehicle type, and economic activity. We will also disaggregate data by gender, education, and other indicators for socioeconomic status.
- **Access to markets and social services for communities along the roads.** Conducting focus group discussions along improved and unimproved roads will allow us to solicit perspectives on how travel patterns have changed over time and whether road users have more access to transportation options and/or markets. The purposeful selection of communities from locations near improved and comparison roads will allow us to get a better understanding of who is benefiting from the roads and changes over time, and to what extent.

D. Transportation cost savings

High transportation prices and costs are a major obstacle to economic growth in sub-Saharan Africa (Teravaninthorn and Raballand 2009). The program logic assumes improved roads will lower transportation costs in Ghana by reducing travel times and VOCs, particularly maintenance and fuel. In a competitive transportation market, reduced costs and the opportunity to earn larger profits should encourage more providers to offer transportation services. The increased competition would then put downward pressure on consumer prices and encourage transportation operators to pass on cost savings to consumers.

However, market imperfections such as barriers to entry often obstruct competition in African transportation markets, and policies and regulations such as subsidies and price ceilings can distort markets, preventing prices from adjusting to changes in costs. Such price rigidity can prevent cost savings from being passed on to consumers. Even if VOC savings are effectively passed on to consumers by traditional operators or by new competitors entering the market, measuring these cost savings poses a considerable challenge. There are likely multiple factors that influence freight costs and passenger fares other than VOCs. This aspect of the performance evaluation will address the third main research question: Are there VOC savings, and are they being passed on to consumers of transportation services? Table III.4 below outlines our related subquestions for assessing what happens to transportation cost savings, with the data sources and key outcomes.

The transportation cost section of the performance evaluation will gather information on transportation service prices and fares from transportation operators, as well as qualitative information on the Ghanaian transportation market structure from key informants within agencies and organizations including the GHA, MRH, and the Ghana Private Road Transport Union. Data from the expanded vehicle intercept surveys will help us check cost data from these sources and inform whether there are more transportation options available to consumers.

Table III.4. Transportation cost savings research questions, data sources, and outcomes

Research questions	Data source and type	Key outcomes
3a. Have vehicle operator costs been reduced since the upgrades to project road segments?	• Administrative transportation fare data—secondary • Transportation service operator interview data—primary • Expanded vehicle intercept survey on improved roads (passenger module)—primary • Vehicle unit costs data—secondary	• Historical transportation fares • Service operator characteristics • Passenger fares charged (GH¢)
3b. Are vehicle operator cost savings being passed on to consumers? Are more transportation services available to consumers?	• Administrative data on the Ghanaian transportation market structure—secondary • KIIs with government ministries and regional transportation departments—primary • Interviews with transport company officials and operators—primary • Focus group discussions	• Qualitative administrative information on transportation rules, regulations, and subsidies • Qualitative information on how fares and tariffs are determined, and opinions on price fluctuations and price elasticity • Operator costs and fares • Perspectives on transportation options

1. Data sources and outcomes

We will draw on the following data sources to create the key outcomes needed for the analysis of transport costs savings:

- **Administrative data.** Data from the MRH, GHA, the Ministry of Transport, and relevant trade unions will allow us to document historical and current fares along improved roads. These data should include information on transportation fare rules, regulations, and subsidies.
- **Transportation service operator interviews.** We will conduct KIIs with officials from government ministries and regional transportation departments to understand how fares and tariffs are determined, and develop questions that examine transport price fluctuations and

elasticity. We will also interview staff at major transport and cargo companies and collect data on their operation costs and fares.

- **Outputs from HDM-4 and RED analyses.** We will use VOCs generated from the HDM-4 and RED analyses to assess changes in the costs incurred by drivers.
- **Expanded vehicle intercept survey.** The expanded vehicle intercept survey, described in the previous section, will also provide data on passenger origin and destination and fares charged.

2. Analytical approach

As noted above, improved roads should lead to costs savings for transport companies and private vehicle owners, which are ideally passed on to customers in the form of lower fares and freight charges. The analytical approach for this piece of the performance evaluation will first start with whether there were indeed cost savings to transport companies and other vehicle owners; if so, we will try to assess whether some of these savings resulted in lower costs for consumers given the current transportation market structure in Ghana.

- **Vehicle operator costs.** HDM-4 and RED measures expected reductions in VOCs given the current road conditions. We will use the output from these analyses to understand and analyze the extent to which operators of different vehicle types benefit from lower costs. This will help us determine whether it is likely that costs have gone down along the improved roads segments.
- **Transportation market structure.** Our analysis will focus on understanding the influence that existing policies and market imperfections may have in limiting observed transportation cost savings from being passed on to consumers. Data collected through document reviews and interviews with key transport sector staff on transportation fare rules, regulations, and subsidies will help us understand the regulatory environment, gather perspectives on the main cost drivers in the market, and identify which channels of cost savings might be passed on to consumers and what market imperfections may limit such pass-ons. The focus group discussions in communities near improved and comparison roads may also provide additional insights into how the transportation market has changed over time.
- **Transportation fares.** We will analyze trends in historical transportation fare data for evidence of fare changes, and map them against external factors identified above. Examples of external factors we may identify include changes in fuel prices, inflation, as well as other large-scale infrastructure upgrades. The elasticity or rigidity of fares to past external shocks may suggest how responsive fares might be to the upgrades made to project roads. We will supplement this analysis with the passenger fare data collected by the expanded vehicle intercept survey and the transportation fare information we collect from the interviews with MRH staff and fleet operators.

3. A note on prices data

NORC conducted a baseline price survey in approximately 300 markets prior to the construction of the feeder roads. The survey collected data on prices of agricultural goods, non-agricultural goods and transport tariffs were collected from each of the markets. Markets in localities with a population greater than 1000 were selected for the treatment group, with a comparison group selected using a matched comparison design. The treatment group was defined broadly; it included 154 markets in localities that are within 120 minutes of the feeder roads upgraded under the Compact. This resulted in the selection of localities that were on average 2.2 km from the upgraded roads and up to 12 km away from the upgraded roads. Comparison groups are located throughout the country.

Our evaluation design does not include a follow-up prices survey for two reasons. First, price data in the baseline does not identify where goods were produced. Data on origin of production is rarely possible to collect, except for goods which have a known location of origin such as a single factory or are imported through the main port. Without knowing where goods were produced (and the price they were sold for), the evaluation will not be able to assess whether prices have changed because of reductions in transport costs from improved roads or other factors. Second, the approach to identifying treatment localities leaves few localities that could be used as a sample. Judging from the map of treatment locations and upgraded roads in the baseline report, and the fact that many localities are far from improved roads, it is unlikely that the improved roads serve the selected localities directly (Struyk et al. 2010). Given these issues with the initial design, we are not recommending to follow up on the initial baseline.

E. Risks and mitigation strategies

There are a number of risks to our proposed design, resulting mainly from our reliance on administrative data and potential challenges with vehicle intercept surveys. We can address these challenges through alternative analysis approaches and additional data collection.

The primary risk to the maintenance analysis is that administrative records may not be available or not of sufficient quality and level of detail to generate a clear picture of maintenance. We will mitigate this risk to the quality of the evaluation by supplementing the administrative data with additional interviews with key stakeholders to systematically gather information on maintenance expenditures.

A risk to the road users analysis is that we may not be able to use the data from feasibility studies to conduct a pre-post analysis of traffic volume and composition because sites and data do not meet the needs of the current evaluation. Where possible, we will mitigate this risk by using the same count sites, and will collect similar primary data using similar methods. Where pre-implementation data either do not exist or cannot be replicated, we will still conduct descriptive analyses of traffic characteristics and try to benchmark them with other existing studies in Ghana.

Another risk is that the challenging logistics of the expanded vehicle survey could affect the quality of the data. In particular, stopped vehicles will be anxious to move and we cannot ask them the number of questions required to get a complete, detailed picture of their transport patterns. We will mitigate this risk by carefully pre-testing the survey and getting road user input as we develop the survey instrument and test it before it is fully rolled out. We also plan on limiting the duration of the survey to under 10 minutes, which seems feasible based on input from conversations with experts in Ghana. We will conduct extensive enumerator training, develop a clear, effective protocol with police for flagging down cars to prevent traffic disruption, and develop effective sampling strategy (for example, flagging down groups of vehicles).

The transportation cost analysis is vulnerable to poor quality or limited data on transportation fares and vehicle operator cost data. If high quality fare data are unavailable, we will rely more heavily on interviews with agency staff and companies, acknowledging the limitations of our findings using these data in any reports. We will also triangulate across data sources when overlapping information is available.

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IV. IMPACT EVALUATION

A. Motivation and research questions

In addition to estimating the economic return of the roads, MCC is interested in learning about the impacts of the investments on economic growth and poverty reduction. However estimating the impact of roads is challenging because the decision to invest in a road relates to location-specific characteristics, such as economic potential or political importance, which can make it difficult to identify a credible counterfactual. Despite the economic justifications for building roads, many studies find little or no impact of roads projects on income and poverty in communities and households located near feeder roads. This may be due to study design, for example by not providing a long enough follow-up window after roads construction or by selecting inappropriate comparison roads. Yet another complicating factor is that roads improvements often have small individual impacts spread across a broad set of beneficiaries, making traditional impact measurement a significant challenge.

The use of remote sensing data has the potential to overcome some of the challenges encountered in previous impact evaluations of roads. Satellite-based measures of economic activity and poverty can be powerful, inexpensive alternatives in cases where survey data are either unavailable or too costly to collect (Jean et al. 2016; Henderson et al. 2012). Further, satellite data are collected over a long period of time and across a broad area, which means they can be used to generate a baseline in cases where surveys or traditional data collection have not been done. We propose to use this type of data, together with information on how roads were selected for construction, to evaluate the impact of the feeder road upgrades in Ghana.[11] The Ghana roads evaluation, coupled with a similar evaluation in Tanzania, presents an opportunity to evaluate the impact of feeder roads investment in two countries and to help develop evaluation approaches for future infrastructure projects.

This chapter presents a proposed impact evaluation design for the feeder roads activity, and the main research question we aim to address is:

- What was the impact of feeder roads improvements on economic activity and income in the areas served by the roads?

To address this question, we propose developing a satellite-based measure of poverty across various locations and points in time, which will be used as an outcome variable in a regression analysis to estimate project impacts. The approach we propose is the same as we are proposing to use to estimate the impact of MCC's road improvements in Tanzanian rural communities. Applying this approach in both Ghana and Tanzania will yield efficiencies in developing the satellite-based measures while providing a second context for establishing the methodology. This approach will enable MCC to understand the impact of road investments on poverty reduction while also advancing the use of satellite data methods to evaluate infrastructure projects. Further,

[11] We are not proposing an impact evaluation for the N1 highway because this section of road represents a unique link in the Ghana highway network and that there is not likely to be a credible counterfactual. We may incorporate the trunk road into the impact assessment if traffic counts show a substantial increase in traffic.

these analyses will present some bounds on the size of impacts that can be detected using satellite-based measures to evaluate the impacts of feeder roads.

B. Background and overview of evaluation

Recent work in measuring the impacts of transportation infrastructure on economic activity has shown that the availability of satellite data can help overcome the difficulty of identifying a counterfactual, through the availability of data over a wide geographic area and across time. The long time span enables analysis of changing outcomes before and after infrastructure investments are made, and the wide geographic coverage allows for the selection of counterfactual comparisons across space. In mostly urban and suburban areas, nighttime light imagery is used to derive light intensity which serves as proxy for economic activity. However, nighttime lights data is of limited use in measuring economic activity in rural areas, especially when these areas are not sufficiently electrified. A potential solution is to employ daytime satellite imagery to estimate the income and poverty in rural areas. Jean et al. (2016) combine survey and satellite data from five African countries (Tanzania, Malawi, Nigeria, Rwanda, and Uganda) to create a proxy measure for economic activity that can explain up to 75 percent of the variation in survey-based economic outcomes.

We propose to build on the work of Jean et al. (2016) to estimate the impacts of the feeder roads investments in Ghana. We will employ newly developed machine learning methods to derive poverty measures from daytime satellite imagery. These methods have been used to estimate decade-scale poverty measures for Tanzania, Malawi, Nigeria, Rwanda, and Uganda and this evaluation will use several advances in the field to produce annual-level measures for locations near the improved roads. We will then estimate regression-adjusted differences in poverty levels between locations near improved roads and those near similar but unimproved roads, flexibly controlling for time variation via year fixed effects. The set of comparison roads will be drawn from a list of feeder roads that were designed and planned as part of the compact, but not ultimately built after the compact was rescoped due to increased costs.

The rest of this chapter describes in more detail the data sources for the evaluation, the construction of satellite-based measures, the proposed framework for analysis and methodological approach, and the proposal for identifying comparison roads.

C. Data Sources

We propose several data sources for this impact evaluation, and below we outline our plan to generate proxy measures of poverty and economic activity using satellite imagery.

1. Nighttime lights imagery

Several researchers have used nighttime lights data to estimate national income (Henderson et al. 2012) as well as income in sub-national regions (Baum-Snow et al. 2015). Previous studies have shown that nighttime lights can explain cross-country difference in income growth (Henderson et al. 2012), as well as differences in income at the sub-national level for less developed countries (Baum-Snow et al. 2015).[12] Recent work by Storeygard (2016) has shown that nighttime lights can be used to estimate the relationship between changing transport costs within countries and economic growth. While we are not using nighttime lights data as an outcome variable for this evaluation, it is a crucial input into the machine learning algorithm as described below.

Economic activity in a given location will be estimated using satellite imagery of light emitted at night from human settlements. Because of the wide geographic coverage and long timespan, the nighttime lights data will be a key input in our machine learning approach to measuring poverty with daytime imagery. We will use imagery collected by the United States Air Force Defense Meteorological Satellite Program (DMSP) and distributed by the U.S. National Oceanic and Atmospheric Administration (NOAA). The DMSP satellites use an Operational Linescan Sensor (OLS) to measure light at night every night across the globe. Light intensity (from cloud-free composites) is reported on an annual average basis for each pixel after non-stable light sources, such as forest fires or moonlight reflecting on clouds or water, have been removed. Each pixel represents 0.86 square km at the equator (pixel size decreases further from the equator) and is assigned a digital number (DN) representing light intensity.

We propose to use DMSP-OLS data from 1992 until 2012 and will extend the DMSP-OLS time series to 2016 by using nighttime light data collected from a different sensor that has been available since 2012. This data is collected using the Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band (DNB), which is carried by a satellite operated by the Suomi National Polar-Orbiting Partnership (Suomi NPP). The NPP-VIIRS data is processed and distributed by NOAA. The NPP-VIIRS data is available on a monthly basis, is more granular (0.54 square km spatial resolution), and can measure a greater range of light intensities.

