Policy Brief
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Quantifying the economic benefits of public transportation in Kampala

In brief:

- Traffic congestion is a major issue in cities around the world with potentially negative effects on outcomes ranging from economic activity to health.
- This brief quantifies the cost of congestion in the Greater Kampala Metropolitan Area (GKMA) and estimates the economic benefits of a planned Bus Rapid Transport (BRT) system.
- The researcher finds the daily cost of congestion in GKMA in was equal to USD 1.5 million (4.2% of GKMA's daily GDP).
- On the other hand, the two BRT lines planned to be implemented in Kampala city are estimated to lead to daily travel time reductions of 173,000 USD (0.5% of the GKMA's daily GDP). This means the costs of construction can be recovered after 12 years.
- The researcher makes three policy recommendations on how public investment in infrastructure can address congestion.

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Cities in gridlock

Traffic congestion is a major issue in cities around the world, particularly in developing countries, with potentially negative effects on outcomes ranging from economic activity to health. While transport linkages are crucial in connecting workers and businesses in cities, current infrastructure levels in many cities are overwhelmed by a rapidly growing number of vehicles. With high population growth and growing purchasing power for vehicles, the need to reduce traffic congestion is likely to become increasingly urgent in many developing cities in the future.

Investments in public transportation systems are crucial in reducing congestion in cities, by expanding the effective capacity to transport large numbers of people. Bus rapid transit (BRT) systems, where buses have priority or sole use on dedicated lanes, may be particularly valuable for high density urban areas. If well designed and implemented, BRT systems can represent a more cost-effective alternative to metro and light-rail systems with comparable carrying capacities.[1] Approximately 170 cities around the world, many of which in developing countries, have implemented BRT systems to improve urban mobility.[2] However, up to date only five African cities have a BRT system, compared to 55 in Latin America.

To shed light on how Kampala could benefit from such investments, this brief analyses the cost of daily commutes in the city, the cost of congestion and the potential benefits of investments in public transportation (both in terms of time savings and in monetary terms). The analysis in this study is partly based on planned BRT projects included in the KCCA's Multi-Modal Urban Transport Master Plan 2040 and estimates the magnitude of the benefits related to these planned public transportation investments.

Quantifying costs and benefits: Methodology

This study quantifies the cost of travel time and of congestion as well as the potential benefits of the KCCA's planned BRT routes.[3]

To estimate the total time spent travelling in Kampala, the study combines information about residents' commuting behaviour from a travel habit survey (THS) conducted in 2016/2017 with data on predicted trip duration from Google Maps. The THS was conducted by ROM Transportation, TNM and Cambridge Systematics from June 2016 to February 2017 in response to a demand from KCCA. It contains information on all of the respondents' trips made the previous day, including trip duration, origin, destination, household income, mode od transport and employment status of roughly 600 respondents and 1400 trips. In-traffic duration predictions for each trip were obtained from Google Maps using the Google Maps Directions API. Data on the road network of Kampala district from OpenStreetMap and an optimisation algorithm in ArcGIS are used to estimate the benefits of two BRT planned by the KCCA.[4]

This study estimates the cost of total travel time by collecting in-traffic predictions from Google Maps for all trips and their time of departure reported in THS. Since Google Maps currently only predicts the duration of trips using private vehicles, the Google Maps data are inflated to match the trip durations reported in the THS more closely. To estimate congestion, each trip's total duration is decomposed into duration due to congestion and duration at free flow speed, i.e. without congestion:

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[1] Robert Cervero (2013) "Bus Rapid Transit (BRT): An Efficient and Competitive Mode of Public Transport" Working Paper
[2] See: https://www.globaldev.blog/blog/bus-rapid-transit-better-urban-mobility-lessons-bogota-jakarta and https://brtdata.org/ (as of 04.05.20)
[3] The analysis of the BRT route implementation includes trips that are made to/from other GKMA districts (Mpigi, Mukono, Wakiso), but only the part of the trip within Kampala district is considered.
[4] To find optimal routes between reported origin and destination locations a Least Cost Path algorithm in ArcGIS was used.

$$\text{duration}_i = \text{duration}_i^{\text{freeFlow}} + \text{duration}_i^{\text{congestion}}$$

As in previous research (Akbar et al. 2018), $\text{duration}_i^{\text{freeFlow}}$ is measured by Google Maps predictions of each trip at 2am when congestion is likely negligible. An estimate of overall congestion can then be obtained by subtracting the duration at free flow speed from total duration for each trip.

