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Effectiveness of transverse speed reducers and exploring factors contributing to road traffic crashes on a rural two-lane highway: A mixed methods study

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Abstract

Background: In Ethiopia, there are an estimated 25.3 road traffic related deaths per 100,000 population, which is much higher than the global average road traffic fatality rate. Speed is the most well-known risk factor influencing both the risk as well as the severity of the resulting injuries. Although there is paucity of data from low-income countries, speed reducers have been widely approved as an effective traffic calming countermeasure in high-income countries. We aimed to (i) explore the effectiveness of transverse vertical speed reducers and, (ii) qualitatively explore stakeholders' perceptions of the factors that affect the risk of road traffic crashes.

Methods: Data on all crashes occurring from September 2010 to August 2015 were obtained. Interrupted time series analysis using Poisson regression was used to estimate the effect of speed reducers on the number of crashes per month before and after their installation in January 2012. Focus group discussions and in-depth interviews were conducted with traffic police, drivers, drivers' training center owners, and community members to describe their perceptions about the effects of the speed reducers. Quantitative and qualitative results were triangulated.

Results: There were 130 crashes during the study period. Of these, 45.4% were property damage only, and 16.9% were fatal. After the speed reducers were installed, there was no statistically significant difference (incidence rate ratio, IRR =1.17, 95% CI[0.60-2.30], p-value =0.644) in the number of crashes per month, but there were changes in the distribution of crash severity (p-value <0.001). Four core themes, with subsequent sub-themes, emerged as perceived contributors to road traffic crashes. Of these core-themes, speedy and reckless driving, were perceived as the strongest force perpetuating road collisions. Qualitative respondents disagreed on whether the speed reducers were effective and expressed concerns such as the lack of signage to warn drivers.

Conclusions: Although speed reducers are proven to reduce collisions in high-income settings, this study in Ethiopia was inconclusive. Inappropriate design for the roadway type, sporadic placement, lack of signage and maintenance, and poor stakeholder coordination may have hampered effectiveness. An evidence-based planning process prior to implementing road design interventions is recommended to achieve the desired results.

Background

According to the WHO 2018 Global Status Report and the Global Burden of Injury study, road traffic crashes (RTCs) continue to be the leading causes of mortality and morbidity worldwide for people aged 5-29 years.[1] A meta-analysis from 15 African countries reported a pooled crash injury rate of 65.2 per 100,000 population and pooled crash death rate of 16.6 deaths per 100,000 population. [2] In Ethiopia, a low-income country in Sub-Saharan Africa, there are an estimated 25.3 road traffic related deaths per 100,000 population, translating to over 23,000 deaths annually[3]. This is much higher than the global average road traffic fatality rate of 17.5 deaths per 100,000 population.[3] Policies relating to drink-driving, speed limit, phone call, and seat-belts use are included in the national legislation; however, because of resource limitations and existence of competing national priorities, the enforcement of these laws is poor.[3,4]

Vehicle speed has been identified as a key risk factor for all kinds of RTCs, influencing both the risk of a crash as well as the severity of the resulting injuries. It follows that controlling vehicle speed can have a double effect of preventing crashes and reducing the severity of resulting injuries.[3,5] "Traffic calming" refers to various road design modifications used for speed management in areas where driver speeds are either excessive or inappropriate for the type and road user mix of a given road.[5] Vertical traffic calming measures use forces of vertical acceleration to discourage speeding. Horizontal measures use forces of lateral acceleration, while audio-tactile measures use vibration, and narrowing measures use a psycho-perceptive sense of enclosure to discourage speeding.[6] Some examples of vertical measures include speed bumps, speed humps, speed tables, and speed slots/cushions.[6–9]

There exists a considerable evidence base supporting the effectiveness and sustainability of vertical speed control measures, mostly generated from high-income countries.[3,5] Logically, the self-enforcing and cost-effective nature of these interventions make them an attractive option for low-income settings, yet there is little reason to believe that findings from high-income settings are direct to low-income contexts which tend to have a higher proportion of non-motorized traffic, more lax vehicle maintenance and safety standards application, lower driver education levels, insufficient police enforcement capacity, poorer quality roads, and weaker political commitment to road safety.[3,10,11] All of these factors could affect the implementation of speed reduction technologies in low-resource settings, highlighting the importance of building a contextually relevant evidence base.[11,12]

Some studies in low- and middle-income countries have reported positive outcomes resulting from the installation of vertical speed reduction measures.[11,12] But far more common is a theme of inadequate planning that leads to ambiguous outcomes. A recent study conducted in Egypt demonstrated how random installation of vertical speed control measures that deviate from standard height, travel length, and spacing recommendations can damage pavement conditions as well as cause excessive speed fluctuation.[13] Experiences in Nigeria,[14,15] Ghana,[5] and Tanzania[16] have also shown that mounting of speed bumps or other road modifications without following established design standards, without consideration of the functional class of the road, and without proper community involvement can have enormous adverse effects on vehicles, drivers, and residents of the area. It has even been suggested that such well-intentioned attempts can increase the incidence of collisions, in addition to causing dissatisfaction among road users and community members.[9]

This study aimed to evaluate the effectiveness of transverse vertical speed reducers installed in January 2012 on a two-lane highway Hintalo Wejerat District, Tigray Region, Ethiopia using interrupted time series analysis, as well as qualitative analysis of community member, driver, owner of the driving center, and police perceptions.

Methods

Study setting

Tigray Region is the northernmost of Ethiopia's nine regional states with a population of over 5.1 million. Of these, 81.5% and 19.5% population live in rural and urban settings respectively. The regional urban center is the capital, Mekelle. The total area of the region is approximately 54,570 square kilometers, covering a diverse landscape from the Tekeze Gorge at 550 meters above sea level to mountain peaks reaching 3,935 meters.[17] In Tigray, rural road expansion and maintenance is managed under the Universal Rural Road Access Program/Rural Roads Authority while the Ethiopian Roads Authority manages the federal road network.[18] The region's road network includes 4,949 kilometers of dry-weather roads, 2,522 kilometers of all-weather roads, and at least 497 kilometers of paved road.[17]

The specific study site, shown in Figure 1, is a 45 km stretch of asphalt two-lane highway in Hintalo Wejerat District that connects Hiwane town (13°06'12.8"N 39°29'41.1"E) and Mehoni town (12°47'57.4"N 39°38'36.2"E). The study site is part of a highway segment that was constructed in August 2010 to bypass the previously existing Alaje mountain pass road, branching off at Hiwane and eventually rejoining it at Alamata town (12°25'12.2"N 39°33'15.1"E). The study highway traverses remote, mountainous terrain and is known to have heavy traffic, since it is part of the main North-South corridor connecting the regional capital, Mekelle, to the national capital, Addis Ababa, as well as to the port of Djibouti. According to oral communication with the head of Hintalo Wejerat District Traffic Police Office, the average traffic volume of the road is approximately 700-1000 vehicles per day. The posted speed limit is 70 km/hr.[3]

Soon after the new highway was constructed, the local police reported a high crash frequency and requested Ethiopian Roads Authority and its contractors to install speed reducers. Consequently, in January 2012, a total of 17 transverse speed reducers were installed along the study highway starting approximately 8 kilometers south of Hiwane (Table 1). The speed reducers are not evenly distributed, rather they are concentrated at sites where the road is curved and inclined. There is a series of four speed reducers (#1-4), followed by one isolated application (#5), followed by another series of four (#6-9), and another series of eight (#10-17). There is a large gap of 32 kilometers between the third and fourth series where the road is straight and flat. The spacing between the speed reducers within each series varies, ranging from 50 to 600 meters apart. Most of the applications span the entire road transversely, but there are two that span only half the roadway (Table 1).