2. Daytime imagery

Daytime imagery will be used to construct measures of assets and consumption in rural and peri-urban areas, which are unlikely to be electrified and their light emissions too faint to be robustly detected. Our evaluation approach involves training a machine learning algorithm to recognize patterns in the Landsat 30m resolution daytime imagery that correlate with location-based measures of household assets and consumption derived from traditional surveys. The Landsat program is run by NASA and the U.S. Geological Survey, and provides a long-running time-series of daytime imagery collected using visible light sensors. We will use patterns in the daytime imagery to predict poverty in locations and time periods where we have daytime imagery but not survey-based measures. The surveys we will use to train and test the algorithm include the Demographic and Health Survey, with rounds conducted in 2003, 2008, and 2014; the Ghana Living Standards Survey (GLSS, 2005-2006 and 2012-2013) and Socioeconomic Panel Survey (2009-2010). This set of surveys provides broad coverage in terms of time and locational sampling, enabling us to train the aforementioned algorithm on data from many points in time and across Ghana.

[12] Nighttime light (NTL) data does not perform well in explaining differences in GDP growth across American cities because most cities have reached the highest level of intensity that can be measured by the DMSP-OLS sensor.

3. Feeder Road Network Information

In addition to satellite imagery, we will collect geographic data on the feeder road network in the regions where MCC built roads. We will work with the DFR, and the GHA to compile data on the local feeder and trunk road network. We will use this data to generate measures of proximity to major markets in each region. If available, we will incorporate historical data on road surface and road quality, as well as previous upgrades, to measure the travel time to the nearest major market[13]. We will use data from the Expanded Vehicle Intercept survey described in Chapter III to assess the validity of this assumption. We will also use data on origins and destinations, as well as information on what is currently transported on the roads, to establish which major markets are most important. Travel times will be estimated by making an assumption about the travel speeds that can be achieved on different types of road surfaces and estimated using the quickest path to travel between locations on a road and key market destinations.

4. Data for developing and testing the poverty measures

We will use several sources of data to develop and test our poverty prediction methods including nighttime lights and consumption and poverty data. The consumption and poverty data will come from a pooled sample of traditional surveys (multiple DHS rounds and various rounds of the GLSS nationally representative survey), Landsat 30m (or comparable) imagery, and a variety of potentially relevant covariates (selected to serve as control variables, e.g., elevation). The machine learning approach designed to predict assets and consumption can use satellite and survey data from both rural and urban areas, including data on nighttime lights.

In rural areas, we plan to explore and contrast different parameterizations for the construction of poverty measures using daytime imagery, building on the approach used in Jean et al. (2016) which uses convolutional neural network (CNN) approaches to the spatial estimation of poverty. This method has been successfully implemented for five countries in Africa, but has only estimated levels of assets over a coarse (decadal) time-span. By integrating additional sources of daytime imagery, alongside local surveys, we will identify the best parameterization for the construction of poverty measures in low-light areas, as well as assess the spatial and temporal granularity at which such estimates can be generated with high degrees of accuracy.

We will first identify the best model parameterization (based on our ability to predict in-sample data through bootstrapped validation) to estimate annual-level asset and consumption measures for each pre-intervention year in which we have survey data: 2004 and 2008 for DHS, 2005/2006 and 2012/2013 for GLSS, and 2008/2009 for the Socioeconomic Panel data. Based on the findings from the pooled cross-sectional model, we will conduct an out-of-sample prediction to locations that were not surveyed in these surveys and for years through 2016.[14] As DHS data

[13] This measure of travel time relies only on data collected on travel times and origins and destinations. It does not use VOC data collected as part of the Vehicle Operator Survey.

[14] In conjunction with ongoing work being carried out by researchers at Stanford University, we may opt to train the algorithm to identify changes in poverty levels (i.e., 2008-2014) rather than baseline levels. We would then use the algorithm to predict the changes in poverty between 2008 and 2016 (and narrower windows) directly, rather than

is also available for 2014 and GLSS data will be available for 2016/2017, we may also seek to train and validate algorithms including these rounds but subsampling the latter to only include locations far from the treated roads (to ensure our prediction is not biased by the actual intervention). We will also explore the feasibility of generating measures for a set of preceding years to test for comparability in pre-trends.

The primary model we will explore parameterizing will be a specific flavor of artificial neural network (ANN), which is CNN. This model, part of a suite of "transfer learning" approaches (Pan and Yang 2010), identifies features in the Landsat daytime imagery that are predictive of nighttime lights—with the latter being an available but noisy proxy for economic well-being in rural areas—and then uses these daytime features to predict sparser consumption and asset measures that are available from surveys. This approach outperforms nighttime lights imagery in predicting variation in economic well-being in Africa in rural area, and Jean et al. (2016) show evidence that a model built using data from one African country can make accurate predictions when applied to other African countries where the model had not been trained. This suggests that our approach can be used to reasonably predict poverty and well-being in countries and regions where validation data are unavailable and within regions of a country where we do not have survey data available.

As a part of this analysis, we will prepare and integrate a large set of candidate ancillary datasets in advance of the data analysis steps. Table IV.1 below lists several pieces of data to be assessed for inclusion. These data sources will (a) enable the identification of candidate control and treatment locations near the improved roads by comparing pre-investment characteristics in the data, (b) enable the estimation of travel-time, as a proxy for access-to-markets, and (c) provide ancillary variables to promote more accurate estimates of impact by controlling for confounding factors.

Table IV.1. Key data sources

Domain	Source	Topic	# of Obs.	Current coverage: Temporal	Current coverage: Spatial	Spatial resolution
Human Development	VIIRS	Nighttime lights	N/A	1992-2016	Global	Grid cell (1km; 250m)
	AidData	International Aid	>2 Million	~1990-2015	Global	Variable
	gROADS	Road networks	N/A	1980-2010	Global	Grid cell (~1km)
Politics	GeoEPR	Political exclusion of ethnic groups	>4 million	1946-2014	Global	Ethnic group boundaries
	GADM	Administrative units	>200,000	1990-2014	Global	Admin unit
	AfroBarometer	Multiple survey questions regarding perception	>30,000	Variable rounds	Africa	Variable

calculating these differences from annual-level predictions of the baseline poverty level. This would base the estimation of changes in poverty on additional temporal data, although it would not use the MCC baseline (as no comparable follow-up data is available). The determination of which approach to take will be based on their predictive performance.

Domain	Source	Topic	# of Obs.	Current coverage: Temporal	Current coverage: Spatial	Spatial resolution
	WDPA	WDPA Environmental protection areas	220,453	2015	Global	Variable
Demography	GPW	Population	N/A	1990-2020 every 5 years	Global	Grid cell (5km / 1km)
	GRUMP	Urban/rural settlements	N/A	1990-2010	Global	Grid cell (1km)
	SRTM	Elevation / Slope	N/A	2000	Global	Grid cell (500m)
	MODIS	Land cover and Fire	N/A	2001-2012	Global	Grid cell (1km)
	UDel	Air temperature & Precipitation	N/A	1900-2014	Global	Grid cell (50km)

D. Analytical approach

1. Empirical specification

Because feeder roads usually provide access for rural areas, we adopt a specification that focuses on estimating impacts on communities that live near to the road. Our base specification will estimate regression-adjusted differences in poverty levels between locations near improved roads and those near similar but unimproved roads, flexibly controlling for time variation via year fixed effects. We will use comparison roads as defined below and the pixel-level as our primary unit of analysis to estimate the following specification in levels:

$$Y_{irt} = \alpha + \beta Post_t * T_r + D_i + D_t + \epsilon_{irt}$$

where Y_{irt} is the outcome for pixel *i* near road *r* in year *t*, $Post_t$ denotes whether the road segment improvements have been completed, T_r indicates whether the nearest road is in the treatment group, and D_i and D_t are fixed effects for pixel and year that control for confounding cross-sectional and common time factors.

While we adopt this as our primary specification, we also recognize that it is possible that the feeder roads improvements may affect more distant populations as well. We will therefore also extend this model to address two key (and related) questions:

1. Do the benefits of the road improvements accrue primarily to those living closest to the roads (say, within a few km), or do they reach farther populations as well?
2. If the benefits reach farther populations, how should we adjust our sample construction to account for spillover effects to neighboring communities?

To address the first question, we will explore the heterogeneity in treatment effects within the treatment group. To do so, we will add an interaction between our main treatment measure and the distance from each pixel to the nearest road. Thus, we will estimate a regression model of the following form:

$$Y_{irt} = \alpha + \beta Post_t * T_r + \lambda Post_t * T_r * Dist_{ir} + D_i + D_t + \epsilon_{irt}$$

In this model, $Dist_{ir}$ is the linear distance between the pixel and the road segment. We will thus be able to assess whether, say, only communities within 1 km of the road experience gains, or whether more distant ones do as well. If we find large treatment effects still accrue at the 5 km distance, we may extend our sample further out to assess at what distance these gains dissipate.

To address the second issue related to spillovers, we will make two adjustments. First, we will estimate a continuous treatment model, in which our measure of treatment is the change in travel time from each location to a set of urban destinations. We will estimate the following specification:

$$Y_{irt} = \alpha + \beta TravelTime_{irt} + D_i + D_t + \epsilon_{irt}$$

$TravelTime_{irt}$ reflects the mean time required for a vehicle to reach the nearest major urban destinations, calculated using the road network and vehicle speeds associated with the road surface quality. This measure captures spillovers in which locations not immediately near the improved road nonetheless experience reductions in travel time because the improved segment serves as their main route to access a key destination. We will describe this measure for an expanded sample that includes both buffers along the matched comparison roads as well as buffers extended in both directions from the improved segments. This will allow us to assess whether there were spillovers that were not estimated in our primary model both by indirectly treating our comparison units as well as by undercounting indirectly treated but nonsampled areas. Our second correction for spillovers involves adjusting our standard errors to account for the resulting autocorrelation in unobservables. To do so, we will estimate spatially lagged standard errors (a la Conley 1999).

All versions of the model measure aggregate impacts of roads on consumption and assets, making it challenging to link the impact evaluation to key proximate outcomes such as reduced vehicle operating costs and travel times for road users. We will use results from the economic analysis, which separately estimates travel time benefits and VOC benefits, to provide an indication of which channel could be driving any impacts on consumption and assets we observe.

2. Selection of comparison roads

The analysis approach outlined above relies on the identification of rural areas located along comparable roads that were not upgraded. We propose to use the roads from a list of feeder roads that were planned and designed as part of the compact, but which were not built because of compact rescoping. Table IV.2 shows the number of segments and kilometers which were built compared with the number of segments and kilometers, which were planned, but not built.

Table IV.2. Planned and built feeder road segments in the Ghana Roads Project

	Number of segments		Number of km	
Region	**Built**	**Not built**	**Built**	**Not built**
Northern	9	15	110	145
Eastern & Central	20	18	146	136
Volta	11	4	101	45

We will assess the suitability of the comparison roads by comparing pre-intervention data on satellite-based poverty rates and income for locations near comparison roads with locations near the roads that were upgraded.

Given that the roads that were ultimately selected for construction were prioritized in the compact rescoping process, it is possible that the comparison group may not be a valid counterfactual. In this event we propose two alternatives. The first approach is to use the ERRs calculated for the built and not built roads to select a subset of roads from within each region that have similar ERRs. The second approach is to use matching techniques to identify rural areas, near feeder roads that have similar baseline characteristics to the areas where MCC roads were built. We would use data on the type of road serving the area and pre-intervention satellite-based poverty measure as the basis for this matching exercise.

3. Steps involved in carrying out the evaluation

To complete the evaluation, the team take the following steps. We will need to acquire road network data from the Department of Feeder Roads in addition to data on roughness and surface type. If we are not able to obtain electronic records or shape files of the road network, we will need to digitize the maps we have received to date. And if we cannot access data for the entire country, working with regional data may be sufficient. After obtaining the roads data, we will develop measures of market access reflecting each location’s weighted average time required to reach other urban markets (weighted by market size) following Donaldson (2016). These measures will capture the changing access due to the MCC-funded road improvements.

We will then develop the poverty measures by obtaining daytime satellite imagery (Landsat 30m time series record) and developing the machine learning algorithm to generate annual poverty estimates. This analysis builds on Jean et al (2016) in developing a convolutional neural network. We will use the Landsat 30m imagery combined with the assets reflected in the geo-referenced Ghana Living Standards Survey to generate annual asset estimates. The final analysis will incorporate additional geospatial data for theory-informed heterogeneity, by merging additional data on agricultural production, climate, and other features and use these to test theoretical predictions about the heterogeneity of treatment effects. Finally we will analyze the main treatment effects due to improved market access and theory-informed heterogeneity tests.

E. Simulation-based power calculations

We use a simulation approach to determine whether the satellite-based consumption measurement strategy is likely to have sufficient statistical power to detect impacts of the road investment projects. Since our estimation method and research context is the same as we are proposing to use for rural communities in the Tanzania roads evaluation, we use the same simulation-based approach to calculate statistical power. We do not use data from Ghanaian household surveys in part because our Tanzanian data includes a measure of the distribution of consumption growth from a long panel dataset. We also believe that data from rural household surveys in Tanzania is similar enough in context to be sufficient to show statistical power for the Ghana evaluation.

Our simulation-based approach involves three steps. First, we develop a probabilistic model of satellite-based consumption data over time that includes a hypothetical treatment effect of road investment on household consumption. The model of satellite-based consumption is based on data from the Tanzania National Panel surveys in 2008 and 2014-15 and factors in additional statistical noise that arises from using satellite-based measures as a proxy for consumption. Second, we use this model to simulate a dataset for 1000 grid cells over 5 years. Finally, using the simulated data, we run a fixed effects regression model to estimate the treatment effect of the road investment and determine whether the treatment effect is statistically significant at p-values of 0.01, 0.05 and 0.1 We repeat the final two steps 1000 times and report summary statistics on how frequently the treatment effect estimate is statistically significant at p-values of 0.01, 0.05 and 0.1. Our simulation approach tests how frequently a hypothetical treatment effect on household consumption of 0.025 (2.5%) would be detected. This effect size is considerably smaller than the projected increase in daily traffic used in MCC's pre-investment ERR models.

1. Simulation specification and data sources

We model four processes as part of the simulation model: i) impacts, ii) initial log annual consumption, iii) annual change in log consumption and iv) satellite-based annual log consumption. Impacts occur along ten road segments, with 100 grid cells associated with each segment, for a total of 1000 grid cells assessed for impact over a five year period.[15] Each road segment is assigned for intervention in a randomly selected year during the first four years of the five year period. A panel dataset is constructed in which each cell receives a treatment binary of 1 during post-intervention years, and a 0 in pre-intervention years. In addition to the treatment data, each cell has data simulated along three additional dimensions.

