



Travel time and perinatal mortality after emergency caesarean sections: an evaluation of the 2-hour proximity indicator in Sierra Leone

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ABSTRACT

Introduction Longer travel times are associated with increased adverse maternal and perinatal outcomes. Geospatial modelling has been increasingly used to estimate geographic proximity in emergency obstetric care. In this study, we aimed to assess the correlation between modelled and patient-reported travel times and to evaluate its clinical relevance.

Methods Women who delivered by caesarean section in nine hospitals were followed up with home visits at 1 month and 1 year. Travel times between the location before the delivery and the facility where caesarean section was performed were estimated, based on two models (model I Ouma *et al*; model II Munoz *et al*). Patient-reported and modelled travel times were compared applying a univariable linear regression analysis, and the relation between travel time and perinatal mortality was assessed.

Results The median reported travel time was 60 min, compared with 13 and 34 min estimated by the two models, respectively. The 2-hour access threshold correlated with a patient-reported travel time of 5.7 hours for model I and 1.8 hours for model II. Longer travel times were associated with transport by boat and ambulance, visiting one or two facilities before reaching the final facility, lower education and poverty. Lower perinatal mortality was found both in the group with a reported travel time of 2 hours or less (193 vs 308 per 1000 births, $p<0.001$) and a modelled travel time of 2 hours or less (model I: 209 vs 344 per 1000 births, $p=0.003$; model II: 181 vs 319 per 1000 births, $p<0.001$).

Conclusion The standard model, used to estimate geographical proximity, consistently underestimated the travel time. However, the conservative travel time model corresponded better to patient-reported travel times. The 2-hour threshold as determined by the Lancet Commission on Global Surgery, is clinically relevant with respect to reducing perinatal death, not a clear cut-off.

INTRODUCTION

Universal Health Coverage and the health aspirations defined by the Sustainable

Key questions

What is already known?

- ▶ Increased travel times to a facility are associated with increased risk of adverse perinatal outcomes.
- ▶ Geospatial modelling has been increasingly used to estimate geographical proximity to health facilities.
- ▶ Geospatial modelled travel time can significantly underestimate the reported travel time.

What are the new findings?

- ▶ Conservative travel time models correspond better with patient-reported travel times.
- ▶ With respect to the risk of perinatal death, the 2-hour threshold as determined by the Lancet Commission on Global Surgery, is clinically relevant but not a clear cut-off.

What do the new findings imply?

- ▶ Geospatial travel time models must be interpreted with caution.
- ▶ Input variables for geospatial travel time modelling should be carefully selected.

Development Goals will not be achieved without access to, and availability of, affordable and safe surgical and anaesthesia care.¹ This includes access to caesarean sections as an integral part of comprehensive emergency obstetric care, which can save the lives of both mother and neonate when performed for the appropriate indications and at the right time.

Studies from Rwanda, Wales, France and the Netherlands have shown an increased risk of adverse perinatal outcomes with longer travel time from home to hospital.^{2–5} For obstetric emergencies, 2-hour access has been widely accepted as the critical time from postpartum haemorrhage to death if no intervention is provided.⁶ However, there is no evidence supporting an exact 2-hour cut-off. The Lancet



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Commission on Global Surgery (LCoGS) adapted this benchmark, setting the target that 80% of the population should live within 2 hours of a facility that can perform caesarean sections, laparotomies and treatment of open fractures.¹ This geographical proximity indicator has been included in WHO 100 Core Global Health Indicators.⁷ Still, few countries have reported on this indicator,⁸ such that the global community needs a robust tool to measure geographic proximity in order to plan and monitor access to care.

Geospatial modelling has increasingly been used to estimate geographical proximity to healthcare,⁹ including emergency obstetrics.¹⁰ However, different geospatial models apply different input variables, such as travel speeds and road network standards.^{11–15} These selected input variables are often not validated, and little is known about how modelled travel times relate to patient-reported travel times.

A recent single-facility study from Rwanda comparing patient-reported travel time with geospatial modelled travel time concluded that the latter significantly underestimated real travel time.¹⁶ Possible reasons for this deviation include applied assumptions about modes of transport, travel speeds and travel routes. In the present study, we extended the analysis to nine hospitals across all regions of Sierra Leone, and we compared reported travel times with estimates produced by two geospatial models.

The aim of this study was to assess the correlation between travel time reported by patients and travel time estimated by two geospatial models and to evaluate the relation between travel time and perinatal mortality.

METHODS

Sierra Leone, in West Africa, reports some of the world's worst maternal and perinatal health outcomes.¹⁷ More than half (54.4%) of the deliveries take place in a health facility,¹⁸ either in one of the 1160 primary healthcare units, or 24 public or 30 private hospitals.¹⁹ The national population caesarean section rate is 2.9%,²⁰ far below the suggested threshold of 10%–19%,^{21 22} and reflects limited access to emergency obstetric services in the country. Delayed and substandard care results in a perinatal mortality rate after caesarean section of 190 per 1000 births,¹⁸ much higher than the national perinatal mortality rate of 39 per 1000 pregnancies.²³

Study participants

This study was part of a prospective multicentre audit comparing outcome of caesarean sections performed by medical doctors and associate clinicians in nine hospitals in Sierra Leone.^{23 24} The study facilities consisted of four district hospitals, one regional hospital, the national maternity referral hospital and three private non-profit hospitals, located in all geographical regions of Sierra

Leone. Women who underwent a planned caesarean section were excluded from the analysis.