Table 1 Description of speed reducers installed in Hintalo Wejerat District

Serial Number	**Distance from preceding speed reducer (Meters)**	**Width**
1	N/A (8 Km south of *Hiwane*)	Full width of road (7 meters)
2	50	Full width
3	185	Full width
4	53	Full width
5	3,000	Full width
6	1,000	Full width
7	48	Full width
8	120	Full width
9	150	Full width
10	32,000	Full width
11	47	Full width
12	600	Half width (on downhill side only)
13	300	Full width
14	73	Full width
15	170	Half width (on downhill side only)
16	130	Full width
17	50	Full width

The speed reducers in the study area are made of asphaltic concrete, and consist of 2.5 sinusoidal undulations, in contrast with other common vertical speed reducer designs which typically have a single raised feature (Figure 2). As shown in Figure 2, the Hintalo Wejerat speed reducers have three 25-centimeter long depressions (approximately 1 centimeter deeper than the original road surface) alternating with two 25-centimeter long raised bumps (of variable height) for a total travel length of 1.25 meters on average, although the measurements are not standard across all of the applications.

Study Design

This mixed-methods study used interrupted time series analysis to quantitatively evaluate the impact of the transverse speed reducers on the number of crashes occurring per month on a 45 km long section of asphalt two-lane highway in Hintalo Wejerat District. Qualitative methods including focus group discussions (FGDs) and in-depth interviews (IDIs) were used to explore community, traffic police, drivers' training center owner, and driver perceptions regarding the speed reducers. The qualitative and quantitative results were triangulated to shed additional light on the speed reducers' effectiveness or lack thereof.

Data collection and statistical methods

Quantitative

Local traffic police report all road collisions involving property damage or injuries using a standardized form. Data was abstracted from the police reports for all collisions occurring in the 45 km study area from September 2010 to August 2015. The pre-intervention period spanned from September 2010 to December 2011. The speed reducers were installed in January 2012. Thus, the post-intervention period was defined from January 2012 to August 2015.

Descriptive statistics were calculated to summarize the characteristics of collisions occurring during the pre- and post-intervention periods. Chi-squared test of homogeneity and Fisher's exact test were used to test for changes in the distributions of categorical variables before and after speed reducer installation.[19] The data was collapsed by month to analyze the outcome (number of collisions per month) using interrupted time series analysis with Poisson regression.[20–24] The proposed impact model is shown below:

$$\mathbf{ln}(\mathbf{E}[\boldsymbol{Y_t}]) = \boldsymbol{\beta_0} + \boldsymbol{\beta_1} * \boldsymbol{t} + \boldsymbol{\beta_2} * \boldsymbol{X_t} + \boldsymbol{\beta_3} * \boldsymbol{PX_t} + \sum_k \left[\beta_{4k}\left(\sin\frac{2k\pi t}{T}\right) + \beta_{5k}\left(\cos\frac{2k\pi t}{T}\right)\right] + \boldsymbol{\varepsilon_t}$$

where $\mathbf{E}[\boldsymbol{Y_t}]$ is the expected number of collisions during a given month, t is a continuous variable indicating time from start to end of the study period that controls for the underlying non-stationarity or time trend (September 2010 = 1, August 2015 = 60), $\boldsymbol{X_t}$=1 represents the post-intervention period and models the level change ($\boldsymbol{X_t}$=0 for the pre-intervention period), and $\boldsymbol{PX_t}$ is a scaled interaction term between time and intervention that models the slope change post-intervention (coded 0 up to the last point before the intervention phase and coded sequentially from 1 thereafter).[20,21] Fourier terms were included to adjust for seasonal patterns: k is the number of pairs of Fourier terms included in the model (k=1 for annual seasonality, k=2 for 6 monthly seasonality, etc.), T is the number of time periods described by each sinusoidal function (T= 12 for 12 months in a year).[22,25] Lastly, $\boldsymbol{\varepsilon_t}$ is the error term at time t. A lag term was not included in the a priori model since the evidence shows that speed reducers tend to have an immediate, rather than gradually occurring, effect on reducing vehicle speeds.[6,7]

Incidence rate ratios (IRR) were derived with their 95% Confidence Intervals (CIs) from the adjusted Poisson model to quantify the effect of speed reducer installation on the number of crashes occurring per month. Effects indicating both the level change (one-time impact of the speed reducers between the time points immediately before and after their installation) and slope change (the difference between the pre- and post-installation slope or trend) were estimated, after adjustments for time trend and seasonality.[20–29] Stata 12 statistical analysis package was used to conduct the quantitative analysis.

Qualitative

Data were collected in two phases, from Jul– Dec 2016 and Sep-Oct 2017. In the first phase, two 90-minute FGDs were conducted among traffic police officers and community residents respectively, each consisting of 8 participants. Following preliminary analysis of the FGDs, four 45-minute IDIs were conducted with two traffic police officers, one official from the Construction, Road, and Transport Bureau of Hintalo Wejerat District and one public transport driver working in the study area. During the second phase, nine additional 45-minute IDIs were conducted with six public transport drivers, two drivers' training center owners, and one community member. Participants for both the FGDs and IDIs were purposively selected based on their potential wealth of information and because of their routine exposure to road traffic related conditions in the study area.

A semi-structured interview-guide (which includes both open-ended and closed-ended questions) was used to facilitate the FGDs. In the IDIs, we used probing questions and participants were given the freedom to respond to open-ended questions in as much depth as they desired. The tools were developed in English and then translated into the local language, Tigrigna. The tools focused primarily on the following issues: (i) The major perceived causes of RTC, (ii) The role of environmental factors and road design in RTC, and (iii) Traffic policy and administrative issues.

The principal investigators (Nigus Asefa and Hannah Yang) went to the study site and conducted both the FGDs and the IDIs in the local language, Tigrigna. Informed written consent was obtained from all participants. All responses were audiotaped and verbatim transcripts were generated from the audio recordings. The results were then coded in Atlas.ti software using an inductive approach. Similar codes were grouped and re-grouped to identify all non-repetitive core themes that emerged from the data.

Results

Quantitative

The study investigators visited the site several times to abstract data from the traffic police reports, conduct FGDs and in-depth interviews, and observe the design and placement of the speed reducers. The photograph in Figure 3 was taken by the study investigators during one of the site visits.