We distinguish between true measures of consumption, which are unobserved and satellite-based measures, which are observable, but statistically noisy measures of true consumption. True initial log annual consumption is modelled using the mean and standard deviation for the rural subsample of the Tanzania 2008/9 National Panel Survey. Unobserved, true initial log annual consumption is modelled as:

$$Y_{i,t=1} = N_i(\mu = 9.8, \sigma = 0.6) \qquad \text{eq.1}$$

where $Y_{i,t=1}$ represents the unobserved true mean annual consumption level for cell *i* and time period 1.

We model subsequent true consumption levels using mean changes estimated in the Tanzania 2014/15 National Panel Survey and distributional parameters on the changes in consumption from Beegle et al. (2011).[16] Unobserved, true annual change in log consumption is modelled as:

[15] The grid cells used in our final analysis will be 30m x 30m, thus providing more than 11,100 cells within 1km of a 10km long road segment. Even if we limit the analysis to only villages along road segments and assume a given village is 1km squared, we will have more than 1000 cells per village, and likely many times that many along a given road segment.

[16] Beegle et al. (2011) use a panel dataset of rural households in Kagera, Tanzania that followed households over a longer duration than the National Panel Survey, making it a better source for the distributional parameters for changes in consumption.

$$C_{i,t} = N(\mu = 0.05, \sigma = 0.15) + \rho * \epsilon_{z,i} \qquad \text{eq. 2}$$

where $C_{i,t}$ represents the unobserved change in consumption levels at cell *i* during year *t*, $N(\mu = 0.05, \sigma = 0.15)$ represents a random value drawn from a normal distribution with a mean of 0.05 and standard deviation of 0.15[17], ρ a parameter for the maximum error (set to 25%), and $\epsilon_{z,i}$ an error term estimated to approximate a within-road intervention correlation of 0.3:

$$\epsilon_{z,i} = N_z(\mu = 0.0, \sigma = (0.3) * 0.15) + N_i(\mu = 0.0, \sigma = (0.7) * 0.15) \qquad \text{eq. 3}$$

where N_z is the component of error that is held constant across all cells *i* which are attributed to road *z,* and N_i the component of error unique to each cell *i*. We then model subsequent levels of consumption based on these changes:

$$Y_{i,t>1} = Y_{i,t-1} * (1 + C_{i,t}) + \theta * T_{i,t} \qquad \text{eq. 4}$$

where $Y_{i,t>1}$ denotes log annual consumption in time periods after the first, θ the hypothetical treatment effect (2.5%), and $T_{i,t}$ a binary value indicating if cell *i* was considered treated at year *t*. Parameters for the initial time period are drawn from equation 1.

Finally, we model the observed, satellite-based consumption levels for each period as a function of the true consumption levels using distributional parameters from Jean et al. (2016). The observed satellite-based annual log consumption is modelled as:

$$Y^*_{i,t} = Y_{i,t} + (Y_{i,t} * U_{i,t}(0.25, 0.45) * B(-1,1)) \qquad \text{eq. 5}$$

where $Y^*_{i,t}$ is the value of change in log consumption a researcher might observe when leveraging satellite-based approaches to the detection of consumption[18], $Y_{i,t}$ the simulated log change in poverty calculated following equations 3 and 4, $U_{i,t}(0.25, 0.45)$ a random (uniform) noise term applied based on the reported variance satellite data can explain in log consumption (see footnote 2), and $B(-1,1))$ a binary random (uniform) draw of a -1 or 1 to adjust for the potential negative and positive directionality of errors.

[17] See parameters drawn from Beegle, Kathleen, Joachim De Weerdt, and Stefan Dercon. "Migration and economic mobility in Tanzania: Evidence from a tracking survey." *Review of Economics and Statistics* 93, no. 3 (2011): 1010-1033.

[18] Parameters are drawn from Jean, Neal, Marshall Burke, Michael Xie, W. Matthew Davis, David B. Lobell, and Stefano Ermon. "Combining satellite imagery and machine learning to predict poverty." *Science* 353, no. 6301 (2016): 790-794, who found that 55% to 75% of the variation in average household asset wealth across five countries in Africa could be explained by satellite modeling (following a cross-validation procedure). The random noise term applied here represents potential variance due to the remaining 45 to 25% of unexplained variance; a uniform term is chosen as a conservative estimator.

2. Results

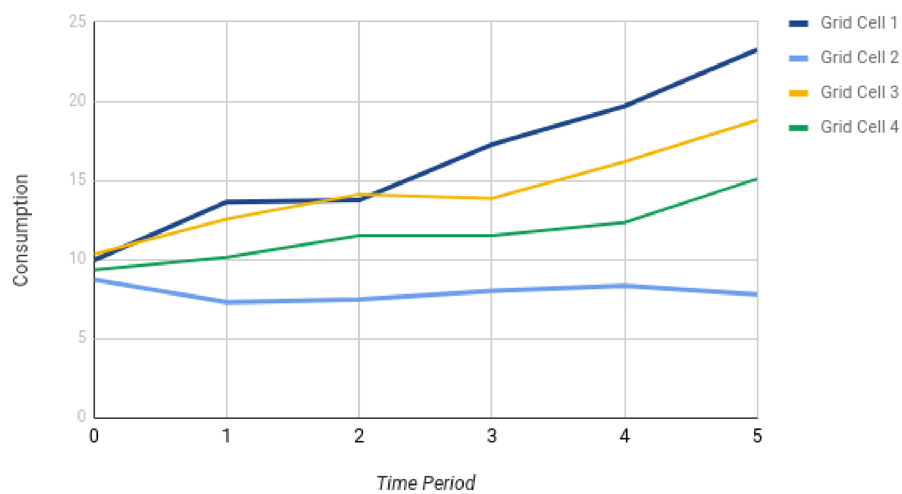
After Y^* is generated, a linear regression model is fit to estimate the impact of the hypothetical road intervention on each plot i:

$$Y_{i,z,t} = \alpha + \theta T_{i,t} + D_t + D_z + \epsilon_{i,z,t}$$

This model reflects the type of model we propose to use in our analysis. A two-step procedure is followed in which first a standard linear model is fit (including an intercept term and road-level fixed effects), and then a heteroskedasticity robust covariance (HC1) is used to re-estimate standard errors and concomitant p-values. Each iteration the p-value at which significance would have been found is recorded.

We ran 1,000 simulations following the procedure outlined above. As an illustrative example of the model, Figure IV.1 below shows the outcome of equation 4 for four randomly selected cells (plots). For θ = 0.025, the distribution of p-values at which significance would have been identified was recorded, as well as the percentage of times significance would have been found at the 0.01, 0.05 and 0.01 levels, respectively. At p <= 0.01, significance was found in approximately 88% of all simulations. At p <= 0.05, significance was found in 90.7% of simulations; at p <= 0.1 it was found in 92.5% of simulations.

Figure IV.1. Example simulated consumption levels



Note: Consumption is measured as the log of consumption and time period is measured in one year increments.

These findings suggest that a satellite-based approach to measuring consumptions has a strong likelihood of detecting true effects, even with relatively small treatment effect sizes. An effect could be detected even while accounting for potential errors in measurement, heteroskedasticity, and both year and intervention fixed effects. This provides sufficient confidence that there is adequate power to detect even quite small effects.

F. Risks and mitigation strategies

There are two potential risks to the proposed impact evaluation, which are described below, along with proposed mitigation strategies.

- **Availability of administrative data.** Some of the models we propose to estimate use measures of travel time and distance that rely on road condition and GIS data on trunk and feeder road networks. We have requested road network data from DFR, but have not been successful to date in obtaining electronic versions of the road network maps. This could signal that receiving comprehensive data on roughness and surface type could also be a challenge. It is possible that some of the road condition data is missing and we are unable to credibly estimate travel times. If this is the case, we will have to adapt or drop our analysis that includes travel times. Missing road condition data will not affect our ability to estimate the main model specification.
- **Poverty measures may be noisy.** Our evaluation design builds on a method that has successfully generated accurate consumption and asset measures that can detect differences across low-level administrative units. We propose to estimate consumption and assets at annual rather than 5- and 10-year time spans. There is a risk that our models may produce noisy estimates of consumption and assets, which would prevent us from detecting impacts of the program. We mitigate this risk by including a broader range of survey data in the machine learning algorithm, including two types of surveys (DHS and GLSS) that range across a number of years. By training the machine learning algorithm to predict consumption and assets across years and survey instruments, we expect to reduce the noisiness of the imagery-based measures and increase the likelihood of detecting a program impact.

V. DATA COLLECTION

In this chapter, we detail our data collection plans for the economic and performance assessments including our data sources and the proposed approach for collecting or obtaining data. As described in previous chapters, the evaluation of the Ghana I Roads Project will draw on a diverse set of data sources to respond to the evaluation questions. As outlined in the guiding principles described in Chapter I, we have developed a plan for high quality and cost-efficient data collection that adheres to both Ghanaian and international standards and enables credible and actionable evaluation findings. We will prioritize primary data collection efforts for variables to which the ERRs are most sensitive and those that vary most by context or across time, in order to obtain robust ERR estimates. As described in Chapter II, we propose a different data collection scope for the N1 highway and for the trunk and feeder roads because the HDM-4 model, used for the economic analysis of the N1, has greater data requirements than the RED model, used for the economic analysis of the trunk and feeder roads.

We organize our proposed data collection approach in three sections: (1) primary quantitative data (roads condition data, and road user data); (2) secondary data, including program administrative data and other data drawn from program documents; and (3) qualitative data obtained from KIIs and focus groups. For each of these data sources, we start with a description of the data and our measurement approach, followed by our approach to collecting high quality data. We end the chapter with a summary of our data quality plans.

A. Primary quantitative data

To estimate the projected ERRs and conduct the performance evaluation, we will collect information on road performance, including primary data on pavement quality, traffic volume, travel times, and VOCs. We separate our description of our primary quantitative data collection approach into engineering roads data, road user data, and VOCs to mirror the inputs for our HDM-4 modeling. Table V.1 provides a summary of the associated equipment/instruments needed, as well as anticipated data collection plans for each road. Because we anticipate using RED for trunk and feeder roads, some variables for HDM-4 analysis will only be collected for the N1 highway. We describe each of the data collection approaches in greater detail below.

We end the section with a description of our data collection process, including our future engagement with an engineering subcontractor and our intended approach to working with the road authorities and relevant government entities on data collection tasks.

Table V.1. Quantitative data sampling, instruments, and quality control

Data type	Sampling	Relevant instruments/ equipment	Illustrative Quality Control Protocols
Roughness*	Full length of N1 highway, trunk and feeder roads	Roughometer from the Ghana Highway Authority	Link roughness data to GPS readings. Review all raw and treated data. Photographic evidence of field application
Deflection	Full segment of the N1 highway, at 500m intervals	Falling Weight Deflectometer	Relative calibration of FWD. Photographic evidence of field application. Spot checks by local consultant.
Geotechnical	Full segment of the N1 highway at 1km intervals. At one or two points along trunk and feeder roads	Dynamic Cone Penetrometer Coring drill (N1).	Testing and spot checks by local consultant. Photographic evidence of field application
Surface condition	Full segment of the N1 highway (manual condition assessment). Full length of trunk and feeder roads (network-level windshield survey)	Visual inspection using manual assessment (N1) and windshield survey (trunk and feeder roads).	Verification by GPS linked video capture. Spot checks by local consultant. Inter-rater reliability testing during training.
Axle load survey	Three day surveys at each station	Mobile weigh stations; vehicle scales from GHA	Calibration and testing of weight stations. Spot checks by local consultant.
Traffic Counts*	Two stations along N1 highway, 1 station on trunk road and 12 stations on sampled feeder roads	GHA Classified Traffic Count instrument.	Training of enumerators. Spot checks by local consultant.
Expanded vehicle intercept survey (including O-D and road user modules)	At 1 station on the N1 and at 6 stations on sampled trunk and feeder roads (approximately 1,000 vehicles along the N1 highway. 20% of traffic on high-traffic trunk and feeder roads. 3 days)	Paper-based survey instrument, with computer data entry in the field.	Pre-testing and piloting of data collection instruments. Training and testing of enumerators. Back checks by local consultant
Vehicle* Operator Survey	Sample of vehicle operators, vendors and maintenance service providers across 3 regions.	Forms based on HDM-4 input requirements	Triangulation, comparisons to other data.

* Variables that are direct inputs for RED (in addition to data from other secondary sources).

1. Road condition data

Road engineering data include four main elements: road roughness, deflection, geotechnical data and surface conditions surveys.

Road roughness. We will measure road roughness using the IRI for the N1, trunk and feeder roads. Our engineering subcontractor will lease a Roughometer III (ARRB inertial profiler) from the GHA. Once we obtain the equipment, the subcontractor ensure the equipment is calibrated as outlined in the Table in appendix E. The road roughness data will be captured for analysis using an IRI software analysis package provided by the equipment manufacturer. Roughness will be reported at intervals of 100m. We will also plan to have continuous video capture to create a viewable and analyzable pavement profile for all road segments under the study.

Deflection. We will measure deflection using a FWD on the full length of the N1. The FWD simulates the load produced by a moving vehicle. Deflection measurement with a FWD will require renting the equipment and hiring experienced deflection measurement teams from GHA. We have confirmed that the FWD exists and is used by the GHA. The FWD will be calibrated and operated as outlined in the Table in appendix E.

Geotechnical data. We will collect subgrade CBRs through DCP testing on the N1. Using DCP readings, in combination with data on deflection, we will be able to obtain the modified structural number, a summary measure of the pavement strength derived from each layer. This will be done for the N1. In some cases, and subject to approval from GHA and DFR, we may be required to collect a limited number of core samples to measure the thicknesses of pavement layers of the pavement and verify that the roads were built as designed. We will compare the thickness measures to the engineering specifications and as-built drawings. We anticipate cutting cores from the asphalt in the distress lane of the N1 highway. Test pits on the trunk and feeder roads will be distributed proportionally across the length of the segment studied. To avoid unnecessarily damaging roads, test pits will be conducted only where there is severe deterioration of the road surface. Tests will be evenly spaced along the N1.

Road surface condition surveys. These surveys are visual inspections of the pavement on road segments, carried out by engineers. Our engineering firm will conduct the survey for the N1. The survey will identify potholing, cracking, raveling, patching, pumping in cracks, deformation, edge-break, bleeding, surfacing, and drainage, and will be conducted using distress definitions from the GHA Road Condition Survey manual. Manual road surface condition surveys will be conducted by raters walking along the full length of the N1 highway, measuring and recording detailed information on all defects. On the full network of trunk and feeder roads, raters will conduct a windshield survey from a slow moving vehicle. They will characterize and record the severity and extent of different distresses for a sub-segment of road. Periodically, the raters will alight from the vehicle to conduct manual surface condition assessments on 100 meter segments. Surface condition data collected on the N1 will be used in the HDM-4 model. Surface condition data collected on trunk and feeder roads is not used in the RED model, but will be used as part of the performance analysis.