Data collection

In each of the participating hospitals, anaesthesia team members were trained to enrol patients and do the in-hospital data collection. Data collection was supervised and reviewed by the primary investigator, during hospital visits at 1–3 weeks intervals, throughout the whole study period. Data were entered into a Microsoft Excel 2016 database in the study facilities and inconsistent or missing data were supplemented from operation logbooks or patient files. During admission, the following data was collected: the patient's address before coming to the hospital; patient-reported estimated time from the place of stay before the delivery to the facility where the caesarean section was performed; other health facilities visited en route to the hospital; and clinical process and outcome data. Except for clinical data, information was provided by patients and their relatives. Follow-up home visits were conducted at 1 month and 1 year after discharge by four research nurses. During the home visits, data collected while admitted was verified, information regarding the means of transport to the hospital was collected and geolocations were recorded. OpenStreetMap was used to review all geospatial data regarding location before coming to the hospital.²⁵

Table 1 Comparison of two geospatial models

	Model I Based on Ouma <i>et al</i>	Model II Based on Munoz <i>et al</i> *
Travel speeds (km/h)		
Tree cover	5	1.5
Scrub cover	5	2.5
Grassland, cropland, bare and cultivated areas	5	1.67
Water bodies (including rivers)	N/A	N/A
Primary roads	100	50
Secondary roads	50	20
Tertiary roads	30	5
Road network†	OpenStreetmap	OpenStreetmap
Spatial grid‡	94 m	94 m
Slope analysis (using DEM in analysis)	No	Yes
Including rural/unclassified roads as tertiary roads	No	Yes

Comparison of two geospatial models based on the methodology described by Ouma *et al*¹¹ and “scenario 3” Munoz *et al*.¹²

*Walking and public transport scenario.

†In this study we extracted the road network from OpenStreetMap while Ouma *et al* combined the road network from OpenStreetmap and Google Map Maker Project and Munoz *et al*. obtained the road network from Centre for Geographical Information Systems – National University of Rwanda.

‡In this study we applied a spatial grid of 94 m compared to a spatial grid of respectively 100 m and 90 m in the original articles. DEM, digital elevation model; N/A, not assigned.

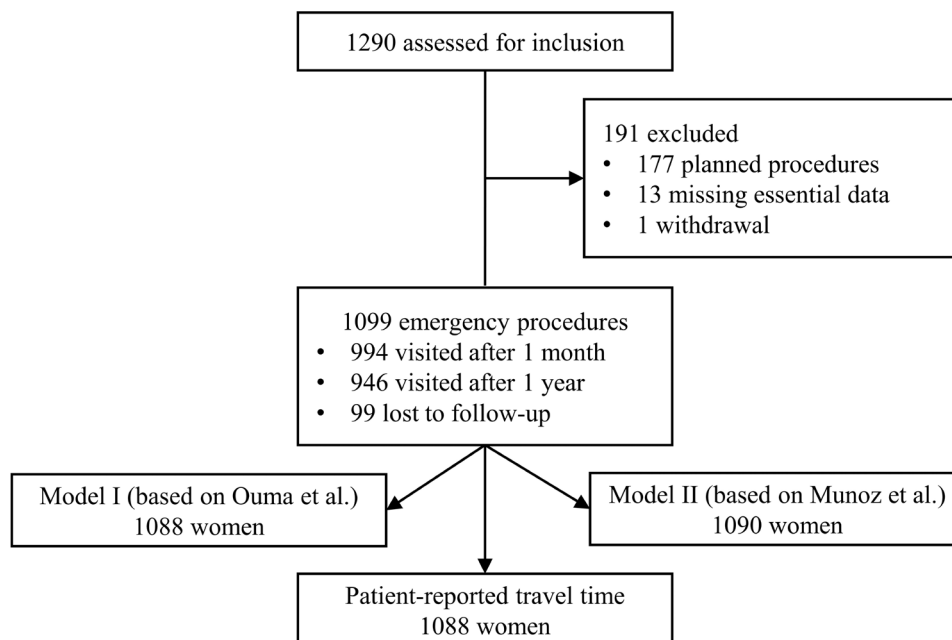


Figure 1 Study flow chart. Caesarean sections included in and excluded from the study. Analysis was performed for all patients, with and without follow-up. For 11 patients, no patient-reported travel time was recorded. For model I (based on Ouma *et al*¹¹) and model II (based on Huerta Munoz *et al*¹²), 11 patients and 9 patients, respectively, had a geolocation that was not assigned a travel time, due to surrounding water bodies.

Geospatial modelling

Two previously published geospatial models were used to create travel time maps. The first (model I) was based on the methods described by Ouma *et al*¹¹, which overestimated geographical access compared with patient-reported travel time in a recent study.¹⁶ Several more conservative national models have been published from Rwanda, Ghana, Tanzania and Zambia.^{12–15} As a sensitivity analysis, the model from Rwanda (Huerta Munoz *et al*¹², walking and public transport scenario) was applied to our data set as it presented the most conservative travel time estimates. Minor adjustments were made to both models to increase the reproducibility (table 1).