Figure 4 shows the crash characteristics during pre- and post-intervention periods. During the five-year study period, there were a total of 29 and 101 RTCs before and after the intervention time (Jan 2012), respectively, that occurred along the 45 km of highway in the study area. There were 22 fatal crashes (16.9%), defined as a crash resulting in one or more fatalities, while 49 crashes (37.7%) resulted in one or more non-fatal injuries. The remaining 59 crashes (45.4%) were property damage only, indicating that there were no injuries or fatalities. The crash severity level is determined by the worst severity sustained by any individual in the crash. In total, there were 73 minor injuries, 50 serious injuries, 31 deaths, and 3,418,350.00 Ethiopian Birr (EtB) or $185,884.96 USD[30] in estimated damages, according to the local traffic police reports.

We assessed the distribution of crash in terms of cause, vehicles involved, time and severity between the two groups (Figure 4). Chi-squared test of homogeneity revealed that the distribution of crash severity differed before and after speed reducer installation (Pearson $Chi^2=34.0$, $p<0.001$), with a property only damage crashes increasing sharply in the post-intervention period (Figure 4). Fisher's exact test was used to test for homogeneity in the remaining categorical variables due to low expected counts. There was a statistically significant difference in the distribution of crash time (p=0.017), marginally significant difference in the responsible vehicle type (p=0.059), and no difference in the reported cause (p=0.248) before and after January 2012. Overall, heavy trucks including 1 or 2 trailer trucks, tanker trucks, and Isuzu trucks were responsible for 74.6% of the crashes (Figure 4). (It is worth noting that the traffic police reporting format does not allow for the description of multiple vehicles involved in a collision, rather it focuses solely on the vehicle at fault for legal purposes.[18]) Speeding was the most common cause (83/130, 63.8%) of collisions followed by failure to respect the right hand rule (32/130, 24.6%), according to local police documentation (Figure 4).

Figure 5 shows the observed number of monthly RTCs during the study period as a smoothed 3-month moving average (solid line), the seasonally adjusted modeled trend (dashed line), and the counterfactual prediction (dotted line). The counterfactual scenario represents the expected number of collisions had the speed reducers not been installed, projected using only the data observed before January 2012. The mean monthly number of crashes during the pre-intervention period was 1.81 ± 0.98 and during the post-intervention period it was 2.30 ± 1.29.

The speed reducers did not appear to have a statistically significant effect on the number of crashes occurring per month, as per the model estimates shown in Figure 6. After adjusting for the slightly decreasing time trend ($\boldsymbol{\beta_1}$= 0.98, 95% CI 0.92-1.03) and seasonality using two sets of Fourier terms ($\boldsymbol{\beta_{4-7}}$), installation of the speed reducers resulted in a non-significant 17% level increase (the immediate impact) in the expected number of crashes from December 2011 to January 2012 ($\boldsymbol{\beta_2}$=1.17, 95% CI 0.60-2.30), and a non-significant slope increase (the gradual impact) of 3.6% over time ($\boldsymbol{\beta_3}$=1.04, 95% CI 0.98-1.10). According to the model estimate, there were 2.10 crashes p er month at the beginning of the period ($\boldsymbol{\beta_0}$).

Qualitative

The mean age of the FGD participants was 35.7 ± 8.4 years, with a minimum of 25 and a maximum of 50 years. Table 2 shows the themes that emerged from discussions and interviews with police officers, community members, and transport drivers regarding their perceptions about the causes of RTC and the speed reducers' effects in mitigating collisions, their effects on drivers and vehicles, and the suitability of their design and application.

Four core themes with associated sub-themes emerged from the inductive analysis of the data (Table 2). According to the current study, the main facilitators contributing to RTCs can be categorized as factors related to drivers, pedestrians and community matters, aspects of road design, and administrative and policy issues.

Table 2 Factors contributing to RTCs in Hintalo Wejerat District, Ethiopia

Themes	**Sub-themes**
Theme I: Driver-related factors	Speedy and reckless driving Failure to yield to pedestrians Lack of adequate training and skill Age and experience of drivers
Theme II: Community and pedestrian-related factors	Perceptions of the community Rural dwellers are at higher risk Inadequate awareness creation
Theme III: Road design aspects	Difficult road topography Cues and signage Unplanned road blockages Environmental and weather conditions Effectiveness of speed bumps
Theme IV: Administrative and policy issues	Lack of necessary personnel, materials, and training for law enforcement Insurance-related problems Driver licensing system

Theme 1 Driver-related factors

The participants repeatedly stressed that driver-related factors, such as speeding, failing to yield for pedestrians, and passing into oncoming traffic were the most common causes of RTCs (Table 1). Among these factors, participants stated that speedy and reckless driving is the major factors contributing to RTCs (Figure 7) and also explained that it is a common phenomenon to see drivers speeding dangerously in residential and business districts where there is increased pedestrian traffic. One participant explained the situation as:

> *"First of all, accidents are really the drivers' fault. There are also some bad places* [roads], *but, most of the accidents are caused by speeding, breaking the speed limit, passing when there is opposing traffic, and not knowing the vehicle's maximum load. So, generally, I say it's the drivers' problem."* **Driver, in his 30's**

Some of the respondents mentioned that a higher frequency of collisions is observed among the younger drivers and those with less driving experience (Figure 6).

> *"The younger drivers and most of the drivers with new licenses tend to drive recklessly with high speed whereas those who are experienced tend to drive slowly".* ***Local resident, in his 40's***

On the contrary, some participants explained that age and experience do not matter according to their observations, citing that many of the crashes occurring on rural, mountainous roads involve trailer trucks which are typically driven by drivers holding level 5 licenses (presumably older and more experienced).

A substantial share of RTCs can also be attributed to driver's impatience and failure to let pedestrians cross the road first. The participants reflected that negligence towards pedestrians in combination with excessive speed are the main problems that lead to RTCs, especially in town/urban areas.

Theme 2 Community and pedestrian-related factors

The current study also found that the community's low awareness about road safety is an important contributor for RTCs, putting rural pedestrians at, particularly increased risk. Some rural individuals associate the left-hand side with bad luck, and they resist walking on the left side of the road as is recommended to increase pedestrian visibility. Some rural people also leave their animals to walk or lie in the middle of the road. Similarly, when people build houses, construction materials are usually left on the streets for extended periods. Such unexpected road blockages can take drivers by surprise. Public transport passengers also contribute to RTCs by implicitly supporting the poor behavior of the drivers, for example by encouraging the over-loading of public vehicles.