2. Road user data

Road user data include traffic counts, axle load surveys, and expanded vehicle intercept surveys. Some of this data will be used for HDM-4 (N1 highway) and RED (trunk and feeder roads) modeling as well as for our performance evaluation.

Traffic counts. We will collect classified traffic counts on a sample of the roads constructed under the compact. Classified traffic counts categorize traffic data by vehicle type. Passenger vehicle categories will include cars, utility vehicles, two-wheel vehicles, and buses. Goods vehicle categories will include light trucks, medium trucks, heavy trucks, semi/full trailers, and tractors. Bicycles and carts make up the two main nonmotorized categories. To compare current traffic volumes to previous ones, we will try and locate data from the feasibility studies. Where possible, we will place the traffic count stations in the same locations as used in the pre-implementation feasibility studies to allow for maximum comparability. However, we will assess these locations to make sure they are appropriate from a methodological perspective; if they are not, we will select alternate locations. We will also visit the sites prior to confirming their selection to assess safety, the presence of proper shelter for enumerators, and that the locations are a true representation of the traffic on the roads.

Our local engineering firm will conduct a 7-day traffic counts along the N1 highway, the Agogo-Dome trunk road and a sample of feeder roads across the regions. The traffic counts will include three-day, 24-hour counts and four-day, 12-hour counts. We will place two traffic count stations along the N1 highway, one along the Agogo-Dome road and 12 stations along the feeder roads. For the trunk and feeder roads one of the 24-hour count days will also be a regional market day. We will adapt the GHA standardized classified traffic count instrument as necessary based on the type of road. For example, we will include pedestrian counts for the feeder roads. Along the N1 we will work with police and our engineering firm to determine the optimal locations of the counts.

Axle load surveys provide information on traffic loading. As in the road condition survey, our engineering firm will partner with the road authorities in Ghana to supply both the technicians and the equipment to weigh vehicles. This survey will require mobile vehicle weight scales placed on the side of the road. We will conduct the axle load survey for 12 hours over three days in each of the axle load stations. We will conduct this survey at one point along the N1 in both directions. Classified traffic counts will be conducted at the same time and location as the axle load surveys on the N1. Through the axle load survey, we will obtain estimates of the average loading per axle by vehicle type, and examine vehicle overloading. It is a fairly common occurrence in Africa for trucks to be overloaded in one direction (to markets) and relatively empty in the other direction. We therefore want to weigh in both directions since the N1 links the port of Tema to other destinations in Ghana and in neighboring countries and we want to be able to weigh overloaded trucks bringing products to the port or taking products to the market from the port. Having data on traffic loading for both directions of travel may show different estimates of the remaining life of each carriageway. While a commercial vehicle is being weighed, we will use the time to conduct part of our freight module from the expanded vehicle intercept survey, described below.

Expanded Vehicle Intercept Survey. As described in Chapter III, the expanded vehicle intercept survey will include an O-D module and a road users module. The O-D module will focus on collecting details on the origin and destination of the respondent's trip, including the activity at the origin and destination, as well as trip purpose.[19] This module will also collect data on travel direction, trip frequency, travel time between the trip's origin and the interview point, and basic driver characteristics such as age, gender, as well as vehicle type and vehicle characteristics. Additional questions include the following:

[19] Activities at origin and destination include (1) home, (2) work, (3) school, (4) shopping, (5) leisure/social, (6) medical facilities, (7) trade (i.e., buying and selling at a market), and (8) other. Trip purpose categories will include (1) to home, (2) to work, (3) to school, (4) business, (5) shopping, (6) government/official, (7) leisure/social, (8) tourism, and (10) other. Trip frequency categories include (1) several times per day, (2) once per day, (3) several times per week, (4) once per week, (5) several times per month, (6) once per month, (7) several times per year, (8) once per year, and (9) rarely or only trip.

- For trucks and other freight vehicles, we will ask questions about cargo type[20] and number of crew members.
- For passenger vehicles, we will inquire about number of passengers, seats, and crew members, and passenger destination and fares charged.

The road user module will contain additional questions related to road use and travel, such as travel patterns, alternative routes and modes of transportation, and travel costs.

To administer the expanded vehicle intercept survey, we will systematically stop traffic on the roads (in accordance with the sampling procedure outlined in Chapter III and Appendix C), and conduct roadside interviews with drivers of each vehicle type, and passengers in commercial vehicles such as taxis and buses. We will conduct the survey during the daytime over three days along the N1 highway as well as along a sample of trunk and feeder roads. We will discuss optimal locations to place enumerators for this survey along feeder roads with the DFR, GHA and local traffic police authorities. We anticipate administering both modules to stopped vehicles; however, based on our pilot results and traffic volume, we may administer the road user module to a subset of stopped vehicles while all respondents complete the O-D module. The two modules combined should take up to 10 to 15 minutes.

Our local engineering firm will work closely with GHA and DFR as well as their regional representatives, to secure approvals and to assist in working with the local police representative. The local police will be responsible for pulling over vehicles in line with our sampling plan. Surveys will be conducted using paper-based forms, with computer-based data entry in the field. 100 percent of survey forms will be entered a second time on returning to headquarters.

Vehicle Operator Survey. To understand changes in costs associated with roads improvements, we will obtain information on vehicle operating costs. With the support of a transport economist, we will survey major transport operators, travel companies, garages, and dealers to obtain both fixed and variable transportation costs such as unit costs of trucks, tires, vehicle maintenance, and fuel. Surveys will be conducted with vehicle fleet operators (bus companies, transport operators, shipping companies) to collect VOCs as well as information on fleet characteristics. We will contact GHA and the World Bank to see if recent VOC exists that can be used to cross-check the primary data we collect.

3. Process for collecting primary quantitative data

All of the data collection activities will be carried out by experienced subcontractors in Ghana and Mathematica staff, working in close partnership with local authorities. After the design report is approved, we will hire a road engineering firm to collect the road engineering data, road user data, and VOCs described above. Our terms of reference (ToRs) for the engineering firm will require that the chosen firm has significant experience in Ghana in the following:

[20] Cargo type categories will include (1) livestock, (2) agricultural produce or inputs, (3) market items, (4) machinery, (5) medicines, (6) fuels, (7) hardware and building materials, and (8) other.

- Working with the relevant roads authorities to collect engineering data, including roughness, deflection, core sampling and road condition
- Training enumerators and conducting traffic counts O-D surveys, and axle load surveys
- Assembling multidisciplinary teams with knowledge of pavement engineering, transportation economics, and highway and rural road engineering

We have also engaged a local engineering expert to serve as the data coordinator for this evaluation. The coordinator will be based in Ghana, and will provide oversight on the data collection process, and participate in or conduct some of the KIIs. Mathematica has already identified a coordinator who brings extensive knowledge of road data collection procedures, and a vast network of contacts within the MRH.

The data collection activities require working very closely with Ghanaian authorities, such as the government agencies responsible for roads planning and maintenance and the police. GHA and DFR will be instrumental in providing the necessary approvals to conduct much of the primary data collection activities. We will partner with the road authorities to lease specific data collection equipment and request secondary data such as vehicle operating costs and roads maintenance data. Road users data collection will require the involvement of local police in order to monitor traffic counts or stop traffic to interview passengers and drivers.

All pavement condition, traffic count, and vehicle intercept survey activities will be conducted in October and November 2018, depending on the geography of the road. We are targeting October to collect data along the N1 highway, and will work with our data collection coordinator to identify the most effective calendar for data collection in other regions given weather variability across Ghana.

B. Secondary data

We will complement the primary data with a number of secondary data sources. Examples of secondary data include construction costs, VOCs, maintenance expenses, and climate. We will request information on a series of documents such as as-built drawings or records, administrative records, and data from the GHA and DFR pavement management systems.

1. Types of secondary data

Road condition data. To supplement the roads engineering data collected by our engineering firm, we will extract geotechnical data from some of the as-built drawings or engineering designs. The as-built drawings/engineering designs will provide us with information related to the pavement type and pavement age, the geometry of the roads, as well as the functional classification of roads.

Road users and other data. As mentioned previously, we will review the VOC data collected by the World Bank, GHA, and DFR and determine whether we can limit or supplement the vehicle operator cost survey described above.

Administrative data. As described in Chapter III, the performance evaluation will rely on a number of administrative data sources. To inform the analysis of maintenance funding, expenditures, and implementation, we will review documented maintenance policies, practices, and financial data. This information will come from the Roads Fund revenue records, the PMMP from GHA, and the MPBS from DFR, and other government departments. In addition, we will review any regulated fares for passengers on along the study roads.

2. Process for collecting secondary data

We will work closely with MCC, MiDA, and our local contacts to request the data described in Table V.2, below. For example, we will prepare draft data request letters for MCC or MiDA to put on their letterhead introducing Mathematica and the evaluation. During the evaluation design trip, we established relationships with staff at MiDA, GHA, DFR, and other roads entities. Our local data coordinator, Jones Quain, can assist as needed in following up on our requests for secondary data. We will liaise first with MiDA M&E team members, Dr. Kofi Marfo and Mr. Albert Nyarko, when collecting secondary data from government sources. Table V.2 includes a list of secondary data that we have received, requested, or are planning to request in order to supplement our primary data collection efforts. We expect that as we begin our data collection planning, we will include additional sources of secondary data.

Table V.2. Secondary data requests

Type of secondary data	Status
Example HDM-4 workspace, calibrated to Ghana	Received
Maintenance annual report for Ghana Highway Authority 2015	Received
Engineering or as-built drawings and final reports for all roads	Partially received
Road feasibility reports	Partially received
Maintenance records from DFR for feeder roads from the Ghana Highway Authority for the N1 and the trunk road	To be requested
Maintenance priority lists from past three years	To be requested
Funding requests for maintenance sent to the Ghana Roads Fund	To be requested
Ghanaian policy documentation (legislation, charters, development plans, regulations)	To be requested
GIS shapefiles showing the current road network for mainland trunk road network	To be requested

C. Primary qualitative data

We will also draw on data from interviews with key informants, including officials from the roads agencies and other stakeholders. These data will primarily inform the performance evaluation research questions on roads maintenance and transportation costs savings. We will conduct the interviews with staff from the following entities:

- GHA (both staff in headquarters as well as staff based in regional offices)
- DFR (both staff in headquarters as well as staff based in regional offices)
- Ministry of Transportation
- Ghana Road Fund Board Secretariat
- Transport operators

The semi-structured instruments will include predefined questions, allowing us to gather specific information while also permitting open-ended conversation that may reshape our interview and, potentially, research questions. A preliminary list of data sources and topics for the KIIs is included in Table V.3, below.

To secure meetings with the relevant representatives, we will first request an introductory letter from MCC or MiDA to GHA, DFR, and other relevant entities. We will also seek the support of our engineering subcontractor and of stakeholders we met during the design trip to help secure meetings with key informants.

In addition to relying on key information interviews, we will also conduct focus group discussions with community members in select communities along the improved roads as well as along comparison roads segments selected from roads that were identified in the compact due diligence process but not improved as a result of compact rescoping. For the N1 highway, we will interview a different set of stakeholders, such as taxi and truck drivers and companies that operate at the Port of Tema, who are most likely to have benefitted from the upgrades. The focus group discussions will provide further information on perceptions of transportation options, costs, and improvement in access to markets and/or other social services.

Table V.3. Qualitative data collection focus areas

Data source	Areas of focus
(Former and current) MiDA representatives who worked on roads during the Ghana I compact including contracting and M&E staff	• Reflections on implementation and sustainability • Perceptions of the implementation of infrastructure interventions • Maintenance practices
GHA and DFR policy, management, and engineering staff	• Perceptions on any road use change, benefits, unintended consequences • Quality control and auditing process • Maintenance practices in the PMMP and MPBS • Data quality in PMMP and MPBS and links to decision making • Priority identification of PMMP and MPBS and links to decision making • Factors driving maintenance decisions • Procurement and road construction processes
Local regional roads officials	• Reflections on implementation • Involvement in roads management process • Satisfaction with roads maintenance practices and roads upgrades and implementation • Perceptions on road uses regionally • Process to communicate road conditions with headquarters • Degree of involvement in maintenance decisions of local roads
Transportation operators	• Perceived benefits of improved roads and perception of maintenance practices • Perceptions of maintenance savings based on improved roads. • Expanded life of vehicle fleet due to improved road conditions • Increased competition since emergence of roads • Changes in fares over time • Share of travel conducted on compact-funded roads
Representatives from Road Funds Board Secretariat	• How levels of funding of the Roads Fund have changed over time • Challenges and successes • Independence of the Roads Fund • Revenue and expenditure data for the Roads Fund

Data source	Areas of focus
Road users (via focus groups)	• Change in travel patterns over time; changes in and satisfaction with access to transportation options and markets. • Involvement in maintenance process

D. Data quality plan

Collecting high quality data depends on developing data collection plans around the realities of local capacity, and building data collection skills as needed. It begins with ensuring the right mode of data collection for the context and developing a reasonable process for data quality checks. For example, electronic data collection can reduce human error, but it depends on the training and oversight of enumerators during the data collection process.

Selecting a high quality data collection firm, strong training of enumerators, and periodic checks. Critical to collecting high quality data is the selection of a highly capable subcontractor, and defining practices to ensure data quality as part of the contract. Prior to selecting the engineering subcontractor, we will check references and include a data quality plan as part of the ToRs. We will then include our standard Mathematica data quality control procedures in the subcontract with the engineering firm and require that all surveys include a piloting stage and a training stage. As an extra quality assurance measure, our local data coordinator will provide oversight to data collection efforts and give regular updates to the evaluation team. He will also conduct unannounced visits to traffic count stations and sites where the traffic users survey takes place at randomly selected collection points. In addition, as we receive engineering data, we will engage our HDM-4 specialist to review the outputs and compare them to previous data available, to assess if there are major discrepancies that could be caused by poor quality data collection practices.

Pairing technology with in-person measurement. To the maximum extent possible, we will use computer tablets or field data entry for data collection related to road users. Computer-assisted personal interviewing (CAPI) software has the potential to reduce errors through internal programmed validity checks, increase the timeliness of data collection by avoiding a separate data entry process, and more closely monitor data collection in the field. Since using CAPI proved infeasible, we will conduct data entry in the field. Data entry forms will be programmed with validity checks to enable correction of forms in the field. Double data entry will minimize data-entry errors. A GPS-linked video camera will be mounted on the vehicle collecting roughness data to ensure proper operation of the vehicle. This footage will be used to control quality for road surface condition data. We will explore using motion-triggered cameras to validate low-volume rural traffic counts. For deflection and roughness, we will calibrate instruments as outlined in the Table in appendix E, and pilot several rounds of data collection to ensure consistent measurements.