To estimate the benefits of the KCCA's planned BRT lines, Kampala's road network was assigned travel speeds that match the trip durations observed in the inflated Google Maps data. Consequently, the speed is set to 3-20 km/h depending on the type of road (footway, residential, motorway etc.) for the main results. Baseline trip durations, i.e. in absence of the planned BRT lines, are then computed by finding the fastest way to travel from origin to destination as reported in the THS. Similarly, scenarios that take into account the implementation of the BRT lines, both individually and combined, are computed by assigning an increased speed of 25 km/h[5] to the corresponding road segments and finding the fastest path between origin and destination. Since the construction of BRT lanes reduces the number of regular traffic lanes and, thereby, likely increases congestion for non-BRT transportation, the latter's speed is reduced by 14% on BRT segments.[6] To model changes in the public transport ridership rate as a consequence of this improvement in public transportation, the elasticity of public transport usage (with respect to the trip duration differential in public vs. private transportation) is estimated in a Discrete Choice Model using data from the THS. Using this elasticity, the public transport ridership rate for each origin-destination pair after the implementation of the BRT lines is predicted as shown in figure 2. To estimate the BRT time savings, trip durations from scenario with BRT lines are subtracted from the one obtained in the baseline scenario, i.e. without BRT lines.

The monetary value of these time savings is computed with a Value of Time (VoT) measure constructed from household-level income data.[7] This allows for a comparison of the monetary value of time savings to GKMA's daily GDP.

Results

Table 1 reports the total travel time in the area of the GKMA, which amounts to USD 5.1 million per day or 13.7% of GDP of the GKMA and 6.2% of Uganda's GDP.[8][9] The magnitude of these numbers highlights the potential economic benefits of investments that reduce traffic congestion and/or increase travel speed.

Table 1: Travel time and congestion per day

Unit	Total travel time	Congestion
Hours	4,686,976	1,512,748
Dollars	5,056,474	1,549,986
% daily GDP GKMA	13.7	4.2

[5] Based on Hidalgo and Graftieux 2008 and ACEA 2013.
[6] The increase in congestion for non-BRT transport on BRT segments is based on Hidalgo and Pai 2009 and Gaduh et al 2017, who analze the implementation of BRT lines in New Delhi and Jakarta respectively.
[7] The baseline VoT measure is defined as follows: Household income by employment status: each household's income is divided amongst its employed persons and assigned only to employed individuals. All others are assigned a VoT of zero. Alternative measures and the correspondimng results are reported in the appendix.
[8] District-level estimates of GDP per capita are based on Wang et al. 2019. Population projections are taken from the Ugandan Bureau of Statistics.
[9] All results are based on travel habits collected in 2016/2017. They are reported per day (including shares of GDP) and in 2016 USD.

% daily GDP Uganda	6.2	1.9

Congestion is estimated to cost USD 1.5 million daily, representing 4.2% of the GDP of GKMA and 1.9% of the GDP of Uganda.

The two BRT lines (depicted in figures 1 and 2), which the KCCA is planning to implement by 2025, are estimated to reduce total travel time by approximately USD 173,000 (≈4%) per day, representing 0.5% of GDP of GKMA.[10]

Furthermore, the time reduction of both BRT lines combined is larger than the sum of time reductions through both lines independently, since more residents make use of the public transportation network when it is more extended, i.e. more attractive to potential users. As shown in figure 1, public transport usage is predicted to increase by 18% (8.8pp) when both BRT lines are available.

The estimates reported in table 2 suggest that the cost of construction of both BRT lines can be recovered after approximately twelve years.[11] However, the results are a lower bound of the true impact since this study does not account for beneficial impacts other than reductions in travel times. Examples of these additional effects are: the spatial reallocation of firms and households leading to higher levels of welfare and output through a more efficient urban structure; positive health effects through a reduction in air pollution and traffic accidents; and beneficial environmental effects through a reduction in transport emissions.