A traffic police officer sheds light on the collectively uncooperative cultural attitude towards law enforcement:

> *"Punishing a driver who made a mistake is thought to be inconsiderate. The Muslim passenger says "Spare him in the name of Allah" and the Christian passenger says "Spare him in the name of God". They ask you: "Don't you have a son?" No one says "He should be punished… he would have killed us all… you rescued us". Everyone says, "Pardon him, and leave him alone." Good awareness has not been created in the community.* ***Traffic police, in his 40's***

Participants expressed that most road safety education activities conducted in the area are misguided. Safety messages are primarily delivered in public meetings, during church holidays, and on market days, thus reaching adult audiences. However, study participants believed that safety education would be more effective if targeted towards youths. Respondents also forwarded that resource constraints hinder road safety awareness, especially in rural communities. Due to the lack of funding and transportation, traffic police are only able to deliver safety messages to rural dwellers when they come to town for a market day or other events. According to the participants, on-the-spot verbal instruction alone is not enough to bring consistent behavior change concerning road safety. Traffic police officers agreed that community awareness of road safety is still in its infancy stage

Theme 3 Road-related problems

Although study participants believed that drivers are the main cause of RTCs, they also revealed how the difficult terrain in the study area, natural factors such as weather, and poor road maintenance could increase the risk of RTC. A public transport driver explained:

> *"There are unmaintained roads where the road markings are not even visible. Let alone the traffic signs, the highways themselves are not maintained. This is not seen as a contributing factor for RTC, although it is, in fact, causing crashes. Most people understand the known factors, which are overloading and speeding. But, there are times when road's poor condition is at fault for the crash."* ***Driver, in his 20's***

There were conflicting views on how the speed reducers affected crash incidence in the study area. Some participants strongly believed the speed reducers decreased the incidence of collisions. As stated by one traffic police officer:

> *"When we look carefully at the places that have speed bumps before and after their construction, there are some where collisions have decreased. For example, in Adi Jebjeb many vehicles were rolling over before the bumps were built, but now it has improved a lot –similarly in Kayih Hamed and Gereb Dedek. Despite the lack of safety warning signs before the speed reducers, most collisions have decreased. In comparison with places that don't have speed reducers, collisions decreased in the areas with speed reducers."* ***Traffic police, in his 40's***

Despite the benefits, the participants also reported drawbacks regarding the design and placement of the speed reducers. Participants reported that the bumps were too tall when they were first constructed and hindered the movement of small vehicles, though they have eroded considerably since then due to poor maintenance. The absence of signage before reaching the speed bumps was also believed to expose unfamiliar drivers to increased risk of RTCs.

> *"Because there is no signal to cue drivers about the speed bumps, they cause accidents among drivers who are unfamiliar with the area, but not really for those of us who know about them. They should have added a reflective signal that is visible at daytime and nighttime. But, one way or another, the speed bumps are useful."* ***Local resident, in his 30's***

Discussants also noted that drivers swerve off the road or out of their lane to avoid driving over the bumps, which could also increase collisions.

Discussants also noted that drivers swerve off the road or out of their lane to avoid driving over the bumps, which could also increase collisions.

Theme 4 Administrative and policy-related issues

Administrative and policy-related problems were reported as additional underlying causes for RTCs. Traffic police struggle to enforce traffic laws is limited due to personnel shortages, budget constraints, and lack of important equipment like patrol vehicles, speed control radars, and breathalyzers. A traffic police officer explained how lack of equipment weakens the capacity of law enforcement to do their job:

> *"Since we don't have speed control radars and other modern equipment we can't apply all the laws. To say: "You are speeding", you should have something to measure the speed. To confidently punish them you need a speed control device. To say: "Stop. You are high, you are drunk", you need to have the necessary equipment."* ***Traffic police, in her 30's***

Flaws in the driver licensing system were cited as one of the most serious problems faced by road safety advocates and are believed to be one of the factors underlying the rampant speeding in the area. All drivers are supposed to undergo training before obtaining their driving license, but according to the study participants that is not always the case. Bribery, forgery, dishonesty, or personal favors allow certain drivers to gain their license without undergoing any training at all. Even drivers who legitimately graduate from a training center tend to lack meaningful experience on realistic road layouts due to the generally weak and non-standardized curriculum (Figure 6).

The participants repeatedly mentioned that the training centers do not provide training in real life driving situations and hence drivers graduating from training centers in the region lack adequate skills to mitigate the possible challenges of a real situation. One of the FGD participants stressed how the government sanctioned training curriculum is ineffective in preparing drivers for work:

> *"When the training centers give training, it's only being given in the town. How can drivers trained only in the town navigate all of the curves, and cliffs of mountainous roads? They should give training in the field. Some organizations won't hire drivers based on the license issued by the Road Transport Authority. Organizations give their own six-month training, again: the trainee assists an able driver, they train in the field, on uphill, on a downhill, at night, during the day, in the rain…They train in all situations. When the licensing process is thorough like this, drivers can really learn the profession. They shouldn't train only in the town and during the day because they will not only be driving in towns and daytime."* ***Traffic police, in his 40's***

Next, there is no efficient way for the traffic police to verify the validity of someone's license. Every Regional State in Ethiopia has the power to issue driving licenses that are valid in all parts of the country. But when a traffic police officer stops a driver in the field there are no quick means of checking the validity of their license or the drivers' past traffic infractions. The participants also suggested that lifesaving first aid training should be provided for traffic police staffs, as they are almost always the first to arrive at the scene of an RTC.

The discussants also indicated that the insurance claim process is another problem that is contributing to increasing RTCs. the current system requires vehicles and wreckage to stay in their position after a collision until insurance company representatives arrive and get their required documentation. This is very serious when the crash happens in a narrow section of the road or a place with low visibility.

Drivers' eyesight and physical fitness may deteriorate over time, but this study has identified that there is no physical examination during the license renewal process. Drivers can simply renew their license by paying a fee and presenting their previous driving license.

Discussion

This mixed-methods study described the characteristics of RTCs occurring over 5-year period on a mountainous, two-lane asphalt highway in Hintalo Wejerat District, Tigray, Ethiopia. Interrupted time series analysis was used to reveal that transverse speed reducers installed in January 2012 did not appear to impact the volume of RTCs. However, the speed reducers may have impacted crash severity according to Chi-squared testing. Local stakeholders' views about the benefits and drawbacks of the speed reducers installed in their community help to elucidate why the intervention was not as effective as hoped, and point towards what can be done differently in the future.

According to local police reports, speeding was the primary cause of crashes, both before (17/29, 58.6%) and after (66/101, 65.3%) the speed reducer installation, documented in 63.8% (83/130) of all collisions. This finding was within the range reported in Ghana, where speed was responsible for 50% of crashes[11], and Kenya where speed was documented 34-70% of the time.[31] In the study area, speed was also reported to be the major contributor of road crash.[32,33] Statements from the interview and FGD participants, who attributed the majority of crashes to drivers' negligence and speedy driving, also support the result of this finding. These results confirm that effective speed control remains a crucial factor in improving road safety in rural Ethiopia.

The discussion participants in this study specified that speedy driving is particularly common among long vehicles and public transportation, and the local police reports indicated that heavy trucks were responsible for the majority of crashes both before (21/29, 72.4%) and after (76/101, 75.2%) speed reducers were installed. In contrast to this finding, a recent study conducted in the European Union reported that heavy trucks were not linked with greater numbers of traffic fatalities or crashes compared with medium or light trucks.[34] The stark divergence between the two studies underscores the importance of contextual differences between high- and low-resource settings. For example, low enforcement capacity could exacerbate issues such as overloading trucks beyond the recommended weight capacity or operation of trucks with mechanical problems that do not meet safety standards. The considerable role of heavy trucks observed in this study calls for special consideration when implementing future speed reduction interventions.