Comparing information from KIIs. When obtaining qualitative data from KIIs, we will compare information from data sources that overlap, assess inconsistencies, and when possible follow up or note the inconsistencies. In addition, for both our qualitative and quantitative research, senior staff review all methods, results, and interpretation via the Mathematica quality assurance process.

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VI. EVALUATION ADMINISTRATION AND MANAGEMENT

In this chapter, we summarize several administrative and management issues related to the successful implementation of the proposed evaluation design for the roads activities.

A. Institutional review board

Mathematica will prepare and submit institutional review board (IRB) applications for the four primary data collection activities that involve human subjects: (1) the expanded vehicle intercept survey, (2) KIIs with roads stakeholders, (3) focus group discussions, and (4) the vehicle operator survey. We intend to use Health Media Lab as our IRB, based on our positive experience with it on previous MCC projects. For the IRB application, we will submit a set of required documents, including a research protocol providing details of the study and data collection activity, copies of data collection instruments, and a completed IRB questionnaire that summarizes the key elements of the data collection protocols and plans for protecting respondents' confidentiality. The data collection instruments that we prepare and share with the IRB will include consent statements approved by MCC that guarantee the confidentiality of respondents. We will work with local data collection partners to identify and obtain any local approvals needed from Ghanaian authorities for the data collection efforts described above. We will also draw on our previous experience submitting IRB approvals in Ghana.

We do not anticipate seeking IRB approval for road condition data and classified traffic counts, as they do not involve intervening or interacting with human subjects or identifiable private information. However, we will obtain all necessary permission and cooperation from roads and police authorities in Ghana to collect these data.

B. Data access, privacy, and documentation

Primary data used for the evaluation will come under three main categories in terms of anticipated access, privacy, and documentation.

1. For **road condition data and classified traffic counts**, we will produce a data collection report that includes the key input data used in modeling road segments in HDM-4, RED, data collection tools and templates, and summary statistics of key variables.
2. For the **qualitative data collection**, including focus group discussions and KIIs with roads stakeholders, we will maintain confidentiality of respondents and follow MCC's latest guidelines regarding access to qualitative data.
3. For the **quantitative surveys**, including surveys of vehicle operators, the expanded vehicle intercept survey, and the axle load survey, we will follow MCC's latest guidelines regarding public use data, and make these data available in a form that is consistent with the confidentiality guaranteed in the respondent consent statements included in the data collection instruments and approved by the IRB.

These products will be de-identified according to the most recent guidelines set forth by MCC. The public use data files will be free of personal or geographic identifiers that would permit unassisted identification of individual respondents or their households. In addition, we will remove or adjust variables that introduce reasonable risks of deductive disclosure of the identity of individual respondents. Mathematica will remove all individual identifiers, including names, addresses, telephone numbers, government-issued identification numbers such as license plates, and any other similar variables. We will also recode unique and rare data by using top and bottom coding or replacing affected observations with missing values. If necessary, we will also collapse into less identifiable categories any variables that make an individual highly visible as a consequence of geographic or other factors (such as ethnic classifications or languages spoken). These measures are designed to retain the usefulness of the data while preserving the privacy of survey respondents.

C. Dissemination

Mathematica will present the evaluation findings in person to MCC and stakeholders in Ghana after completing a draft of the analysis report. These presentations will be valuable for both disseminating the findings to relevant stakeholders and gathering feedback from them to revise the draft report. In addition, we will collaborate with MCC and stakeholders to identify a variety of forums—including conferences, workshops, and publications—to share results and encourage donors, implementers, and policymakers to integrate the findings into future programming.

D. Evaluation team

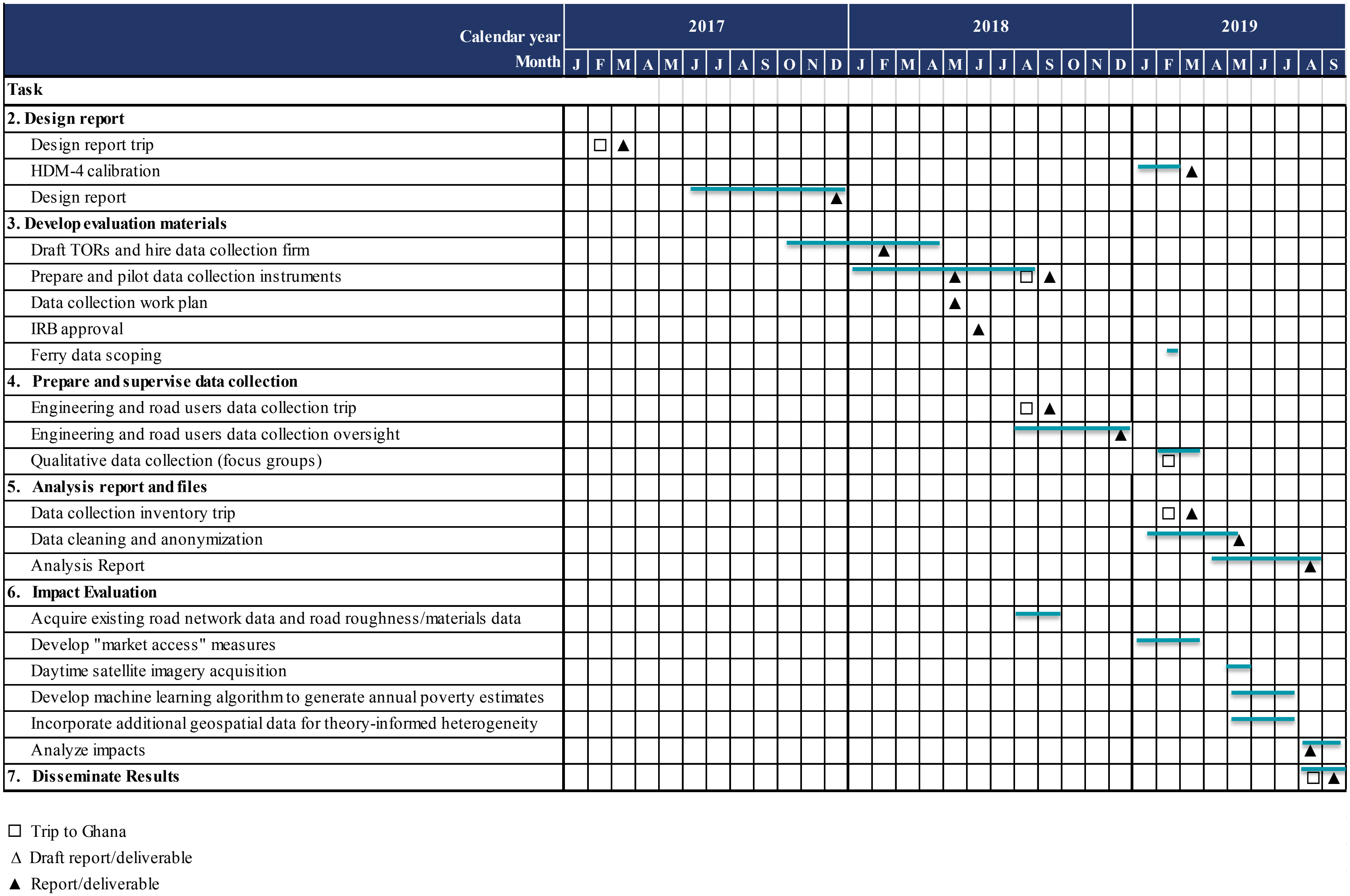
Mathematica's evaluation team brings together strong design, data collection, and HDM-4 and RED expertise. Our core team includes Dr. Anu Rangarajan, Ms. Delia Welsh, and Dr. Harry Evdorides. Dr. Rangarajan will serve as project director, providing leadership and technical support for all aspects of the project. Ms. Welsh, as deputy project director, will oversee the evaluation team on a day-to-day basis and lead the performance evaluation under the project. Dr. Evdorides will serve as senior advisor and work closely with Dr. Anthony Harris to provide quality assurance of all HDM-4 related inputs and deliverables. Dr. Sarah Hughes will oversee all data collection activities. Other Mathematica staff, including those with experience in analyzing quantitative and qualitative data, will assist key staff in carrying out the evaluation. Our team will draw on the expertise of Ing. Roberto Armijo who will lead the HDM-4 modeling and oversee the on-the-ground piloting of data collection. Finally, Mr. Jones Quain, our local research coordinator, will assist us in identifying and obtaining secondary and administrative data, serve as a liaison between the Mathematica team and local stakeholders, and oversee primary data collection activities.

E. Evaluation timeline and reporting schedule

We aim to begin collecting road condition data, axle load surveys, classified traffic counts, and expanded vehicle intercept survey on the roads on the N1, trunk, and feeder roads in October 2018. On the N1, we will conduct the expanded vehicle intercept survey and the axle load surveys at the same time as traffic counts to ensure that we obtain a representative sample of vehicles interviewed and weighed. To minimize disruptions to traffic, axle load surveys will not occur at the same time as the expanded vehicle intercept survey. Axle load surveys for each direction of travel will happen on subsequent weeks, since there is only one vehicle scale available. Axle load surveys will occur on the same day of the week and will be accompanied by classified traffic counts. We aim to begin collecting primary data that are not seasonal in nature, including administrative data on maintenance KIIs, focus group discussions, and the vehicle operator survey between September 2018 and March of 2019.

We will produce the draft analysis report, which will integrate findings from all evaluation components by August of 2019. We will then present the draft analysis report to stakeholders and obtain their feedback before finalizing it in September of 2019.

Figure VI.1. Projected timeline for the evaluation



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APPENDIX A:

SUMMARY OF STUDIES IN THE LITERATURE REVIEW

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Table A.1. Impacts on beneficiaries near improved roads

Study	Country	Study design [a]	Short description
MCC studies			
NORC (2013)	Honduras	Matching with continuous treatment effect	Evaluates the impact of upgrading 65 km of secondary roads and 495 km of rural roads one to two years after project completion. Results include reduced travel times to health centers and municipal capital; reduced travel costs to hospitals, health centers, and basic markets. No evidence of impact on utilization of social services and on employment or school attendance.
Alevy (2014)	Nicaragua	DiD with matched comparison group	Evaluates the impact of upgrading secondary roads totaling 68 km in length one year after project completion. Does not find evidence of impact on the cost and availability of a basket of basic consumer goods, but finds increases in household consumption of perishable goods.
NORC (2013)	Georgia	DiD with matched comparison group	Evaluates the impact of rehabilitating 220 km of a regional highway connecting the economically isolated Samtskhe–Javakheti region to the capital one year after road completion. Finds increased traffic and average speed of vehicles and decreased travel times to the capital and local markets. Also increases in the number of industrial facilities along the improved road segments. No evidence of impact on land use or cropping patterns, utilization of health care centers, household income, consumption, or asset ownership.
Fortson et al. (2015)	Armenia	DiD with comparison group	Evaluates the impact of 27 rural road segments originally intended to be upgraded under the MCC compact and later financed by the World Bank after one to two years of exposure. Finds that the project decreased travel times by households to sell agricultural products and increased use of roads for noncommercial purposes (e.g., shopping and visiting relatives). Does not find impacts on utilization of social services, agricultural production, household income, consumption, and poverty.
Non-MCC Studies			
Iimi et al. (2015)	Brazil	DiD with matched comparison group	Evaluates the impact of roads improvements and related investments to allow year-round passage in the four poorest regions in the state of Tocantins one year after completion. Finds reduced travel times to population centers and increased use of public transportation, car ownership, and perceived access to health centers and schools when available in close proximity. Impact on girls' enrollment in school varied by region. No impact on labor composition across different sectors or household income.
Khandker (2009)	Bangladesh	Household fixed-effects	Evaluates the impact of two projects rehabilitating rural roads and market improvement three to four years after completion. Finds decreased travel costs, increased school enrollment and employment, lower fertilizer prices, and increased aggregate crop prices, agricultural output, and per-capita household expenditure.

Study	Country	Study design [a]	Short description
Non-MCC Studies (*continued*)			
Mu and van de Walle (2011)	Vietnam	DiD with matched comparison group	Evaluates the impact of a rural road rehabilitation project in 18 provinces two years after completion. Finds increases in the presence and availability of local open-air temporary markets for goods and services, primary and secondary school enrollment, and off-farm activities (mostly in the service sector).
Lokshin and Yemtsov (2005)	Georgia	DiD with matched comparison group	Evaluate the impact of rural roads improvement projects in 41 villages one to two years after completion. Finds increases in the number of non-agricultural small and medium enterprises and reductions in barter trade. No evidence of impact on the sale of agricultural products.
Akee (2006)	Palau	DiD with comparison group	Evaluates the impact of a newly built road connecting rural areas to more urban areas one year after project completion. Finds increases in non-agricultural wage-sector employment, reduced self-employment in agriculture, and decreases in the number of immigrants sent abroad. Finds increased car ownership but no impacts on household income or wages.
Gonzalez-Navarro et al. (2015)	Mexico	RCT	Evaluates the impact of upgrading feeder roads connecting peri-urban residential neighborhoods to larger road networks one year after project completion. Finds increases in property values along the newly paved roads, vehicle and appliance ownership, and home improvements.
Escobal and Ponce (2004)	Peru	Matched comparison group	Evaluates the impact of rehabilitating rural roads in high-poverty districts four years after the start of the project. Finds increases in household income, mainly from increases in non-agricultural wage employment. Finds no evidence of impacts on annual consumption from increased income, but finds increased investments in durable goods, namely livestock.
Dercon et al. (2007) [b]	Ethiopia	Household fixed-effects	Evaluates the impact of road improvements on consumption and poverty in rural areas. Finds increases in consumption and reduction in the incidence of poverty.
Jalan and Ravallion (2002) [b]	China	Dynamic growth modelling	Evaluates the impacts of roads constriction on consumption, assuming that initial road placements are exogenous. Finds that higher density of roads (kilometers per 10,000 people) positively correlates with higher rates of consumption.

[a] DiD = Difference-in-Difference; RCT = Randomized-controlled trial.

[b] Study did not report exposure period.