Based on the two models, two maps were generated for each of the nine study hospitals (see online supplemental figure 1), using the open-source WHO tool AccessMod V.5.6.0,²⁶ freely available geospatial data and geographical information systems (GIS) desktop software (QGIS V.3.12, Open Source Geospatial Foundation Project). The input layers for each map analysis were a Digital Elevation Model (DEM) with a resolution of 94m and a vegetation map extracted from the 2016 Africa land cover (Contains modified Copernicus data (2015/2016), ESA Climate Change Initiative-Land Cover project 2017). Rivers and road networks, with primary (including trunk roads), secondary and tertiary roads (including unclassified roads for model II), were retrieved from OpenStreetMap.²⁵ The models were based on the assumption that patients would reach the nearest road at walking speed and then continue with other means of transport. Road and non-road speeds varied between the models. For model II, an anisotropic analysis using the DEM was

incorporated, implying that travel speeds were affected by the slope of the terrain. For each patient, travel time to the facility was extracted from the facility-specific maps with QGIS V.3.12 software.

Statistical analysis

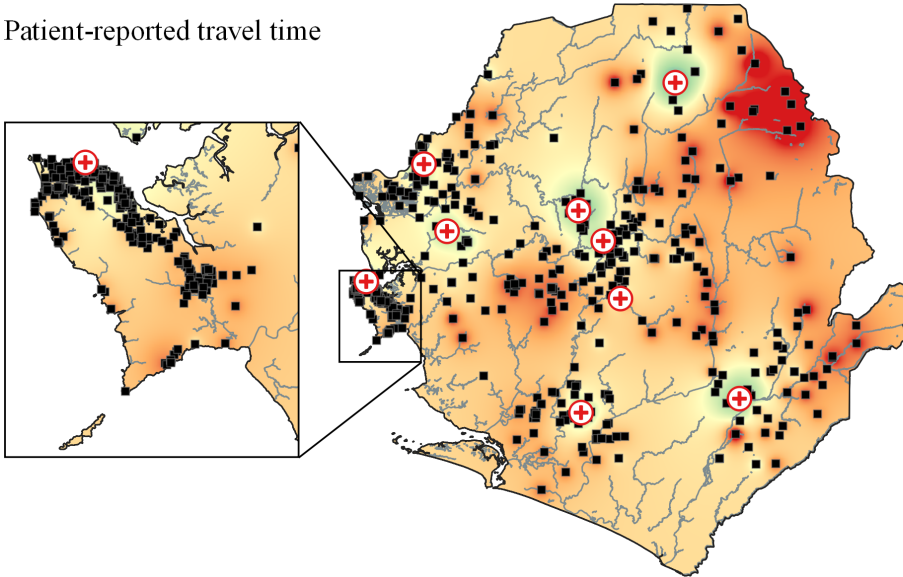
Univariable linear regression analysis was used to compare patient-reported and geospatial modelled travel times. For each patient, a conversion factor was calculated by dividing the modelled travel time by the patient-reported travel time. Median and IQRs were used to present the non-normally distributed variables travel time and conversion factor. Travel time comparisons were presented using scatter plot with regression line and analysed with correlation coefficients. Statistical analyses were performed with STATA V.16.0 (StataCorp). P values of less than 0.05 were considered statistically significant. For patients that used multiple means of transport, the main mode of transport was presented. Maps were produced with QGIS V.3.12 to illustrate patient-reported and geospatial modelled travel times, using the raw output of the AccessMod tool and an interpolated surface of patient-reported travel times. The interpolation was produced using inverse distance weighting.

Written informed consent was obtained from each woman by signature or thumbprint, either before or as soon as possible after surgery. The study is registered in the international clinical trial register (ISRCTN16157971).

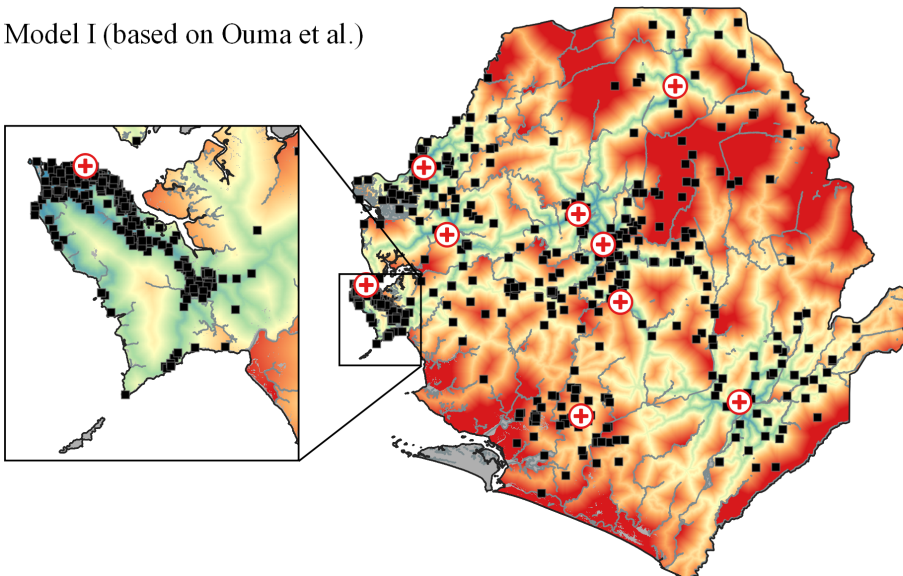
Patient and public involvement

Patients were involved in the selection of the content of the health promotion packages provided as an incentive

Patient-reported travel time



Model I (based on Ouma et al.)