To examine the impact of speed reducers on the risk of a crash, an interrupted time series approach was deemed appropriate for several reasons. First, the speed reducers were a population level intervention introduced at a clearly defined point in time (January 2012), and although no baseline survey was conducted beforehand, the outcome (crashes) was already being captured by the existing traffic police reporting system.[21,27] Moreover, the literature explains the irrelevance of simply comparing the mean number of crashes before and after speed reducers were implemented, due to the particular characteristics of time series data such as non-stationarity, seasonality, autocorrelation.[20,28] By relying on multiple observations both before and after the intervention, interrupted time series analysis enables the researcher to more effectively control for these characteristics, as well as any pre-existing trends.[20,21] In this study, the expected number of crashes per month was found to be decreasing slightly (Slope=0.977, 95%CI: 0.92-1.03) prior to the installation of the speed reducers. This could be due to regression-to-the-mean, however, since the roadway was newly constructed in September 2010 prior data was not available to obtain a more stable estimate of the pre-existing trend. Different types of effects, both immediate and gradual, can also be identified through time series analysis.[20,21,29] In this study, there was a non-significant 17% level increase (IRR 1.17, 95% CI:0.60-2.30), or a jump in the expected number of crashes immediately following the intervention. There was also a non-significant 3.6% slope increase (IRR 1.036, 95% CI: 0.98 - 1.10), which indicates a gradual increase over time compared with the pre-existing trend in the absence of the intervention. The immediate level increase could have been due to the lack of signage to warn drivers of the new road feature, as mentioned by the discussion and interview participants. The slope increase could be explained by drivers' risky adaptive behaviors such as lane departure, excessive speeding in between bumps to make up time, or perhaps decreasing the effectiveness of the bumps due to profile erosion.

Vehicle speed influences not only the risk of a crash occurring, but also the severity of the resulting injuries.[3,5] Chi squared test of homogeneity indicated that the distribution of crash severity (property damage only, minor injury, major injury, fatal) was not the same before versus after the speed reducers were installed. Before the installation of speed reducers, all of the collisions resulted in injury (22/29, 75.8%) or fatality (7/29, 24.2%). Afterwards, the majority of crashes resulted in property damage only (59/101, 58.4%), with a smaller proportion of injuries (27/101, 26.8%) and fatalities (15/101, 14.9%). Although the speed reducers may not have reduced the number of crashes per month, this finding implies that they may still have been effective at reducing vehicle speeds thus resulting in less severe crashes.

Failure to consider the road characteristics when designing and placing the speed reducers may have decreased their effectiveness. The geometric design (travel length, rise profile, and height) of speed reducers determine the velocity at which motorists travel over the application, and spacing or placement determines the extent to which motorists can accelerate between applications. It follows that the design and spacing should be tailored to obtain the desired behavior from motorists. In general, shortening the travel length and increasing the height forces point deceleration, while closer spacing limits driver speeds along an extended road segment. The literature states that speed humps, which are the least intrusive vertical speed reducer design due to their longer travel length (3.7-4.3m) and shorter height (10cm), are recommended for roads with speed limits of 50 km/hour or less and should be spaced at intervals of 90-150 meters to optimally restrict driver acceleration between humps.[6–9,35]

Low community involvement and poor coordination between the contractor, government offices, and local stakeholders were apparent based on results from the qualitative portion of this study. The inadequate planning process may have contributed to the non-standard design and placement, lax maintenance practices, and overall weak ownership of the speed reducers in Hintalo Wejerat. Similar studies conducted in other African countries, as well as documents and manuals from numerous transportation agencies, have also emphasized the importance of a proper planning process before implementing vertical speed reducers.[5–7,11–16] Planning should begin with the selection of an appropriate site including a formal requesting procedure and public consultation process. This should be followed by a traffic engineering study to diagnose the road conditions at the site. Next, potential interventions should be identified and prioritized based on the needs of the specific street or neighborhood. The selected intervention should then be constructed, keeping in mind operation and maintenance concerns. Lastly, the effectiveness of the intervention must be monitored and evaluated continuously.[5–7,11–16]

There were contradicting perceptions about drivers' age and experience. Some of the study participants stressed that the risk of road crash is more common among young and novice drivers, which can be explained by deliberate contraventions [36] and low motive for compliance with traffic laws.[37] This is consistent with other studies conducted elsewhere.[33,38,39] On the other hand, some of the study participants noted that crashes among older-aged heavy truck drivers are also common in their area, and heavy trucks (presumably operated by older and more experienced drivers) were responsible for 74.6% (97/130) of the crashes as documented by police reports. These reports are in line with some studies, which reported a U-shaped relationship between age and risk of RTC. According to these reports, a higher rate of RTC was observed among drivers younger than 27 or less than one year of driving experience and older than 63-years of age or greater than five years of driving experience, respectively.[38,40] As suggested by Reason et al., this U-shaped relationship could be due to the fact that young drivers may violate the traffic law more often, whereas older drivers may be more vulnerable to make unintentional driving errors.[41]

Findings from this study underscore the importance of continued monitoring. FGD participants observed that drivers were swerving recklessly to avoid driving over the speed reducers, and failure to respect the right hand rule (32/130, 24.6%) was also documented by police reports as a common cause of crashes. This indicates that the intervention should be re-evaluated and other types of road modifications such as shoulder and median barriers may be beneficial.

Limitations of the study

The main limitation of the study is the small number of crash events, which may have precluded the statistical significance of the results. Additionally, though the interrupted time series design explicitly models secular trends such as population growth or gradual changes in traffic volume, the statistical adjustments may be inadequate resulting in biased estimates. Outside events such as petrol shortages or other concurrent road safety interventions could also threaten the validity of the study. Regression-to-the-mean bias may also be present since the number of pre-intervention observations was fewer than the number of post-intervention observations. In future studies, a larger number of data points prior to the intervention would help to get a more stable estimate of the underlying trend. Data from an untreated comparison roadway or Full Bayesian estimation could also be used to gain a more valid prediction of the expected number of crashes that would have occurred without the intervention. However, the increased time, monetary, and computational costs were problematic for the scope of this study. Lastly, reliance on routine data can also introduce bias, because it may not always be complete or may be affected by changes in data collection requirements.

Conclusion and recommendations

Ethiopian Roads Authority should establish evidence-based design and placement standards for speed reducing road modifications that are specific to the roadway functional class and empirically measured traffic characteristics such as vehicle speeds, traffic volume, road user mix, and emergency vehicle access. These standards should be followed both by governmental workers and private contractors. An established requesting process, a high level of community involvement, and an intensive needs assessment including baseline measurement of the problem and an expert engineering study should all precede the construction of any speed reducing device, while regular maintenance and evaluation should follow it. On the other hand, increasing the number of traffic police, providing patrol vehicles, and procuring speed radars and breathalyzer machines could improve the capacity of traffic police to enforce existing laws and control driver speeds. Behavioral change campaigns addressing the drivers as well as community members (pedestrians and passengers) could also be effective if tailored to the local society and culture.