Table A.2. Broader economic effects of roads

Study	Country	Study design	Short description
Donaldson (2017)	India	General equilibrium trade model	Examines the impact on income of railroad network construction in India in the 19th and early 20th century. Guided by the predictions from a general equilibrium trade model and using rich archival data, the study finds that access to the network reduced trade costs and interregional price gaps, increased interregional and international trade, and improved income.
Atkin and Donaldson (2015)	Ethiopia and Nigeria	Theoretical model	Investigates the cost of intranational trade for consumers in remote locations resulting from poor transportation networks and imperfect transport market. Finds that the effects of long distance on the cost of intranational trade are approximately four to five times larger in these two countries than in the U.S. Also finds that intermediaries are able to capture a greater fraction of the benefits of price reductions, leaving little to pass on to the consumers in communities in remote locations.
Storeygard (2016)	Fifteen Sub-Saharan countries	Natural experiment (exogenous changes in oil prices)	Examines the role of transport costs in determining income of cities in 15 Sub-Saharan countries where the largest city is a port. Using satellite-based nighttime lights data to measure economic activity, the study finds that exogenous changes in transport costs, caused by world oil price fluctuations, led to increases in the income of cities near the port compared to similar cities 500 km away.
Donaldson and Hornbeck (2015)	U.S.	General equilibrium trade model	Examines the impacts of the expansion of the U.S. railroad network on the agricultural sector in 1890. Uses historical county-level data on agricultural land value combined with satellite data on railroad expansion to identify a counterfactual scenario where no railroad network existed. Finds that railroad access led to moderate increases in U.S. gross national product.
Banerjee et al. (2012)	China	Natural experiment (exogenous variation in distance from straight lines connecting historical cities)	Examines the long-term impacts of access to transportation network on income and growth across different sectors in China during a period of rapid economic growth. Finds that regions closer to transportation networks have higher levels of GDP per capita, income inequality, number of firms, and average firm profits, but the level differences are small in magnitude. Also finds no difference in income growth between regions closer and farther from transportation network during the two decades of rapid economic growth between 1986 and 2006.
Asher and Novosad (2016)	India	Regression discontinuity	Examines the impacts of a national rural road construction program that connected isolated villages to the regional transportation network. Finds that the program led to large movements of labor across sectors—decreasing the share of households and workers participating in agriculture and increasing the share participating in wage labor—and also decreased agricultural production and increased income from wage labor.
Gollin and Rogerson (2014)	Uganda	General equilibrium model	Examines the reasons a large fraction of the workforce in poor economies live in rural areas and engage in subsistence agriculture, using a multisector multiregion general equilibrium model. Finds that a closed economy with lower agricultural productivity needs more people to engage in subsistence farming to meet food requirements through domestic supply, and high transportation costs are an important contributor for households to locate near the source of production. Concludes that productivity increases have little impact on resource reallocation in remote areas because high transportation costs prevent households from selling increased output.

Study	Country	Study design	Short description
Casaburi et al. (2013)	Sierra Leone	Regression discontinuity	Examines the impact of a rural road rehabilitation program on crop prices in Sierra Leone. Finds that the program lowered the price of rice and cassava, more so in areas further away from large urban centers and with lower productivity, likely because improved road quality decreases the cost of reaching local markets where farmers and traders conduct business. Also finds that the effects on prices were weaker in areas with better cell phone coverage because reductions in travel times were less relevant for farmers and traders who could negotiate prices over phones.

APPENDIX B:

LIST OF VARIABLES FOR HDM-4 AND RED

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Table B.1. HDM-4 and RED variables and data sources

Variable description used in HDM-4	Likelihood of calibration	Used in RED model	Data source
Climate data			
Average rainfall	Calibrate		Secondary
Duration of dry season	Calibrate	X	Secondary
Mean temperature	Calibrate		Secondary
Moisture index	Calibrate	X	Secondary
Number of days temperature exceeds 32 C	Calibrate	X	Secondary
Temperature range	Calibrate	X	Secondary
Pavement characteristics, road inventory and road works			
Altitude	Calibrate	X	As-built drawings, roads agency
Carriageway width	Calibrate	X	As-built drawings, roads agency
Construction age	Calibrate		As-built drawings, roads agency
Effective number of lanes	Calibrate		As-built drawings, roads agency
Horizontal curvature	Calibrate	X	As-built drawings, roads agency
Number of surface layers	Calibrate		As-built drawings, roads agency
Posted speed limit	Calibrate	X	As-built drawings, roads agency
Preventative treatment age	Calibrate		As-built drawings, roads agency
Rise plus fall	Calibrate	X	As-built drawings, roads agency
Shoulder width	Calibrate		As-built drawings, roads agency
Superelevation	Calibrate	X	As-built drawings, roads agency
Surface type	Calibrate	X	As-built drawings, roads agency
Surfacing age	Calibrate		As-built drawings, roads agency
Area potholed	Calibrate		Engineering survey
Base type	Calibrate		Engineering survey
Deflection (FWD)	Calibrate		Engineering survey
Drainage condition	Calibrate		Engineering survey
Mean rut depth	Calibrate		Engineering survey
Environmental Coefficient of Roughness	Calibrate		Secondary
Subgrade California Bearing Ratio (CBR)	Potentially calibrate		As-built drawings, core samples
Structural number	Potentially calibrate		Engineering survey
Drainage factor	Potentially calibrate		Secondary
Area with all cracking	Potentially calibrate		Engineering survey
Area with wide cracking	Potentially calibrate		Engineering survey
Crack initiation factor	Use default values		Secondary
Crack progression factor	Use default values		Secondary
Pothole progression	Use default values		Secondary
Ravelling initiation	Use default values		Secondary
Ravelling progression	Use default values		Secondary
Roughness age term	Use default values		Secondary
Roughness progression	Use default values		Secondary
Rut depth progression	Use default values		Secondary
Sand patch texture depth	Use default values		Secondary
Seasonal effects on Structural No	Use default values		Secondary
Skid resistance	Use default values		Secondary
Roughness	Calibrate		Engineering survey
Time lapses to patching	Potentially calibrate		Secondary

Variable description used in HDM-4	Likelihood of calibration	Used in RED model	Data source
Project finance data			
Analysis period	Calibrate	X	Model assumption
Discount rate	Calibrate	X	Model assumption
Unit cost for construction	Calibrate	X	Project documents
Interest rate	Calibrate	X	Secondary
Road user data			
Cost of fuel	Calibrate	X	Vehicle operator survey
Cost of maintenance labor	Calibrate	X	Vehicle operator survey
Cost of oil	Calibrate	X	Vehicle operator survey
Cost of overhead	Calibrate	X	Vehicle operator survey
Cost of retreaded tire	Use default value	X	Vehicle operator survey
Cost of tire	Calibrate	X	Vehicle operator survey
Cost of vehicle/price	Calibrate	X	Vehicle operator survey
NMT Variables	Calibrate	X	Vehicle operator survey, traffic counts
Equivalent standard axles	Potentially calibrate		Axle load survey
Annual loading	Potentially calibrate		Transport sector reports, road agency
Cost of travel time/cost of passenger work time	Potentially calibrate	X	Transport sector reports, road agency
Cost of cargo	Potentially calibrate		Vehicle operator survey
Cost of crew	Potentially calibrate	X	Vehicle operator survey
Average service life	Use default values	X	Vehicle operator survey
Base number of retreads - NR0	Use default values		Transport sector reports, road agency
Desired speed	Use default values		Transport sector reports, road agency
Engine speed - a0	Use default values		Transport sector reports, road agency
Engine speed - a1	Use default values		Transport sector reports, road agency
Engine speed - a2	Use default values		Transport sector reports, road agency
Engine speed - a3	Use default values		Transport sector reports, road agency
Engine speed - Idle	Use default values		Transport sector reports, road agency
Number of axles	Use default values		Vehicle operator survey
Number of wheels	Use default values		Vehicle operator survey
Operating weight	Use default values		Vehicle operator survey
Optimal life depreciation parameters	Use default values		Transport sector reports, road agency
Percentage of private use	Use default values		Vehicle operator survey
Power - braking	Use default values		Transport sector reports, road agency
Power - driving	Use default values		Transport sector reports, road agency
Power - rated	Use default values		Transport sector reports, road agency
Projected frontal area	Use default values		Transport sector reports, road agency
Time driven on wet roads	Use default values		Transport sector reports, road agency
Travel on snow covered roads	Use default values		Transport sector reports, road agency
Travel on wet roads	Use default values		Transport sector reports, road agency
Tyre type (New and used)	Potentially calibrate		Vehicle operator survey

Variable description used in HDM-4	Likelihood of calibration	Used in RED model	Data source
Wheel diameter	Use default values		Transport sector reports, road agency
Aerodynamic drag coefficient	Use default values		
Aerodynamic drag coefficient multiplier	Use default values		
Average annual utilization	Use default values	X	Vehicle operator survey
Hours driven	Use default values	X	Vehicle operator survey
Traffic data			
Annual average daily traffic	Calibrate	X	Traffic counts
Hourly distribution of traffic	Calibrate		Traffic counts
Traffic growth rate	Calibrate	X	Traffic counts/secondary

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APPENDIX C:

SAMPLE SIZE

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I. Formula

The U.K. Department of Transport (U.K. DOT) Design Manual for Roads and Bridges includes the following formula for the estimation of appropriate sample sizes (S) for origin-destination surveys (U.K. DOT 2009; Guy and Fricker 2005).

$$S = \frac{P(1-P)Q^3}{\left(\frac{E}{1.96}\right)^2 (Q-1) + P(1-P)Q^2}, \text{ where}$$

Q = total traffic flow, in number of vehicles

E = the acceptable error or accuracy (expressed as the number of vehicles); and

P = the proportion above which it is unlikely that the proportion of flow that is of interest falls (that is, if we wished to estimate the number of vehicles traveling to destinations outside Ghana, and believed that no more than 10 percent of traffic was traveling to international destinations, P = 0.10).

Solving the equation for E, in order to calculate the sampling error for a given sample size yields: $E = 1.96 * \sqrt{\frac{\left(\frac{P(1-P)Q^3}{S}\right) - P(1-P)Q^2}{Q-1}}$

II. Parameter estimates for the N1 Highway

To generate pre-implementation economic rates of return (ERRs) for the N1 highway, Jacobs Consultancy (2006) estimated annual average daily traffic (AADT) for the N1 highway by applying a 5 percent annual increase over the 2002 AADT. Here, we use the largest resulting AADT estimates for 2015 for Q.

For S, we use 0.5 percent of these AADT estimates, which translates into an hourly survey rate of 28 vehicles total, including both directions of travel, assuming a 12-hour survey period. While 0.5 percent is lower than is typical for O-D surveys, we have settled on this proportion due to the logistical challenges of conducting a survey alongside a busy highway, the diminishing returns of further increasing the sample sizes, and a concern for data quality.

To identify plausible values for P for a range of outcomes, we reviewed the final feasibility study, for which O-D surveys were conducted at two sites along the N1 highway. Using the detailed origin-destination data provided by BCEOM and Inter-Consult (2008), we estimated mutually exclusive proportions of trips within greater Accra area, inter-regional trips within Ghana, and inter-country trips. In addition, we estimated the proportion of vehicles that were carrying agricultural products (Table C.1).

Table C.1. Proportion of vehicles by O-D and purpose of travel

Outcome	Proportion of AADT (%)
Trips within greater Accra area	84
Inter-regional trips within Ghana	14
International trips	2
Vehicles carrying agricultural products	9

Source: Authors' calculations based on BCEOM and Inter-Consult (2008).

No baseline data on origins and destinations were available to carry out the same calculations on the feeder or trunk roads.

III. Sampling error estimation

We used these estimates of P and the AADT of the different trunk roads to estimate E for each outcome and trunk road. This results in estimated sampling errors of less than 2.2 percent of AADT for all calculated outcomes (Table C.2). Reducing the value of S to 0.25 percent (in case we choose to conduct the road users' module with a subsample of stopped vehicles) still results in an error rate of 2.4 percent for the percent of traffic carrying agricultural products. We expect that these low errors will also allow us to conduct subgroup analyses (e.g., O-D patterns for freight vehicles only) with adequate confidence.

Table C.2. Estimated sampling error for the N1 highway, by outcome

Outcome	Projected AADT (Q)	Sampling rate (%)	Average surveys per day	Number of days	Estimated sample (S)	Estimated sampling error (E) (Number of vehicles)	Estimated sampling error (E) (% of AADT)
Origin-destination							
Trips within greater Accra area	67,500	0.5%	338	3	1,013	1,507	2.2%
Inter-regional trips within Ghana	67,500	0.5%	338	3	1,013	1,449	2.1%
International trips	67,500	0.5%	338	3	1,013	502	0.7%
Other outcomes							
Percent of traffic carrying agricultural products	67,500	0.5%	338	3	1,013	1,156	1.7%
Percent of traffic carrying agricultural products (0.25 percent subsample)	67,500	0.25%	169	3	506	1,641	2.4%

Source: Authors' calculations based on Jacobs Consultancy (2008) and BCEOM and Inter-Consult (2008).

Notes: Outcomes are based on a one-day O-D survey conducted as part of a final feasibility study by BCEOM and Inter-Consult 2008). Purpose of travel was asked of all road users stopped and was not disaggregated by vehicle.

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APPENDIX D:

DATA QUALITY PROTOCOL COMPARISON TABLE

The table below summarizes the data collection efforts proposed for the Ghana roads evaluation and how these differ from the guidance described in in Annex 4- Data Collection Quality Protocols of the evaluation contract.

Table D.1. Comparison of data collection protocol

Measurement	Standards included in MCC data collection protocol (Annex 4)	Deviations between MPR data collection plans and annex 4, and rationale for deviation
IRI (N1, trunk, and feeder roads)	• Outer wheel path of each lane per relevant ASTM standards using a Class 3 or better IRI measuring device.	• As per manufacturer's requirements, sensor is mounted on driver's side of rear axle. Outer wheel path is not measured.
Deflection (N1 only)	• Measurements on all selected roads during or at the end of the rainy season so as to obtain the modulus of every pavement layer and subgrade. • Measurements at every kilometer at intervals of no more than 100 meters for the entire chainage. • Deflection measurement shall be taken by the FWD for all bitumen surfaced roads and Benkelman Beam for gravel roads. • Based on the deflection results and traffic counts (see below), the Contractor shall determine the remaining structural life of the roads investment using an appropriate fatigue curve to be identified by the Contractor and approved by MCC before use.	• Data will be collected at the end of the rainy season. • Measurements at every 500m for the entire chainage of the N1 highway. We believe 500m increments will save on data collection costs and provide representative deflection data. • Based on the deflection results and traffic counts (see below), we will determine the remaining structural life of the roads investment using the Traffic Research Laboratory fatigue curve.
Geotechnical (N1, trunk, and feeder roads)	• Determine the Adjusted Structural Number (SNC) based on the As-Built drawings and geotechnical results and compare to the thicknesses checked with a Ground Penetrating Radar (GPR) with GPS capability for a thorough verification of the thickness of the built road vis a vis the design. • Based on the geotechnical results provided in the As-built drawings, the Contractor shall determine the subgrade modulus and its resulting California Bearing Ratio (CBR), the modulus of every layer and Adjusted Structural Number for use in HDM-4.	• The Adjusted Structural Number will only be calculated for the N1. • The Adjusted Structural Number (SNC) will be based on the thicknesses in As-Built drawings with verification from select core/bores. Where as-built drawings are not available, we will rely on core/bores and DCP testing alone. GPR has not been used in Ghana and has not been calibrated for the country. • DCP testing will be used to estimate the CBR on the N1 highway.