- Legend
- Study Hospitals
 - Patient locations*
 - Rivers
- Travel time (minutes)
- < 30
 - 30 - 60
 - 60 - 120
 - 120 - 240
 - > 240
 - No data

Model II (based on Munoz et al.)

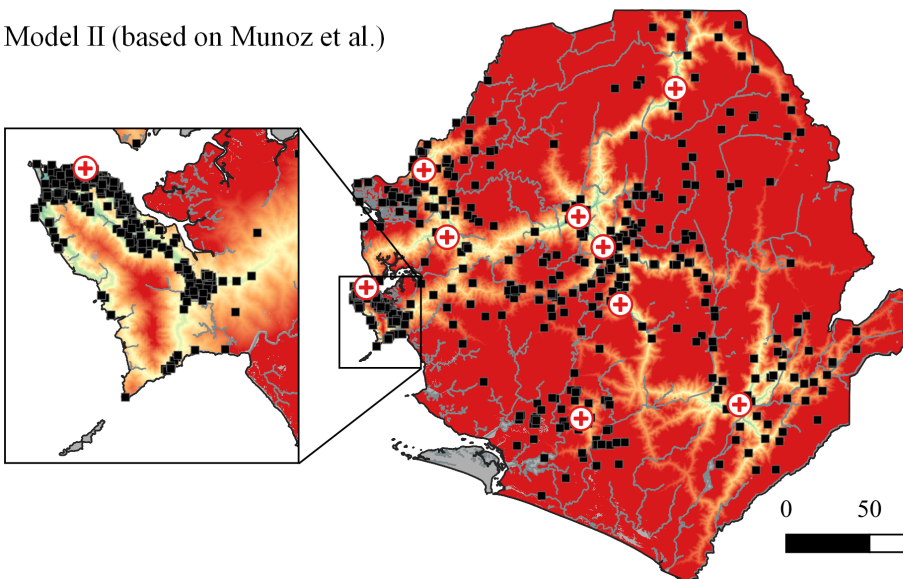


Figure 2 Patient-reported and geospatial modelled travel time (model I based on Ouma *et al*¹¹, model II based on Huerta Munoz *et al*¹²) to the nine study hospitals. Patient locations before travelling to the caesarean section Hospital. *Patient locations before travelling to the hospital where the caesarean section was performed.

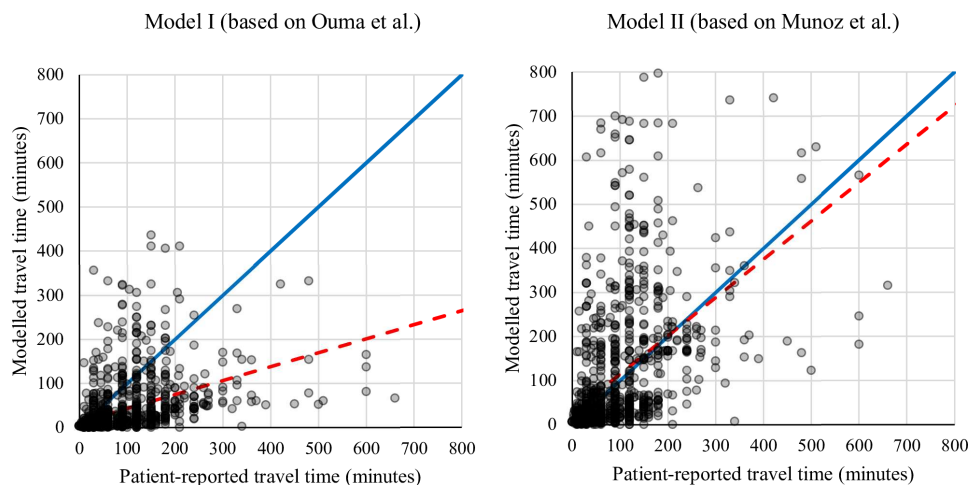


Figure 3 Scatter plot comparing patient-reported travel time and modelled travel time for model I based on Ouma *et al.*¹¹ and II based on Huerta Molina *et al.*¹² There was a moderate positive relationship between patient-reported travel time and model I ($r=0.420$; $p<0.001$) and model II ($r=0.487$; $p<0.001$). The red dotted line is the regression line, for model I ($y=0.32 * x+12$) and model II ($y=0.87 * x+28$). The blue line represents equality.

during home visits and provided feedback on the burden of the questionnaires.

RESULTS

Between 1 October 2016 and 5 May 2017, 1276 caesarean sections were included in the study, among which 177 were planned and 1099 were emergency caesarean sections (figure 1).²⁴ Of all emergency caesarean sections, 994 (90.4%) were followed up with a home visit after 1 month and 946 (86.1%) after 1 year. Patient-reported travel time was retrieved for 1088 women (99.0%). Geospatial modelled travel time for emergency caesarean sections was obtained for 1088 women (99.0%) and 1090 women (99.2%) for model I (based on Ouma *et al.*) and model II (based on Huerta Munoz *et al.*¹²), respectively. Figure 2 presents the patient-reported and modelled travel times for the nine hospitals combined.