Overall, better coordination between contractors, local police, and different governmental sectors is needed to attain ownership and sustainability of road design interventions. Finally, the findings of this study demand further investigation on how road modifications and traffic calming technologies can be effectively adopted in low- and middle-income settings to reduce RTC.

Declarations

Ethical consideration

The Institutional Review Board of Mekelle University College of Health Sciences approved this study. A supporting letter was also obtained from the Tigray Traffic Police Commission. The collision data was received and analyzed in a de-identified format. Informed written consent was obtained from each discussion and interview participant. The investigators explained the study objectives and assured participants that their responses would be confidential and that they could refuse or withdraw from the study at any time.

Consent for publication

No details, images, or videos relating to an individual person is included.

Availability of data and materials

Data are presented on tables and figures, however, if additional information is required, the datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

No competing interest exist.

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Authors' contributions

Conception or design of the work: NA, HY; Data collection: NA, HY; Data analysis and interpretation: NA, HY, but also inputs from TG, ZH, AH; Drafting the article: NA, HY; Critical revision of the article TG, ZH, AH. All authors read and approved the final manuscript.

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List of abbreviations

FGD- Focused Group Discussion
IDI- In-Depth Interview
IRR- Incident Risk Ratio
RTC- Road Traffic Crash

WHO- World Health Organization

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Figures

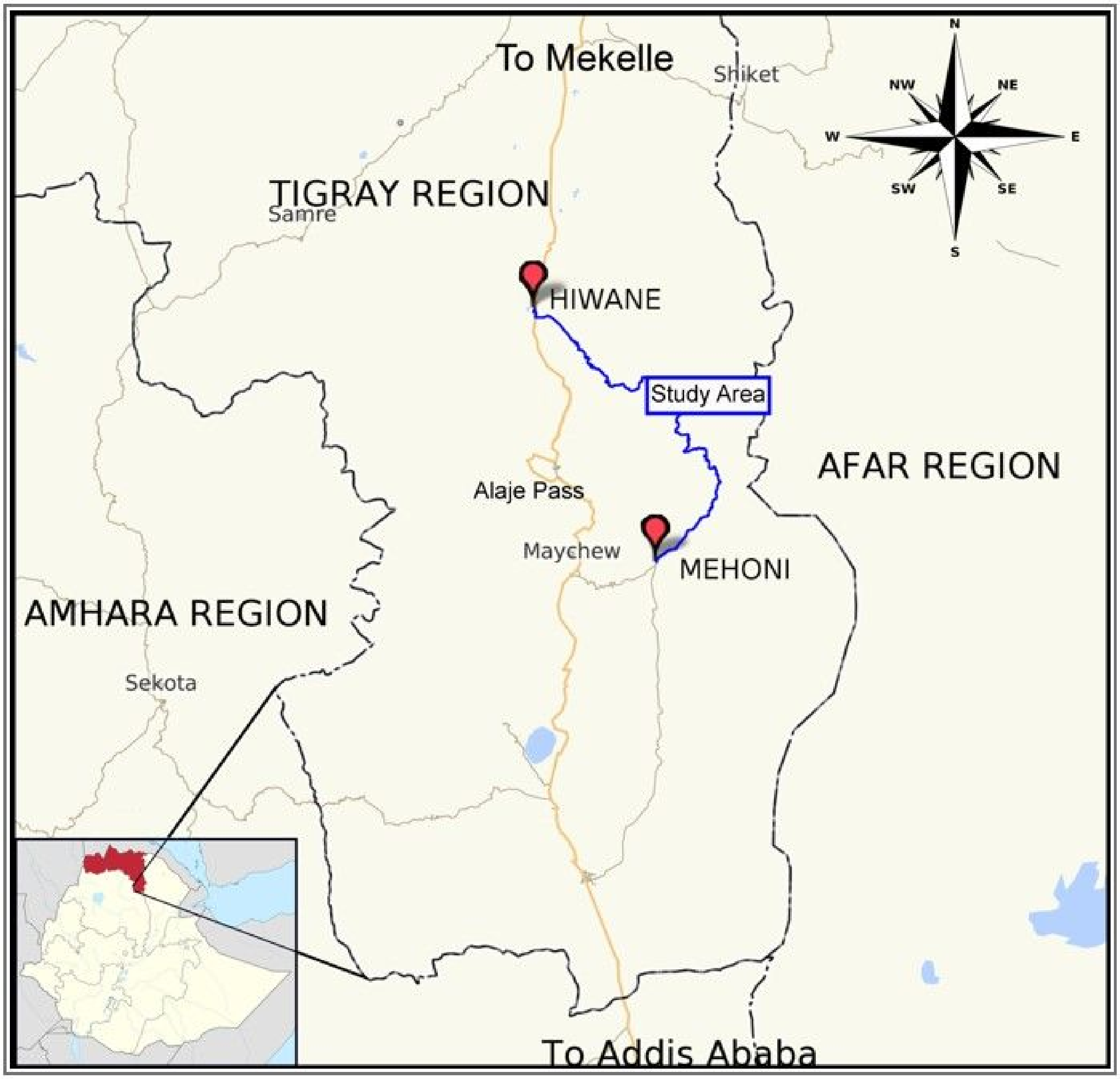

Figure 1

Map of the study area, Hintalo Wejerat District, Tigray, Ethiopia

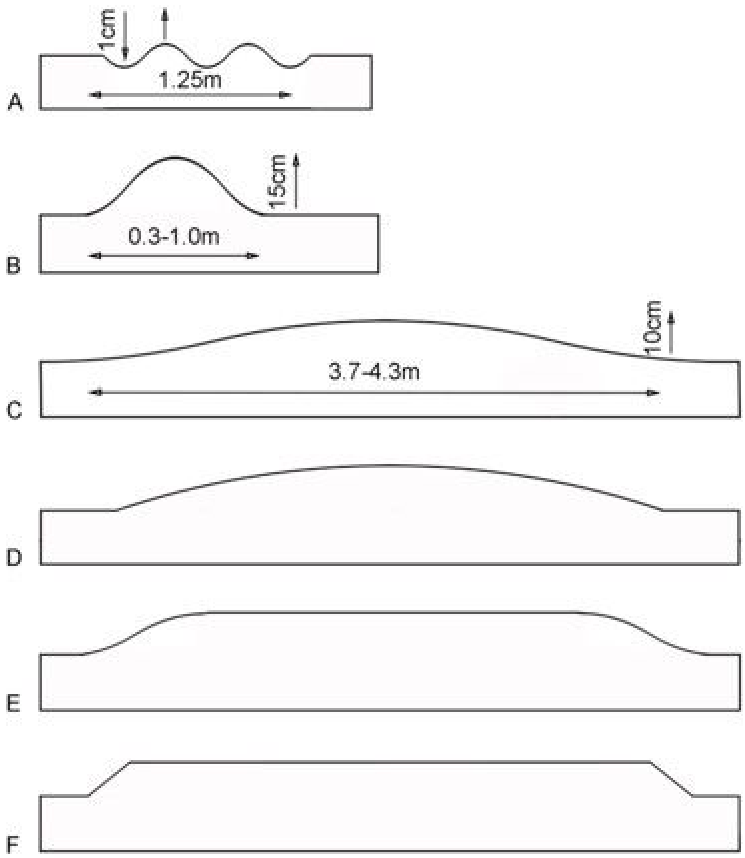

Figure 2

Cross-sectional profile of Hintalo Wejerat speed reducers compared with other common transverse vertical speed reducer designs (A) Hintalo Wejerat speed reducer- 2.5 sinusoidal undulations; (B) Speed bump; (C) Speed hump- Sinusoidal; (D) Speed hump- Circular; (E) Speed hump- Parabolic; (F) Speed table