Table 2: Results of BRT implementation scenario

Unit	Total travel time	BRT line 1	BRT line 2	BRT lines 1 & 2
Hours	3,556,152	81,758	66,848	166,714
Dollars	4,244,076	77,388	65,099	173,207
% GDP GKMA	11.5	0.2	0.2	0.5
% GDP Uganda	5.2	0.1	0.1	0.2

The BRT lines' estimated benefits depend on the system's operating speed. While the results in table 2 are obtained for a constant operating speed of 25 km/h based on the literature, figure 2 shows how sensitive the estimated benefits are to changes in the operating speed. In comparison to the baseline speed of 25 km/h, the economic benefits of both BRT lines together are found to be almost 50% higher with an operating speed of 30 km/h and 70% lower if the BRT sytem runs at 20 km/h. The differences between the speed scenarios arise from *i)* the BRT line completing any given distance at a different speed and *ii)* from differences in BRT ridership rates as the system as a whole becomes more/less attractive at a higher/lower operating speed (figure 1). This emphasises the importance of ensuring a sufficiently high operating speed.

[10] Assuming that the congestion for non-BRT transport does *not* increase on BRT road segments leads to travel time reductions (in USD) that are 9.8%, 2.4% and 9.5% higher for the implementation of BRT line 1, BRT line 2 and both lines together, respectively.
[11] The cost-benefit calculations assume accost per kilometer of 7m USD per lane and the construction of two lanes.

Figure 1: Changes in public transport ridership

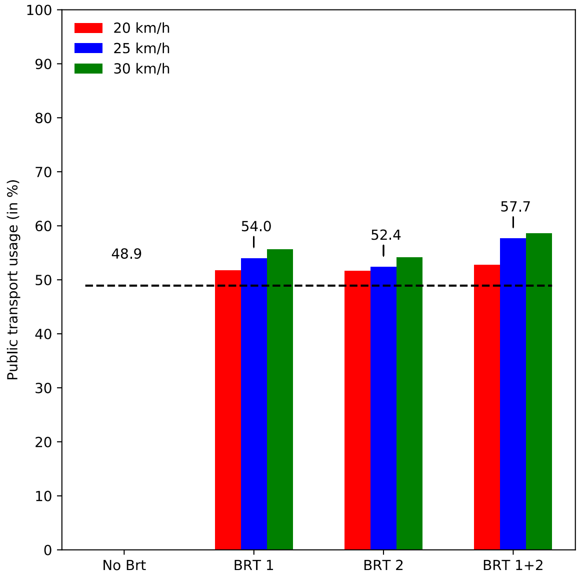
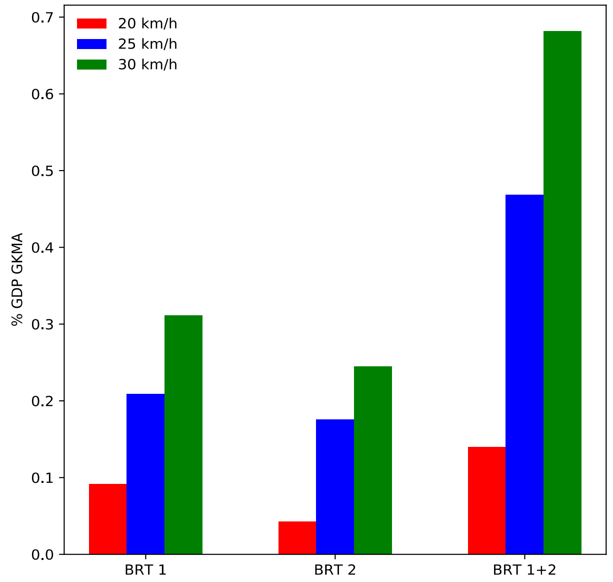


Figure 2: Time savings by BRT speed



It is important to note that the impact of the two BRT lines differ by division. Figures 3,4 and 5 show the monetary value of total travel time and the time reduction through both BRT lines combined and separately. In these figures, the travel time (reduction) of each trip is attributed to the individual's division of residence. The monetary value of total travel time ranges from 0.6% in Rugaba Division in the west to 4.3% of GDP in Nakawa Division in the east. Nakawa Division is also the area that benefits most from the introduction of both BRT lines together. Its travel time savings as a share of GDP are almost three times higher than that of the second most positively affected area, Rugaba Division. The estimated total travel time and travel time savings are relatively low in Central Division since the majority of households live outside of the city centre. As shown in figure 3, both BRT lines taken separately affect the city's divisions to different degrees, highlighting the importance of taking the regional impact into account when planning investments in public transportation.

Figure 3: Total travel time.