The median travel time reported by patients was 60 min (IQR 30–120), which was longer than that estimated with model I (13 min, IQR 4–44) and model II (34 min, IQR 13–153). There was a moderate positive relationship between patient-reported travel time and model I ($r=0.420$; $p<0.001$) and model II ($r=0.487$; $p<0.001$). In the linear regression analysis, for every unit increase in patient-reported travel time, the modelled travel time increased by 0.32 units (95% CI 0.27 to 0.36) for model I and 0.87 units (95% CI 0.76 to 0.96) for model II (figure 3). Taking these findings into account, the 2-hour threshold, as defined by LCoGS, correlates with a modelled travel time of 5.7 hours with model I and 1.8 hours with model II. The accuracy of both models in predicting if a woman lived within the 2-hour proximity threshold of the hospital was 79% (see online supplemental figure 2); however, model II had much higher specificity (69%) compared with model I (20%).

Of all 938 patients that reported means of travel, 67 (7.1%) reported two or more means of transport.

Patients whose main mode of transportation was boat and ambulance had the longest reported and modelled travel time (table 2). In total, 478 women (43.5%) visited one other facility and 13 (1.2%) visited two other facilities before reaching the hospital where the caesarean section was performed and thereby had longer reported and modelled travel times. In model I, 94 women (8.6%), and in model II, 122 women (11.2%) did not visit the hospital with the shortest travel time (see online supplemental figure 3). The study accounted for this result by using hospital-specific models. Women in the poorest quantile and women with no formal education reported a travel time approximately twice as long as those in the richest quantile and with higher education.

The overall perinatal mortality rate was 219 per 1000 births. Women who reported a travel time of 2 hours or less had significantly lower perinatal mortality compared with those with a longer travel time (193 vs 308 per 1000 births, $p<0.001$). Lower perinatal mortality was also found for modelled travel time of 2 hours or less in model I (209 vs 344 per 1000 births, $p=0.003$) and model II (181 vs 319 per 1000 births, $p<0.001$). When moving the threshold from 2 hours to 30 min, the perinatal mortality rate was significantly lower for both reported travel time ($p=0.025$) and model I ($p=0.040$), and borderline significant for model II ($p=0.071$) (figure 4).

DISCUSSION

Key findings

This study aimed to assess the correlation between travel time reported by patients and travel time simulated with two geospatial models. The 2-hour access threshold, as defined by LCoGS, deviated from model I (5.7 hours) but was comparable with model II (1.8 hours). The secondary aim was to evaluate its clinical relevance and therefore assess the relationship between travel time and perinatal mortality. The 2-hour access threshold is

Table 2 Patient-reported and modelled travel times by category

Category	N	Patient-reported	Model I – based on Ouma <i>et al</i>		Model II based on Munoz <i>et al</i>	
		Travel time in minutes; median (IQR)	Travel time in minutes; median (IQR)	Conversion factor;* median (IQR)	Travel time in minutes; median (IQR)	Conversion factor;* median (IQR)
Main mode of transport						
Boat†	5	180 (90–180)	120 (70–129)	0.67 (0.29–0.72)	279 (103–489)	1.55 (0.43–2.72)
Ambulance‡	399	90 (50–150)	32 (11–64)	0.28 (0.16–0.62)	86 (27–213)	0.89 (0.41–1.90)
Private car	20	43 (35–53)	6 (3–9)	0.11 (0.05–0.21)	12 (7–30)	0.25 (0.19–0.53)
Taxi and poda poda	221	50 (30–100)	7 (3–15)	0.12 (0.07–0.20)	17 (9–35)	0.29 (0.18–0.50)
Motorbike	223	30 (15–80)	6 (3–66)	0.40 (0.20–0.84)	24 (9–153)	1.16 (0.53–2.35)
Walking only	67	20 (10–30)	3 (1–8)	0.13 (0.07–0.40)	9 (5–24)	0.50 (0.20–1.20)
Other	3	120 (30–160)	16 (1–226)	0.10 (0.03–1.88)	34 (3–449)	0.21 (0.10–3.74)
Missing	161	83 (40–130)	19 (7–49)	0.23 (0.13–0.51)	44 (20–156)	0.76 (0.35–1.40)
Referral facilities						
None	608	40 (20–90)	7 (3–20)	0.20 (0.10–0.40)	19 (8–50)	0.5 (0.26–1.21)
One	478	90 (45–150)	31 (10–73)	0.31 (0.15–0.67)	78 (26–214)	0.88 (0.39–1.95)
Two	13	120 (90–180)	187 (44–233)	1.27 (0.58–1.94)	531 (170–573)	3.82 (1.51–4.63)
Wealth quantiles						
I (poorest)	53	113 (60–173)	78 (39–118)	0.67 (0.23–1.27)	179 (88–359)	1.85 (0.72–3.65)
II	57	105 (48–180)	76 (33–101)	0.60 (0.32–1.28)	187 (93–234)	1.63 (0.81–3.04)
III	110	90 (60–150)	48 (21–97)	0.43 (0.24–1.00)	171 (77–290)	1.55 (0.87–2.51)
IV	239	60 (30–120)	25 (6–60)	0.35 (0.19–0.80)	62 (20–199)	1.12 (0.51–2.33)
V (richest)	521	45 (20–90)	6 (3–16)	0.15 (0.08–0.25)	17 (9–38)	0.39 (0.23–0.81)
Missing	119	88 (40–135)	17 (7–39)	0.21 (0.11–0.42)	39 (17–95)	0.60 (0.31–1.26)
Education						
None	397	80 (30–150)	30 (6–75)	0.34 (0.18–0.73)	78 (19–219)	1.03 (0.47–2.20)
Primary	138	60 (30–120)	15 (4–60)	0.23 (0.12–0.73)	42 (13–196)	0.78 (0.33–1.97)
Secondary	377	45 (23–100)	7 (3–22)	0.17 (0.10–0.36)	22 (11–55)	0.47 (0.27–1.10)
Tertiary	82	40 (20–70)	5 (2–8)	0.12 (0.06–0.24)	14 (7–25)	0.33 (0.18–0.76)
Missing	105	90 (45–150)	19 (9–41)	0.22 (0.12–0.45)	40 (24–103)	0.68 (0.33–1.31)
Total	1099	60 (30–120)	13 (4–44)	0.22 (0.11–0.51)	34 (13–153)	0.70 (0.30–1.57)