Figure 3

A heavy truck passes across a transverse speed reducer in Hintalo Wejerat District, Tigray, Ethiopia

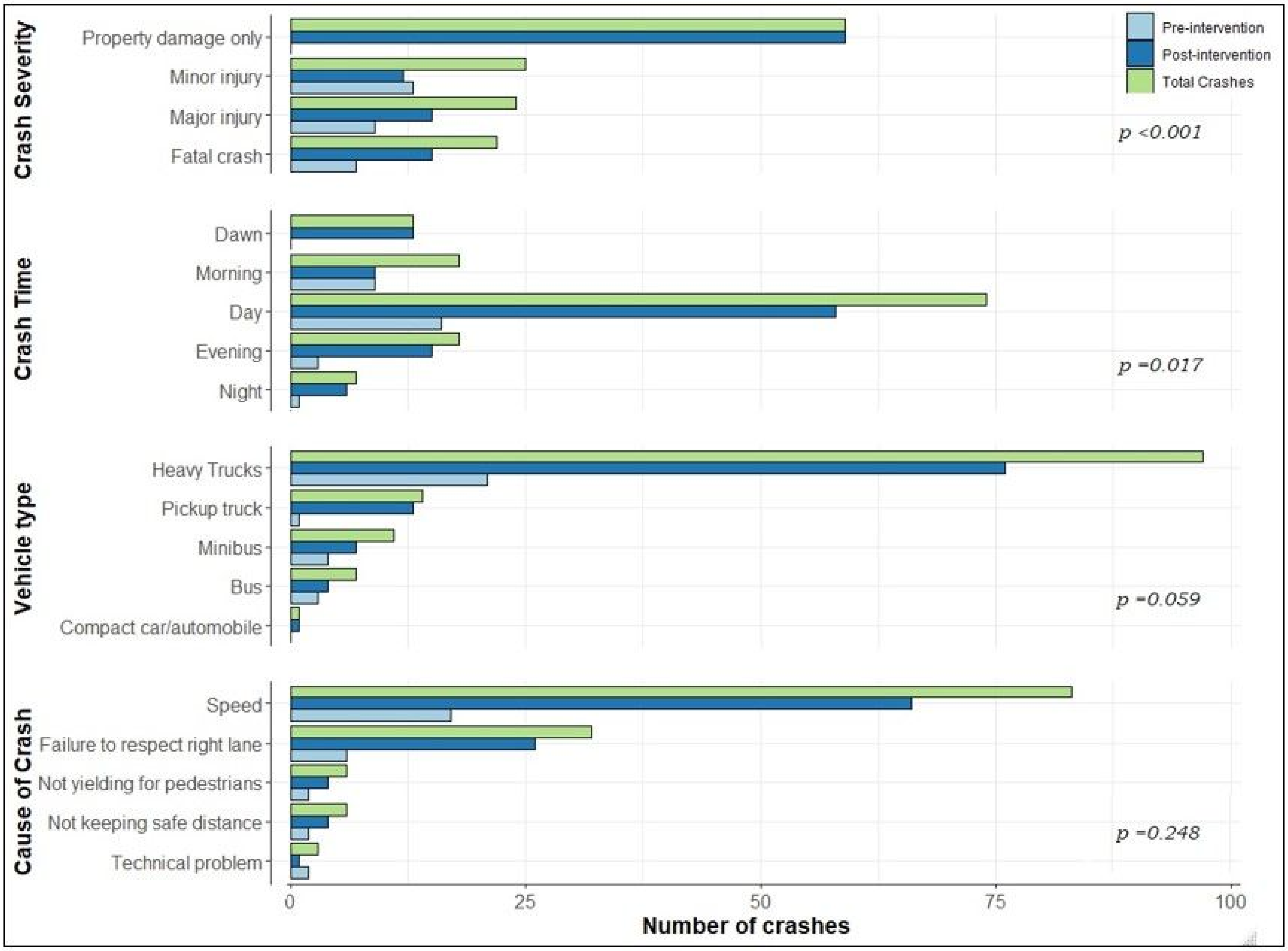

Figure 4

Crash characteristics on a section of rural road in Hintalo Wejerat District, Tigray, September 2010 - August 2015.