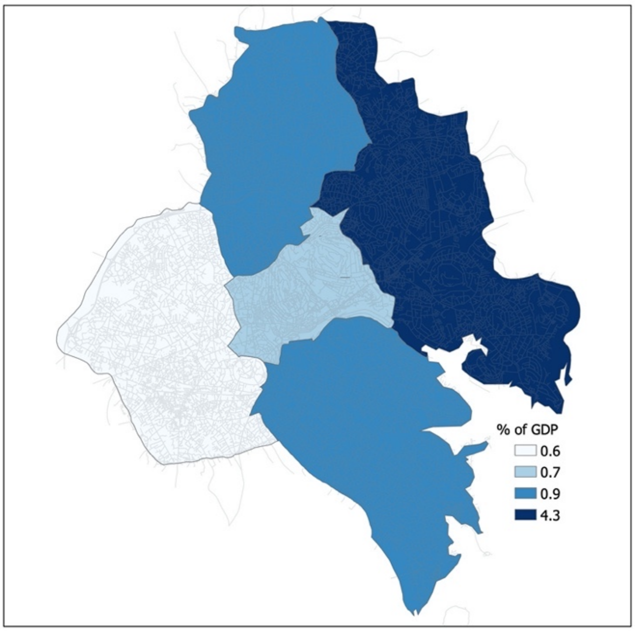


Figure 4: Travel time reductions through BRT lines 1 and 2

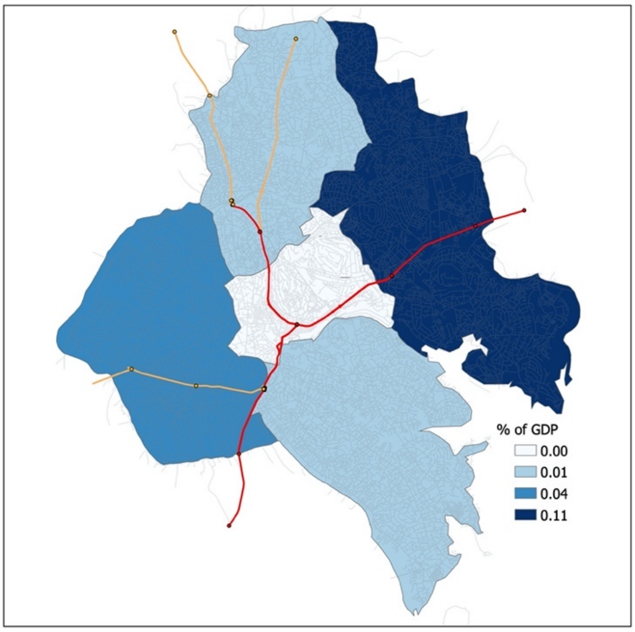
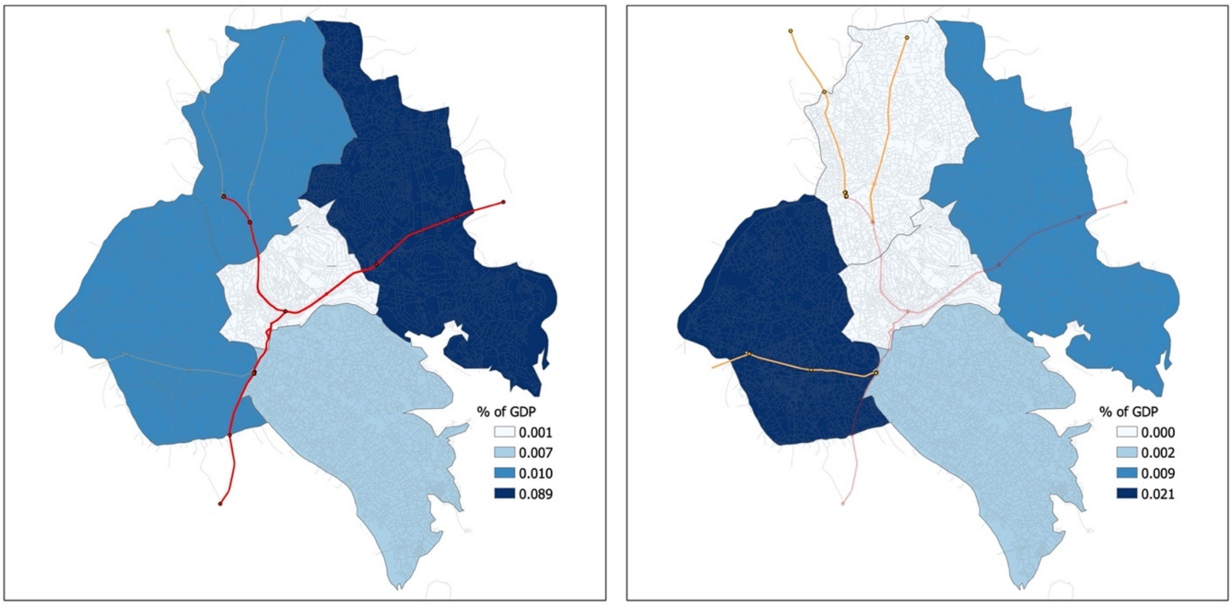