Comparison of patient-reported and modelled travel times presented by category. The geospatial models are based on Ouma *et al*¹¹ and Munoz *et al*.¹²

*Conversion factor from patient-reported travel time to modelled travel time.

†All five patients used an ambulance and two patients used a motorbike in addition to a boat.

‡45 patients used a motorbike, 10 walked and 2 used a taxi in addition to an ambulance.

IQR, Interquartile range; N, number.

clinically relevant for perinatal mortality, with lower rates associated with shorter travel times, for both reported and modelled travel times.

Interpretation

This study endorses the previous finding that the geospatial travel time model described by Ouma *et al*¹¹ underestimates reported travel time.¹⁶ However, we found that the more conservative model described by Huerta Munoz *et al*¹² provides estimates that are closer to patient-reported travel times. Possible reasons for the difference between patient-reported and modelled travel times are the fact that modelled travel time does not take into account the

actual mode of transport and the actual route—including facilities that are visited before reaching the facility where the caesarean section is performed. Variations in road and traffic conditions due to, for example, seasonal variation and time of the day are other important factors influencing actual travel time.^{27 28}

We also found that between 9% and 11% of the patients did not go to the hospital with the shortest modelled travel time. It is possible that other reasons than shortest travel time play a role in patients' choice of facility, such as expected quality of care.²⁹ The first model did not include trunk roads; consequently, one of the

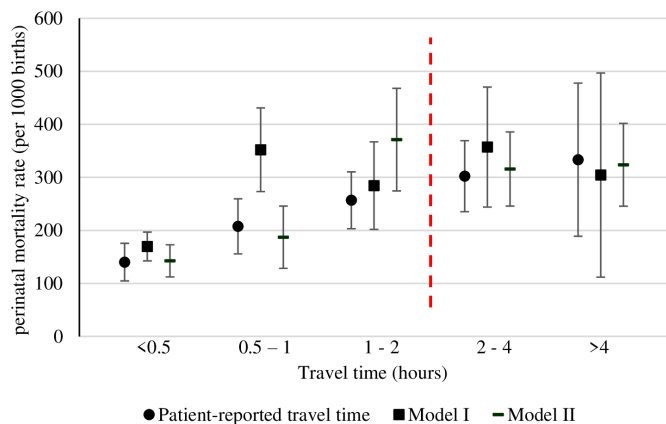


Figure 4 Perinatal mortality rate (per 1000 births) after caesarean section by patient-reported and modelled travel time groups with 95% CI. Model I (based on Ouma *et al*¹¹), model II (based on Huerta Munoz *et al*¹²) and Lancet global surgery indicator threshold of 2 hours (red dotted line). Travel time is defined as the time between home and the facility where the caesarean section was performed.

hospitals was not connected to the road network, leading to longer modelled travel times. Local knowledge of the actual status of the road network and transport system may provide more reliable data than internet-based maps.^{30 31} In a study from the Pacific region reporting on the LCoGS indicators, 5 of the 14 countries that estimated the proportion of the population living within a 2-hour access were based on manual or non-mapping techniques and not on geospatial modelling.³⁰

Patient-reported travel times were provided by the woman and her relatives during admission. The accuracy and reproducibility of the patient-reported travel time as the golden standard can also be questioned, especially in a society with high illiteracy and taking into account the impact of traditional perceptions of time.^{18 32} In addition, the stress of labour may result in a distortion of time perception.³³

Implications

In the context of the commitment of governments to providing Universal Health Coverage and attempting to reach the Sustainable Development Goals, health system planning is essential. Patients will only access the care they need if human resources and supplies are available at the right location and at the right time. Geospatial models can assist in identifying populations living in geographical areas with inadequate access to certain health services, such as emergency obstetric care. Freely available geospatial data, such as DEMs and land-cover maps of increasingly higher quality are continuously becoming available. This, together with open source GIS software, improves access to geospatial modelling techniques and can support evidence-based planning and resource allocation for emergency referral systems in low-resource settings.^{12 34}

An important implication of this study is that geospatial modelling techniques only provide valuable information if input variables are chosen carefully. For example, when modelled travel time is used to compare access to health-care between different countries, care must be taken in the interpretation of the results, as road conditions and transport systems might differ between countries. In low-income countries with more significant infrastructural challenges, a more conservative model with lower travel speeds should be considered.