Measurement	Standards included in MCC data collection protocol (Annex 4)	Deviations between MPR data collection plans and annex 4, and rationale for deviation
Road condition (N1, trunk, and feeder roads)	• Evaluate the road condition, namely any distress encountered (cracking, bleeding, raveling, rutting, potholing, etc.) in accordance with the LTPP Distress Identification Manual (June 2003) or other relevant and approved methodology and determine the cause(s) of deterioration. • Any maintenance operation(s) performed since construction should also be identified. Note all performed measurements will also need to be shown in accordance with HDM4 data input requirements (this will require a calibration between the LTPP and HDM4 cracking values for example.) • The Contractor shall graphically illustrate the distress(s) found on the aerial imagery collected for the entire chainage, with appropriate LTPP distress identification and severity shown on the aerial image(s). For example, fatigue cracking of moderate severity should be shown on the image in the location on the aerial image with coloring to show moderate severity. MCC suggests using Red for High, Yellow for Moderate and Green for Low.	• Distress identification will follow the Ghana Highway Authority Road Condition Survey manual (2003) • N1: Surface condition data will be collected at the project level. The data collector shall walk along the road in order to identify and record the type, location, extent and severity of the various distresses present. Information Quality Level for surface condition data, will meet the IQL-2 requirements for HDM-4. • Feeder and trunk roads: Surface condition data will be collected at the network level, as outlined in GHA Road Condition Survey manual (2003). At approximately 1km intervals, the data collector walk a 100m section and record the type, location, extent and severity of various distresses present. We are not using HDM-4 to evaluate the trunk and feeder roads so a less detailed approach is appropriate.
Axle load (N1, trunk, and feeder roads)	• The traffic evaluation shall distinguish between domestic and international traffic and shall consider the degree of vehicle overloading for the purpose of estimating the truck factor (average ESALs per heavy vehicle) to be used. Each road shall be measured over a period of one week from 6am to 8pm. • The stations will be integrated into the aerial imagery and itinerary diagrams.	• We will collect axle load data along the N1 Highway for a duration of three days between 6am and 6pm. • We will collect axle load data on a sample of up to five feeder and trunk roads for a duration of three days. This will be determined if the roads have a high volume of heavy traffic.
Expanded vehicle intercept- O/D module &road user module (N1, trunk, and feeder roads)	• The surveys will be conducted for two consecutive market and non-market days at each site from 6am to 8pm. The stations should not be located near urban areas so as to avoid inclusion of local traffic in the survey. The primary elements to be collected are the 1) Origin and Destination, journey purpose, travel time, vehicle classification, passengers per vehicle, number of passengers in employment, number of crew, type and approximate weight of merchandise or goods transported. • A minimal interview sample rate of 20% of each vehicle type will have to be achieved at each site. • The stations will be integrated into the aerial imagery and itinerary diagrams.	• The surveys will be conducted for three consecutive days, for 8 hours per day. • 1000 interviews (an estimated minimal interview sample rate of 0.5%) will be achieved along N1 highway; 20% sample rate for high traffic trunk and feeder roads. • Interviews will be conducted with a representative sample of traffic over the course of the day. Sampling by vehicle type is impractical on the N1 given the logistics involved with stopping traffic on a large urban highway. • We propose collecting lower-resolution imagery rather than aerial imagery, as the cost is very high.

Measurement	Standards included in MCC data collection protocol (Annex 4)	Deviations between MPR data collection plans and annex 4, and rationale for deviation
Vehicle operating cost	• The survey shall be carried out at major transport operators, travel companies, garages, and vehicle concessionaires and on a sample of private road users from the O-D work and in accordance with HDM4 Volume 5 requirements.	• No deviation
Traffic Counts(N1, trunk, and feeder roads)	• Develop a traffic counting procedure in accordance with the Traffic Monitoring Guide issued by the US Federal Highway Administration or equivalent. • The stations will be integrated into the aerial imagery and itinerary diagrams.	• Traffic counting procedure based on GHA standards and on recommendations from local experts. GHA standards follow international standards. Vehicle classification is sufficiently disaggregated to allow for like-for-like comparisons with baseline traffic counts. • Local and international experts have recommended the following traffic count length: seven-day traffic count to include three-day, 24-hour counts and four-day, 12-hour counts, with one of the 24-hour count days being a regional market day. • The stations will be integrated into the itinerary diagrams. We are collecting GPS linked video of all the roads. The cost of aerial imagery is very high.
Satellite Imagery	The Contractor shall collect recent satellite imagery for pre-construction work at a resolution of 50cm or better and aerial imagery at a resolution of 5cm or better for the constructed works of each road and overlay the collected data.	• We are not proposing to collect aerial imagery because we will collect GPS-linked video, mitigating the need for 5 cm or better aerial imagery. • We will use satellite imagery in the impact evaluation (30m Landsat) that is freely available.
Qualitative Data Collection on Prices and Wages.	The qualitative data collection will gather information on prices and wages in communities located near the roads and to get at a sense of perceptions of the benefits of the road. This data will help MCC understand whether the benefits of the roads extend beyond fares.	• We have proposed an impact evaluation using nighttime light and daytime satellite imagery to measure the impact on economic activity in place of the prices and wage survey.

APPENDIX E:

QUANTITATIVE DATA COLLECTION STANDARDS

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The table below describes the required data standards for the quantitative data collection in the evaluation. This table will be part of the contract between Mathematica and the relevant data collection subcontractor.

Table E.1. Quantitative data collection standards

Data Type	Sample unit	Sample size	Relevant instruments/ equipment	Data standard	Data processing	Anticipated quality control protocols
Roughness	All roads	14 km of N1 highway 75 km of Agogo-Dome trunk road 358 km of feeder roads across 8 districts IRI reported at 100-meter intervals	ARRB Roughometer III Device is compliant with Class 3 device as per Word Bank Technical paper 46	ASTM Standard E950/950M Roughometer III User Manual Word Bank Technical paper 46	Data will be processed using Roughometer Data Processing software (ARRB) to produce IRI measurements.	• Calibration will be conducted as per ASTM Standard E950 and the Roughometer III manufacturer’s manual. • Photographic documentation of field application • Video data will be collected from the vehicle carrying the instrument to ensure that it is driven in the wheel tracks and at the designated speed (where safe to do so). • Verification tests will be conducted to establish the repeatability and bias of the IRI measurements produced by the instrument. This will be done by (i) conducting repeated tests on the same sections of road to ensure that average IRI is within 5% (see for example Sayers and Karamihas 1998) and (ii) by conducting test runs on a 320m test section with roughness calculated using rod and level and comparing the test results. Resulting IRI measurements should be within 0.5 m/km for a paved road to satisfy the requirements for Class 3 device (Sayers et. al. in World Bank Technical Paper 46.)

Data Type	Sample unit	Sample size	Relevant instruments/ equipment	Data standard	Data processing	Anticipated quality control protocols
Deflection	Road segment	Full length of N1 highway only Readings taken every 500m at staggered intervals in each direction. Readings will be taken in the outer wheel-path of the outer lane.	Dynatest Falling Weight Deflectometer (FWD) Model DYNATEST 8002-288	ASTM Standard D4694	Elmod6 software will be used for data processing and storage. The adjusted structural number, structural number, and remaining life will be calculated using DARWin 3.01	• Photographic evidence of field application. • Relative Deflection Calibration will be conducted as per ASTM D4694 • Documentation on calibration of deflection sensors conducted by the manufacturer will be submitted to MCC. • Field tests and calibration reports will be documented by the data collectors and submitted to MCC.
Geotechnical	Road segment	N1: Coring and DCP tests conducted at 2km intervals along the distress lane. Test locations in each direction of travel staggered at 1km intervals. Feeder roads and trunk roads: one small hole (less than 300mm x 300mm) taken from a good section of each feeder road. DCP tests conducted in same area.	TRL Dynamic Cone Penetrometer (DCP) for testing CBR Coring equipment (N1): Motorized coring machine with 150mm diameter core barrel and diamond core bit. Materials for patching (as appropriate for road): Gravel, Water, Cement, Crushed Stone, Bitumen Emulsion, Chippings Asphalt Concrete	Layer thickness measured directly form core holes and small pits. DCP penetration resistance data will be used to estimate CBR Core/bore and DCP data will be used to determine pavement thickness	Data will be processed using the TRL UK DCP Program software, or equivalent software proposed by data collector	• Random spot checks by local engineer • Photographic evidence of field application. • Photographic evidence of repair work for cores and holes

Data Type	Sample unit	Sample size	Relevant instruments/ equipment	Data standard	Data processing	Anticipated quality control protocols
Surface condition	Road segment	N1: Full length of N1 highway (project-level data collection) Feeder and trunk roads: Network level data collection (windscreen survey) conducted for full length of network. Short segments of 100m collected at intervals of 1km.	Manual inspection using Trumeter measuring wheel, Camera, 1.5 meter metal straight edge, Steel measuring tape	Distress identification will follow the Ghana Highway Authority Road Condition Survey manual (2003) N1: Surface condition data will be collected at the project level. Distress identification will follow the GHA manual. The data collector shall walk along the road in order to identify and record the type, location, extent and severity of the various distresses present. Information Quality Level for surface condition data, will meet the IQL-2 requirements for HDM-4. Feeder and trunk roads: Surface condition data will be collected at the network level, as outlined in GHA Road Condition Survey manual (2003). At approximately 1km intervals, the data collector walk a 100m section and record the type, location, extent and severity of various distresses present.	Pavement distress will be translated into indicators required for HDM-4 analysis of N1 highway.	• GPS linked video capture to check random sections of road against manual classification and inspection of surface condition. • Spot checks by local engineering consultant. • Collective training of pavement raters to ensure that pavement condition is interpreted in a consistent and uniform way. • Periodic rater reviews to verify raters are collecting uniform and consistent data. • Surface condition collected at the network level (feeder and trunk roads) will be compared with video data as well as with data collected on short 100m segments.
Axle load survey	Road segment	Conducted for 3 days for 12-hours N1: Traffic counts will take place concurrently with the axle load survey.	CAS Vehicle Weighing Scale, Model RW-2601P (Static weigh scale)	Classification of heavy vehicle axle configurations as per Ghana Highway Authority.	Individual Axle load measurements will be translated into 8-tonne Equivalent Standard Axle measurements	• Spot checks by local engineering consultant **Calibration:** • Documents certifying periodic calibration of mobile weigh stations and permanent weigh station will be provided to MCC. This involves a truck with known weight being used to calibrate the weigh station.

Data Type	Sample unit	Sample size	Relevant instruments/ equipment	Data standard	Data processing	Anticipated quality control protocols
Traffic Counts	Points along road segment.	A total of 15 stations; 7-day counts, 12-hour counts for 4 days and 24-hour counts for 3 days (to include regional market day). Where possible, counting locations will be placed outside of urban areas (N1 is an urban highway).	Paper-based data collection, with computer based data entry in the field	Classification of vehicles used on paper forms will be based on standard GHA vehicle classification, with any additional vehicle types based on knowledge of local context. Pedestrian traffic will be counted on feeder roads.	Classified traffic counts will be converted to Annual Average Daily Traffic (AADT) using seasonal adjustment factors provided by GHA and DFR	• Training of enumerators, including testing based on pilot traffic counts to ensure proper vehicle classification. • Photographic evidence of traffic counts being conducted. • Spot checks by local engineering consultant.
Expanded vehicle intercept survey	Points along road segment, coinciding with location of traffic count stations. Sample of vehicles will be representative of traffic patterns during survey	N1: 1000 completed surveys with vehicle operators. High-traffic feeder/trunk roads: Approximately 20% of traffic Low-traffic feeder/trunk roads: all traffic. 8-hour day * 3 days; larger sample for feeder roads	Paper-based data collection, with computer based data entry in the field	Purpose-designed survey	N/A	• Pre-testing and piloting of data collection instruments. • Training and testing of enumerators. • Data quality checks for 10% of the sample based on uploaded data, conducting by local engineering consultant. • 100% of questionnaires will be double-entered
Vehicle Operating Cost survey	Vehicle operators, vendors and maintenance providers	5 major transport operators 5 garage /mechanics 5 freight companies 5 vehicle sellers – second hand and new. Coverage by vehicle type based on common vehicles sold and/or used in each region. Data will be collected on the above from each of Northern Region, Greater Accra Region and Ashanti region.	Paper based survey	VOC forms based on HDM-4 input requirements	N/A	• Pilot surveys to test questions and responses • Call back checks by local consultant to verify contacts and information collected

N/A = not applicable.

APPENDIX G:

FEEDER ROADS SAMPLING MEMO

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MEMORANDUM

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TO: Cindy Sobieski and Jack Molyneaux

FROM: Anthony Harris, Laura Meyer, Harry Evdorides, and Delia Welsh **DATE:** 10/17/2018

SUBJECT: Final sampling of feeder roads for traffic counts and vehicle intercept survey, and placement of stations for traffic counts, axle load and vehicle intercept survey

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This memo outlines the final sampling procedure for selecting the feeder roads on which we will conduct traffic count and vehicle intercept surveys. The memo provides an overview of the final sampling approach, summarizes data on feeder roads and explains in detail the steps taken for sampling. We then list the selected sample for roads where the traffic counts and vehicle intercept survey will occur. The memo also discusses the placement of traffic count stations, VIS stations and axle load stations along all roads being studied.

1. Sampling approach

We sampled 12 out of 40 feeder roads for traffic counts from within groupings of roads (referred to as strata) that were created based on the road's region, surface treatment, and traffic volume (high/low). A road was selected for the sample from within the strata with a probability of selection that depends on the length of the road relative to the total length of all roads within the strata. On an ad hoc basis, 2 important roads were selected with 100% certainty and we have documented the rationale for this choice. The remaining 10 roads in the sample were allocated to strata to ensure that at least one road was selected from each strata. Roads for vehicle intercept surveys are selected from the sample of roads where traffic counts will occur, with the aim of including roads from each region and with each characteristic.