Figure 5: Monetary travel time reductions (in %) through BRT line 1 (left) and BRT line 2 (right)



Policy recommendations

The analysis above suggests three key policy recommendations:

1. Invest in public transportation infrastructure given large potential economic gains.

The results of this study suggests that the cost of congestion is relatively high ($\approx$ 4.2% of daily GKMA GDP) and that planned infrastructure projects lead to sizeable economic gains. In particular, the results suggest that the economic benefits, resulting exclusively from travel time reductions, offset the initial costs of construction after 12 years. Taking into account the spatial reallocation of firms and households leading to higher welfare and output through a more efficient urban structure might reduce the recovery period to 7-9.5 years.[12]

Although including positive effects on health and the environment would further increase the benefit-cost ratio, they are not taken into account here due to the unavailability of estimates in the literature that are compatible with the context of this study. Additionally, the data used in this study suggest that the average travel speed ($\approx$18.6 km/h) is relatively low in Kampala. A recent study using a similar methodology finds an average travel speed of 24 km/h in a sample of 154 Indian cities and 35 km/h for Central Chicago, US.[13] Against this backdrop, the potential gains of investments in public transportation in Greater Kampala appear to be large.

2. Take differential impacts of public transport investments on divisions into account.

Public transportation infrastructure is likely to affect certain areas of a city more than others, e.g. based on proximity and/or commuting habits. This could give rise to an inefficient

[12] Tsivanidis 2019 estimates the reallocation and general equilibrium effects to account for 20-40% of the overall impact on welfare and output for TransMilenio (BRT system in Bogotá, Colombia)
[13] Akbar et al. 2018

allocation of economic activity that hinders productivity spillovers in areas of the city that are not well connected since firms are likely to take the availability of public transportation infrastructure into account when choosing their location.[14] Furthermore, real estate prices have been shown to rise in response to public investment in infrastructure in affected areas in previous studies. As a result, socio-economic segregation could increase if some areas are neglected in terms of their connectedness to public (transportation) infrastructure.

It is therefore important to balance interests and needs of the population in different parts of the city when designing the public transportation infrastructure. In the case of Kampala, the two BRT lines considered in this study are estimated to benefit the Rugaba Division in the eastern part of the city more than the remaining ones. For this reason, it is important to ensure that the other divisions are sufficiently connected to the city's public infrastructure system in future public transportation projects.

3. Systems need to be planned in detail to ensure planned operating speed.

The estimated economic benefits of the BRT system are sensitive to the its average operating speed, as shown in figure 1.

BRT systems that achieve a high operating speed share some common features: rights-of-way configurations, i.e. a lane (median or on one/both side(s)) is reserved for BRT buses, instead of mixing BRT buses with the regular traffic. Auxiliary passing-lanes at stations have been found to increase the operating speed in case of multiple BRT lines considerably. At particularly busy intersections, high-quality systems make use of (relatively cheap) traffic signal schemes that prioritise BRT buses or (more expensive) grade separation, i.e. the separation of BRT bus flows and regular traffic through lanes at different heights (e.g. bridges). The spacing of stations should depend on the surrounding area's density. In well-functioning BRT systems, stations are typically spaced in distances of 500 - 1500 meters depending on the population density of the surrounding area. In addition to ensuring the system's travel speed, adequate spacing of stations is also required to achieve a high BRT ridership. The latter also increases with the system's length (in combination with other forms of public transportation), since a larger public transportation network makes its usage more attractive to potential users. To achieve a sufficiently high BRT ridership, prices also need to be affordable for the overall population. If an adequate average operating speed or ridership are not met, the system's economic benefits shrink. Achieving them, thus, needs to be a key priority in the planning, implementation and maintenance processes.

[14] Bird and Rauch 2015

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