Patient-reported and modelled travel times are related not only to the risk of maternal death in a situation of postpartum haemorrhage, but also to the risk of perinatal mortality. Applying the 2-hour threshold is pragmatic and useful. However, it is important to realise that this is not a ‘hard’ timeline, and that the group with travel time below 30 min had the best perinatal outcome. This is in line with findings from high-income settings where travel times longer than 15–20 min were associated with poorer perinatal outcome.^{3–5} In most high-income settings 2 hours travel time to reach emergency obstetric care would be considered too long and efforts to shorten travel time to improve perinatal outcome should be made in all settings.

There is an inherent tension between centralisation, which potentially increases travel times for patients but improves quality of care, with calls to reduce travel times taken to reach facilities. Underlining the importance of minimising travel time for the best possible outcome, should therefore be considered alongside issues of quality of care.³⁵ Indeed poor quality of service delivery related to decentralisation of the health system has resulted in calls to redesign and centralise health systems to improve quality of care in low-income and middle-income countries.³⁶ Primary health facilities might create an obstacle for patients in need for a caesarean section and delay access to the required treatment, centralisation can shorten the time to reach the facility that can provide emergency obstetric services.

One recent study modelled the geographical feasibility of service delivery redesign that shifted deliveries from primary care clinics to hospitals in six countries in order to improve the quality of care and concluded that this would reduce 2-hour access by at most 10%.³⁷ This reduction of maximum 10% should be interpreted with caution, taking into account the possible over estimation of accessibility with modelled travel time. In addition, centralisation will disproportionately be disadvantageous for those living in the remote areas having already the poorest outcome and might lead to increasing disparities in health outcomes.

Strengths and weaknesses

The prospective design, in combination with follow-up home visits, made it possible to collect adequate data on the geolocation and clinical outcomes of women who delivered by caesarean section in nine different hospitals. Patient-reported travel time was compared with the

estimates produced by two different models. As many roads are not passable during the rainy season, the inclusion period was purposefully selected during the dry season (October 2016 to May 2017), to maximise the follow-up rate. However, only the patients who reached the hospitals and received the caesarean section were included in the study. Therefore, the most vulnerable group, which has inadequate access to healthcare with potentially longer travel times, might have been excluded from the study, resulting in selection bias. If this study had been performed during the rainy season, patient-reported travel times would have been longer, and this would have favoured a more conservative model.

CONCLUSION

Standard travel time models consistently provide an underestimation of the time needed to access emergency obstetric care, compared with patient-reported travel times. However, conservative travel time models come closer to patient-reported travel times. There is a relation between geographical proximity and perinatal mortality: the shorter the travel time to the hospital, the lower the mortality, for both reported and modelled travel time. The 2-hour threshold, as determined by the LCoGS, is clinically relevant to reducing the risk for perinatal death. Nonetheless, it is not a hard timeline, and 2 hours might be too long regarding perinatal outcome.

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REFERENCES

- Meara JG, Leather AJM, Hagander L, *et al*. Global surgery 2030: evidence and solutions for achieving health, welfare, and economic development. *Lancet* 2015;386:569–624.
- Niyitegeka J, Nshimirimana G, Silverstein A, *et al*. Longer travel time to district hospital worsens neonatal outcomes: a retrospective cross-sectional study of the effect of delays in receiving emergency cesarean section in Rwanda. *BMC Pregnancy Childbirth* 2017;17:242.
- Paranjothy S, Watkins WJ, Rolfe K, *et al*. Perinatal outcomes and travel time from home to hospital: Welsh data from 1995 to 2009. *Acta Paediatr* 2014;103:e522–7.
- Combie E, Charreire H, Le Vaillant M, *et al*. Perinatal health inequalities and accessibility of maternity services in a rural French region: closing maternity units in Burgundy. *Health Place* 2013;24:225–33.
- Ravelli ACJ, Jager KJ, de Groot MH, *et al*. Travel time from home to hospital and adverse perinatal outcomes in women at term in the Netherlands. *BJOG An Int J Obstet Gynaecol* 2011;118:457–65.
- World Health Organization, UN Population Fund, United Nations Children's Fund, Adverting Maternal Death and Disability Program. *Monitoring emergency obstetric care: a Handbook*. France: World Health Organization, 2009.
- World Health Organization. *Global reference list of 100 core health indicators*. Geneva, Switzerland: World Health Organization, 2018. <https://www.who.int/healthinfo/indicators/2018/en/>
- Holmer H, Bekele A, Hagander L, *et al*. Evaluating the collection, comparability and findings of six global surgery indicators. *Br J Surg* 2019;106:e138–50.
- McLafferty SL. GIS and health care. *Annu Rev Public Health* 2003;24:25–42.
- Bailey PE, Keyes EB, Parker C, *et al*. Using a GIS to model interventions to strengthen the emergency referral system for maternal and newborn health in Ethiopia. *Int J Gynaecol Obstet* 2011;115:300–9.
- Ouma PO, Maina J, Thurairana PN, *et al*. Access to emergency hospital care provided by the public sector in sub-Saharan Africa in 2015: a geocoded inventory and spatial analysis. *Lancet Glob Health* 2018;6:e342–50.
- Huerta Munoz U, Källestål C. Geographical accessibility and spatial coverage modeling of the primary health care network in the Western Province of Rwanda. *Int J Health Geogr* 2012;11:40.