2. Summary of the feeder roads portfolio

We categorized the 40 feeder roads using data from Compact documentation, including post-project Economic Rates of Return (ERRs), data collected during the rescoping process, and project documentation (feasibility studies, design drawings and construction completion reports). We divided roads into surface treatment (gravel, bituminous or mixed gravel/bituminous), traffic volume and region. Low volume roads have less than 300 vehicles per day on average, based on the post-upgrade AADT that was estimated during the rescoping process. Table 1 shows the distribution of road segments by grouping as well as the total length in each grouping.

Table 1. Upgraded feeder roads, by type, region, and post-upgrade traffic counts

	Low traffic (less than 300 AADT)						High traffic (Less than 300 AADT)							
	Bituminous		Gravel		Mixed		Bituminous		Gravel		Mixed		Total	
	n	km	n	km	n	km	n	km	n	km	n	km	n	km
Central	2	15					3	37					5	52
Eastern	4	20	6	40	3	19	2	12					15	91
Northern	1	13	4	57	2	32	1	3			1	6	9	111
Volta	4	26					7	75					11	101
Total	11	73	10	97	5	51	13	127	0	0	1	6	40	355

3. Steps taken to select final sample

The sample for traffic counts consists of roads that (1) cover key road characteristics, including the type of road surface, location, and traffic volume, in a way that will allow us to extrapolate traffic growth rates for non-sampled roads, and (2) cover roads where high costs and benefits imply that the selected road would strongly affect the overall ERR for the Feeder Road activity. For a given length of road, low-volume, gravel roads will have a smaller impact on the overall ERR than high-volume, bituminous roads; the former have both lower costs and lower benefits, while the latter have higher costs and higher benefits. Oversampling from roads that strongly affect the overall ERR for the Feeder Road activity gives us a more accurate estimates of the project ERR. However, oversampling economically important roads comes at the expense of getting accurate estimates of ERRs for low-volume gravel roads. We are still interested in understanding the ERRs for low-volume, cheaper roads, so we carried out a sampling process that balances these competing interests.

After discussion with MCC, and considering multiple options for a measure of roads' contribution to the overall Feeder Roads Activity ERR (See Annex 1), we concluded that length is the most appropriate measure of size, due to its simplicity, objectivity, and its relationship with both cost and benefits. Moreover, this approach can be easily replicated on other, similar projects where roads may need to be sampled.

The sampling process for selecting roads for traffic counts involved the following steps.

1. We reallocated mixed roads to either the bituminous or gravel category to reduce the number of strata. We assigned roads that were primarily bituminous to the bituminous category and roads that were primarily gravel to the gravel category. Three mixed roads in Northern region were categorized as bituminous. Three mixed roads in Eastern region were categorized as gravel. SAN-21 was approximately 50% bituminous and was categorized as bituminous, with the understanding that if it was selected the traffic count would be conducted along the bituminous portion of the road.

2. We allocated the 12 sampled roads across the resulting 10 groupings based on the characteristics in table 2. Table 2 shows the number of roads to be selected from each stratum.
3. Roads with a very high economic importance were selected with 100% probability. These are roads with a length of 10 kilometers or more and an AADT of 1000. Two high traffic bituminous roads, one in the Volta Region, and one in the Central region, met these criteria.

Table 2. Strata for roads selection

	Low traffic (less than 300 AADT)				High traffic (Less than 300 AADT)				Total	
	Bituminous		Gravel		Bituminous		Gravel			
	n	sample (s)	n	s	n	s	n	s	n	s
Central	2	1			3	2*			5	3
Eastern	4	1	9	1	2	1			15	3
Northern	1	1	4	1	2	1			9	3
Volta	4	1			7	2*			11	3
Total	13	4	13	2	14	6			40	12

4. Finally, we randomly selected the remaining 10 roads from the target strata with a probability that is proportional to a road segment's length.[21]

The sample selection process for selecting roads for the vehicle intercept survey was purposive and set out to meet the following criteria:

1. Roads selected for the vehicle intercept survey must also have been selected for traffic counts.
2. At least one road from each region should be selected. In the case of Volta region, one road should be chosen from the cluster of roads built in the Hohoe district (northern Volta region) and another should be chosen from the southern part of Volta region.
3. Both roads with very high economic importance should be selected.
4. The sample should include at least one gravel road and at least one road with low traffic volume.

These four criteria allow for a number of possible combinations of roads to select for the vehicle intercept survey sample.

[21] We used the length reported in contractors' completion reports, and the MiDA compact completion report. In two cases the lengths that were completed with MCC funding differed from what was planned. In one case, the contractor added an additional 0.6km to the end of a bituminous road while remaining within their authorized budget. In another, only 4.3km of the road's 7.9 km was funded by MCC, and the rest was paid for by the Department of Feeder Roads (DFR). In the former case, we include the additional length, and in another, we exclude the DFR-funded portion in order to accurately capture the returns of MCC's investments.

4. Selected sample

The resulting sample for traffic counts, shown in table 3, comprises half high-traffic and half low-traffic roads, and is representative of all regions, and road types. Table 3 also shows two changes to the sample made after observing the roads during the pilot trip.

Table 3. Road selection for traffic counts

ID	Name	Length	Traffic volume	Surface type	Region	District (at time of construction)	Lot	Post-project AADT
AES15B	Amanfrom – Bawjiase*	10.8	High	Bituminous	Central	Awutu Efutu Senya	EC3	4305
AES14	Awutu Breku-Bontrase-Obrakyire	18.9	High	Bituminous	Central	Awutu Efutu Senya	EC2	478
AES19	Ofaakor-Apra-Loye	11.3	Low	Bituminous	Central	Awutu Efutu Senya	EC2	255
AKS10A	Nsawam-Odeikrom	6.7	High	Bituminous	Eastern	Akwapim South	EC1	1090
AKS22	Yaw Duodo-Pepawani	4.7	Low	Bituminous	Eastern	Akwapim South	EC1	155
AKS1	Kofi Kwei-Sakyikrom-Adoagyiri	9.5	Low	Gravel	Eastern	Akwapim South	EC3	134
SAN17	Kumbungu – turn-off to Botange	6.2	High	Mixed**	Northern	Tolon Kumbungu	NR2	772
SAN24	Pong - Landokura - Gubua	13.6	Low	Gravel	Northern	Savelugu Nanton	NR2	75
~~SAN12~~	~~Yong-Sandu-Guno - Kpano -Kpano Jn~~	~~27.5~~	~~Low~~	~~Mixed**~~	~~Northern~~	~~Savelugu Nanton~~	~~NR2~~	~~33~~
SAN13	Savelugu - Zoggu	13.4	Low	Bituminous	Northern	Savelugu Nanton	NR1	272
KTU1	Avi Hevi-Tadzevwu-Abor*	27.7	High	Bituminous	Volta	Ketu	VR5	1992
~~KTU2~~	~~Avalavi-Dekpoyaa-Dekpodome~~	~~12.0~~	~~High~~	~~Bituminous~~	~~Volta~~	~~Ketu~~	~~VR6~~	~~363~~
STO5	Dabala-Lakpo-Agbakope	7.02	High	Bituminous	Volta	South Tongu		
HOH3	Tafi Mador-Jordanu	9.8	Low	Bituminous	Volta	Hohoe	VR3	218

Note: The two crossed out rows of cells indicate that these two changes to the sample were made after observing the roads during the pilot trip.

* Denotes roads that were chosen with 100% certainty.

Following the pilot trip we propose two changes to the selected sample. First, it is clear that roads KTU1 and KTU2 are very similar segments and shifting a station from one of these roads will improve the representativeness of the traffic data. In order to have broader representation of Volta region, we dropped KTU2 and reselected a road from the South Tongu district. The road was selected from the three possible roads from within this district with a probability proportional to length. All three roads are high traffic, bituminous roads. This segment should provide a better representation of traffic for the other roads in South Tongu district. Table 3 shows the replacement road selection.

Second, SAN12 should be replaced with SAN13, and a traffic count station should be placed between the turn-off to Sandu (SAN12) and the road to Zoggu. This portion of the road is an important link between the rural communities served by these roads and the regional market town of Savelugu. Placing a vehicle intercept survey station at this location will permit us to estimate whether traffic is originating from communities along the SAN 12 road and communities along the remainder of SAN13. Table 3 shows the replacement road selection.

From these 12 roads, we have purposively identified a sub-sample of six roads on which to conduct the vehicle intercept survey. The selected roads as well as the reason for selecting them are shown in the Table 4.

Table 4. Road selections for VIS

ID	Name	Length	Traffic volume	Surface type	Region	Reason for selection
AES15B	Amanfrom – Bawjiase*	10.8	High	Bituminous	Central	Economic importance of road based on traffic volume and length.
AKS10A	Nsawam-Odeikrom	6.7	High	Bituminous	Eastern	Example of high traffic volume road in Eastern region. Also important because it provides a link between regional center of Nsawam and other communities linked by MCC roads.
SAN24	Pong - Landokura - Gubua	13.6	Low	Gravel	Northern	Low traffic volume gravel road. Based on pilot trip, this section is representative of other gravel feeder roads in the Northern region. A significant portion of the length built in the Northern region are low-volume gravel roads.
SAN13	Savelugu - Zoggu	13.4	Low	Bituminous	Northern	Based on the pilot trip, this section should be selected because it serves as an important link between the town of Savelugu and the rural communities linked by the feeder roads.
KTU1	Avi Hevi-Tadzevwu-Abor*	27.7	High	Bituminous	Volta	Economic importance of road based on traffic volume and length
HOH3	Tafi Mador-Jordanu	9.8	Low	Bituminous	Volta	Represents roads and road users in northern part of Volta region. This segment is also an example of a low volume bituminous road.

* Denotes roads that were chosen with 100% certainty.

5. Selecting locations for traffic count stations, vehicle intercept survey and axle load survey on N1, trunk and feeder roads.

Final locations for the traffic count stations on the feeder and trunk roads were selected using the following criteria:

1. Stations will be located outside of built-up areas to avoid counting short, within-village journeys.
2. For roads that connect to a regional center or large highway, the station will be located as near as possible to the regional center or main junction so as to capture all traffic coming from communities along the road.

3. For roads that connect two regional centers or two large highways, the station will be located nearest to the larger centre or junction.
4. Stations will be located in a place where traffic counters can safely and comfortably view traffic.
5. Where stations also have a vehicle intercept survey, we will take advice from the police on where vehicles can be safely pulled over for interviews.

Final locations for the traffic count stations on the N1 were selected using the following criteria:

1. One count station will monitor traffic on the segment between Mallam junction (start of N1 project) and the Achimota junction (N6 highway joins N1) and second station will monitor traffic on the segment between Achimota junction and the Tetteh Quarshie Interchange (end of N1 project.
2. Stations will be located in a place where traffic counters can safely and comfortably view all lanes of traffic.
3. The axle load survey and the vehicle intercept survey, as well as one traffic count, will take place at the Dzorwulu junction (5.617974, -0.192555). This location was chosen in consultation with the Accra traffic police because it provides space for vehicles to safely pull over to conduct the survey. This location coincides with axle load surveys and O-D surveys conducted as part of the feasibility study.

Table 5. Approximate location of count stations (coordinates in D.D.)

ID	Name	Latitude	Longitude
AES15B	Amanfrom – Bawjiase*	5.611565	-0.461227
AES14	Awutu Breku-Bontrase-Obrakyire	5.531087	-0.522032
AES19	Ofaakor-Apra-Loye	5.596411	-0.477749
AKS10A	Nsawam-Odeikrom	5.833222	-0.326077
AKS22	Yaw Duodo-Pepawani	5.860396	-0.223457
AKS1	Kofi Kwei-Sakyikrom-Adoagyiri	5.794410	-0.377237
SAN17	Kumbungu – turn-off to Botange	9.567379	-0.988338
SAN24	Pong - Landokura - Gubua	9.706773	-0.815338
SAN13	Savelugu - Zoggu	9.637804	-0.796843
KTU1	Avi Hevi-Tadzevwu-Abor*	6.094879	0.873909
STO5	Dabala-Lakpo-Agbakope	5.993672	0.687960
HOH3	Tafi Mador-Jordanu	6.861316	0.371850
	Agogo – Dome	6.966060	-0.972007
N1	Mallam – Achimota	TBD	TBD
N1	Achimota – Tetteh Quarshie	5.617936	-0.192539

* Denotes roads that were chosen with 100% certainty; all other roads were sampled.

TBD = to be determined.

Annex 1: Calculating ERRs for a single road and for all feeder roads as a single project

This is a simplified representation of the model used in the Feeder Roads closeout ERRs. It does not include the different type of traffic volume change (normal, generated, diverted).

Variables used in ERR model:

$$Length \text{ of road R } in\ km = l_R$$

$$\frac{Cost}{km}\ for\ road\ in\ year\ t = c_{R,t}$$

$$AADT\ at\ time\ t\ for\ vehicle\ type = V_{t,type}$$

$$VOC\ in \frac{\$}{km}\ for\ vehicle\ type = c_{voc,R,type}$$

$$Vehicle\ types = \{pv, tr\} - private\ vehicle,\ truck$$

Formula for annual benefit in a given year:

$$Benefit_{t,R} = l \cdot 365 \cdot \left(V_{t,pv}\left(c_{voc,upgraded,pv} - c_{voc,existing,pv}\right) + V_{t,tr}\left(c_{voc,upgraded,tr} - c_{voc,existing,tr}\right)\right)$$

Formula for annual cost in a given year:

$$Cost_{t,R} = c_{R,t} \cdot l$$

Present value of investment benefits:

$$PV_R = \sum_{t=0}^{20} \frac{l \cdot 365 \cdot \left(V_{t,pv}\left(c_{voc,upgraded,pv} - c_{voc,existing,pv}\right) + V_{t,tr}\left(c_{voc,upgraded,tr} - c_{voc,existing,tr}\right)\right)}{(1+r)^t}$$

Present value of investment costs:

$$PV_R = \sum_{t=0}^{20} \frac{l \cdot c_{R,t}}{(1+r)^t}$$

Overall NPV of a road *R*:

$$NPV_R = l_R \sum_{t=0}^{20} \frac{1}{(1+r)^t} \cdot (365 \cdot \left(V_{t,pv}\left(c_{voc,upgraded,pv} - c_{voc,existing,pv}\right) + V_{t,tr}\left(c_{voc,upgraded,tr} - c_{voc,existing,tr}\right)\right) - c_{R,t})$$

The ERR for an individual road is the value of *r* such that $NPV_R = 0$.

The ERR spreadsheet calculates the Feeder Road project ERR by summing the net benefits of each road in a given year across all 40 roads. The net present value

The Feeder road project ERR across all 40 roads is the value of *r* defined by the following equation:

$$NPV = 0 = \sum_{t=0}^{20} \frac{1}{(1+r)^t} \sum_{R=1}^{R=40} \left(Benefit_{t,R} - Cost_{t,R}\right)$$

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