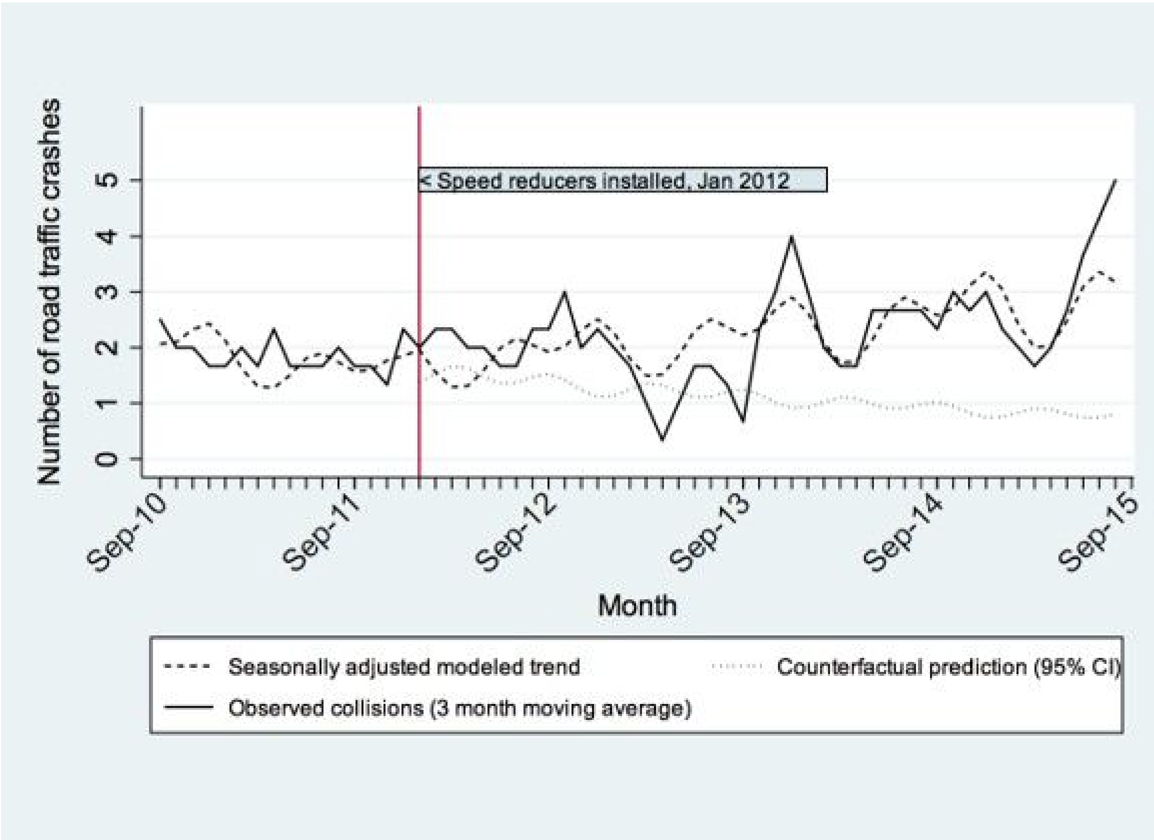

Figure 5

Observed number of collisions, modeled trend, and counterfactual prediction in Hintalo Wejerat District, Tigray, September 2010 - August 2015

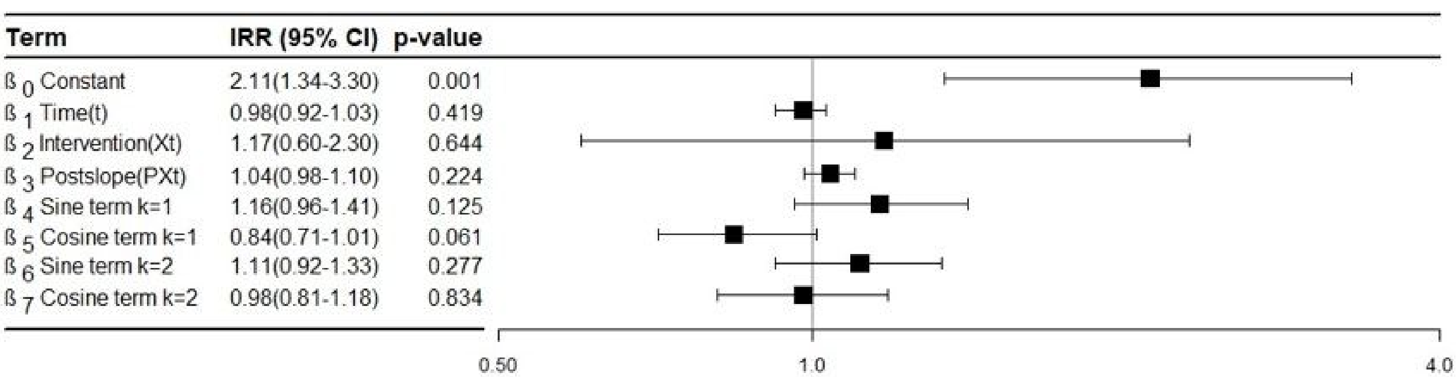

Figure 6

Seasonally adjusted Poisson regression model estimating of the impact of speed reducer installation on number of monthly collisions, Hintalo Wejerat, Tigray, September 2010-August 2015. IRR: Incidence rate ratios; 95% CI: 95% Confidence interval

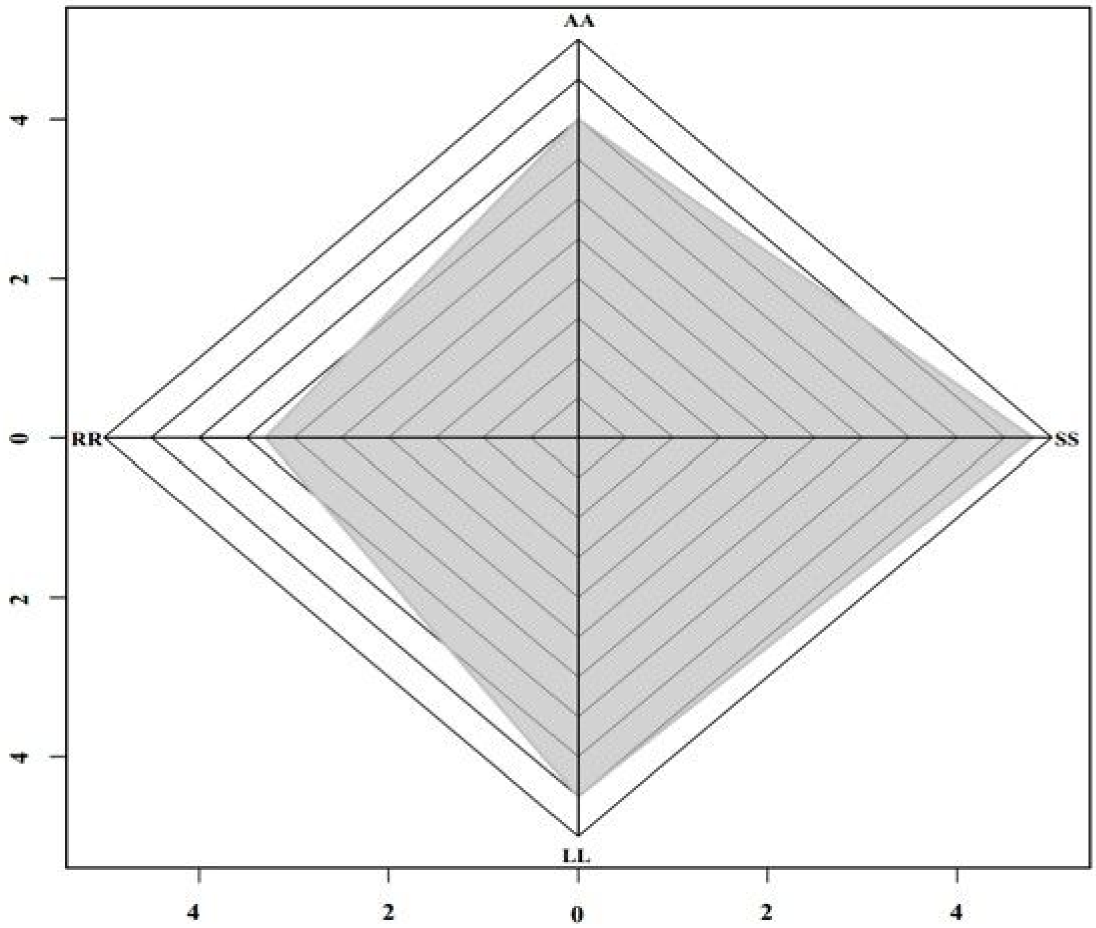

Figure 7

Visual representation of factors related to road traffic crash. The frequency with which each factor was mentioned by study participants is depicted on a 5-point scale, increasing from the center to the corners of the diamond. Speedy driving (SS=4.8/5) and flaws in the licensing system (LL=4.5/5), were the most commonly mentioned factors that contribute to road traffic crashes.