- 13 Gething PW, Johnson FA, Frempong-Ainguah F, *et al*. Geographical access to care at birth in Ghana: a barrier to safe motherhood. *BMC Public Health* 2012;12:991.
- 14 Chen YN, Schmitz MM, Serbanescu F, *et al*. Geographic access modeling of emergency obstetric and neonatal care in Kigoma region, Tanzania: transportation schemes and programmatic implications. *Glob Health Sci Pract* 2017;5:430–45.
- 15 Esquivel MM, Uribe-Leitz T, Makasa E, *et al*. Mapping disparities in access to safe, timely, and essential surgical care in Zambia. *JAMA Surg* 2016;151:1064–9.
- 16 Rudolfson N, Gruendl M, Nkurunziza T, *et al*. Validating the global surgery geographical accessibility indicator: differences in modeled versus patient-reported travel times. *World J Surg* 2020;44:2123–30.
- 17 World Health Organization. *Trends in maternal mortality: 1990 to 2015: estimates by who, UNICEF, UNFPA, world bank group and the United nations population division*. Geneva, Switzerland: World Health Organization, 2015.
- 18 Statistics Sierra Leone (SSL) and ICF International. *Sierra Leone demographic and health survey 2013*. Freetown, Sierra Leone and Rockville, Maryland, USA: SSL and ICF International, 2014.
- 19 Government of Sierra Leone Ministry of health and sanitation. *National health sector strategic plan 2017-2021*. Freetown: Government of Sierra Leone Ministry of health and sanitation, 2017.
- 20 Holmer H, Kamara MM, Bolkan HA, *et al*. The rate and perioperative mortality of caesarean section in Sierra Leone. *BMJ Glob Health* 2019;4:e001605.
- 21 Molina G, Weiser TG, Lipsitz SR, *et al*. Relationship between cesarean delivery rate and maternal and neonatal mortality. *JAMA* 2015;314:2263–70.
- 22 World Health Organization Human Reproduction Programme. Who statement on caesarean section rates. *Reprod Health Matters* 2015;23:149–50.
- 23 van Duinen AJ, Westendorp J, Kamara MM, *et al*. Perinatal outcomes of cesarean deliveries in Sierra Leone: a prospective multicenter observational study. *Int J Gynaecol Obstet* 2020;150:213–21.
- 24 van Duinen AJ, Kamara MM, Hagander L, *et al*. Caesarean section performed by medical doctors and associate clinicians in Sierra Leone. *Br J Surg* 2019;106:e129–37.
- 25 OpenStreetMap. OpenStreetMap [Website], 2020. Available: <https://www.openstreetmap.org>
- 26 Ray N, Ebener S. AccessMod 3.0: computing geographic coverage and accessibility to health care services using anisotropic movement of patients. *Int J Health Geogr* 2008;7:63.
- 27 Makanga PT, Schuurman N, Sacooc C, *et al*. Seasonal variation in geographical access to maternal health services in regions of southern Mozambique. *Int J Health Geogr* 2017;16:1.
- 28 Ahmed S, Adams AM, Islam R, *et al*. Impact of traffic variability on geographic accessibility to 24/7 emergency healthcare for the urban poor: a GIS study in Dhaka, Bangladesh. *PLoS One* 2019;14:e0222488.
- 29 Houben RMGJ, Van Boeckel TP, Mwinuka V, *et al*. Monitoring the impact of decentralised chronic care services on patient travel time in rural Africa—methods and results in Northern Malawi. *Int J Health Geogr* 2012;11:49.
- 30 Guest GD, McLeod E, Perry WRG, *et al*. Collecting data for global surgical indicators: a collaborative approach in the Pacific region. *BMJ Glob Health* 2017;2:e000376.
- 31 Watters DA, Guest GD, Tangi V, *et al*. Global surgery system strengthening. *Anesthesia & Analgesia* 2018;126:1329–39.
- 32 Babalola SF, Alokun OA. African concept of time, a Socio-Cultural reality in the process of change. *J Educ Pract* 2013;4:143–7.
- 33 van Hedger K, Necka EA, Barakzai AK, *et al*. The influence of social stress on time perception and psychophysiological reactivity. *Psychophysiology* 2017;54:706–12.
- 34 Delamater PL, Messina JP, Shortridge AM, *et al*. Measuring geographic access to health care: raster and network-based methods. *Int J Health Geogr* 2012;11:15.
- 35 Kruk ME, Gage AD, Arsenault C, *et al*. High-Quality health systems in the sustainable development goals era: time for a revolution. *Lancet Glob Health* 2018;6:e1196–252.
- 36 Hanson C, Schellenberg J. Redesigning maternal health services: is centralisation the answer in low-resource settings? *BMJ Glob Health* 2019;4:e001488.
- 37 Gage AD, Carnes F, Blossom J, *et al*. In low- and middle-income countries, is delivery in high-quality obstetric facilities geographically feasible? *Health Aff* 2019;38:1576–84.