Safe and accessible bus stops on high-speed rural roads

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1 ABSTRACT

This scoping study seeks to address the issue of pedestrian safety while accessing bus stops on high-speed rural roads in Sweden. Through an exploration of both existing and innovative design solutions, this work aims to inform the development of safer crossings for pedestrians, specifically addressing the unique safety needs of vulnerable groups such as children, the elderly, and the disabled, within the context of Vision Zero and the Safe System approach to road safety.

A mixed-methods approach was taken. An initial spatial and descriptive analysis of a representative sample of pedestrian impacts near bus stops on high-speed rural roads was conducted, shedding light on the patterns and factors contributing to these collisions. To gain a broader perspective, a 'call for information' was issued to various road safety networks across Europe, fostering collaboration and knowledge exchange. Subsequently, a thorough review of existing design guidelines was undertaken, culminating in the creation of an 'idea catalogue' that includes both existing and innovative hypothetical solutions.

The spatial analysis revealed patterns in pedestrian casualties, particularly during dark conditions. While existing guidelines, such as the Vägar och Gators Utformning (VGU), provide foundational solutions, they also include ambiguities leading to potential inconsistencies in implementation. The idea catalogue showcases a range of interventions, from graded crossings and speed management techniques to novel Cooperative Intelligent Transport Systems (C-ITS).

2 BACKGROUND

2.1 PEDESTRIAN SAFETY ON HIGH-SPEED RURAL ROADS

In Sweden, pedestrians comprise the largest share of Vulnerable Road User (VRU) fatalities (VRUs – pedestrians, cyclists, moped users, or motorcyclists) (Eriksson et al., 2022). This suggests that there is a pressing need for measures to improve road safety for pedestrians. This concern is particularly relevant in the context of the Vision Zero road safety paradigm, that aims to eliminate all road deaths and serious injuries (Björnberg et al., 2023). Vision Zero's strategy is complemented by the 'Safe System' approach to road safety, which seeks to minimise the risk of road traffic collisions by designing and managing roads, vehicles, and speeds in a holistic and integrated way (International Transport Forum, 2016).

Significant progress has been made in urban environments, where traffic separation, speed limit reductions to 30km/h, and a less user-dependent safety mindset have greatly improved pedestrian and other VRU safety. However, in rural environments, where higher vehicle speeds are allowed and traffic separation requirements are less strict, there remain problematic scenarios. One such scenario involves pedestrian access to/from bus stops on high-speed rural roads, where current designs are at conflict with the mindset of Vision Zero, and the Safe System approach. These stops are often located on roads with high-speed limits (80-100km/h) and limited pedestrian facilities, making it difficult for pedestrians to cross safely. This can result in a higher risk of road traffic collisions for pedestrians, as they may need to cross the road to access a bus stop without the benefit of a designated pedestrian crossing, footbridge, or underpass. Furthermore, wider roads in rural environments, often without refuge islands, result in longer crossing distances for pedestrians, which can increase their exposure to collision risk. The lack of appropriate infrastructure to support safe pedestrian access is the primary safety issue. However, building underpasses, footbridges, or signalised crossings can be an expensive investment that may be financially unviable due to the low expected number of pedestrians who would use them.

Another issue is the lack of visibility for drivers; rural roads often lack street lighting, which can make it difficult for drivers to see pedestrians; internationally, approximately two-thirds of pedestrian casualties occur during dusk/dark conditions (Zegeer & Bushell, 2012). In Denmark, the injury rate for pedestrians in rural areas is 7.4 times greater in low light conditions, compared to 2.4 times greater in urban areas (Jensen, 1999). Rural roads also often have low traffic volume, which leads drivers to become complacent and drive at higher speeds. In free-speed conditions, i.e., unconstrained by road geometry, weather conditions, or traffic conditions, 27% of drivers on rural roads in Ireland (roads with speed limits of 80km/h or greater) travel over the speed limit (Irish Road Safety Authority, 2018). Speed compliance is also a significant challenge in Sweden, with only roughly half of the traffic adhering to speed limits in 2020 (Hurtig et al., 2023). Vehicle impact speed is a decisive factor in the injury severity outcomes for pedestrians. The risk of serious injury or fatality for a pedestrian struck by a vehicle increases disproportionately with its speed (Lubbe et al., 2022). While the majority of pedestrian casualties occur in urban environments, pedestrian deaths are common in rural areas due to high vehicle speeds, lack of pedestrian facilities, and longer emergency response times (Mueller et al., 1988).

Globally, there has been a push towards promoting more active and public transport use as a sustainable alternative to private vehicles. In rural environments, the longer distances between destinations presents challenges for active travel such as walking or cycling. As a result, public transport becomes a key facility for these communities. However, rural communities are often underserved by public transport networks, which acts as a discouraging factor for many potential users (Hansson et al., 2022). Given the importance of public transport in bridging the mobility gap in rural areas, it's imperative that safety concerns, especially those related to pedestrian access, do not act as further barriers to its use.

2.2 SPECIAL GROUPS FOR CONSIDERATION

The safety and accessibility needs of children and young people must also be considered, since they may be less experienced and less aware of the risks posed by traffic, and their smaller size can make them less visible to drivers. While the vast majority of non-fatal pedestrian injuries (93%) are a result of falls, i.e., trips, slips etc., most fatalities are a result of impacts with vehicles (Eriksson et al., 2022). Among VRU fatalities in Sweden, there are differences in age distributions: for pedestrians, there appears to be a particular issue for the elderly (75+ years old), and for children (0-14 years old) (Figure 1). While children will naturally be overrepresented among pedestrian casualties due to the fact that they cannot obtain licences, or even cycle substantially, these figures highlight the need to consider younger pedestrians. Higher fatality numbers among the elderly may be due to a number of factors, including reduced mobility, slower reaction times, and increased vulnerability to severe injuries. For example, Figure 2 demonstrates how probability of pedestrian MAIS3+F injury occurrence (at least serious injury or fatality) varies as a function of closing speed Lubbe et al. (2022). This clear upward trend in injury probabilities with increasing age underscores the heightened vulnerability of the elderly in collisions.

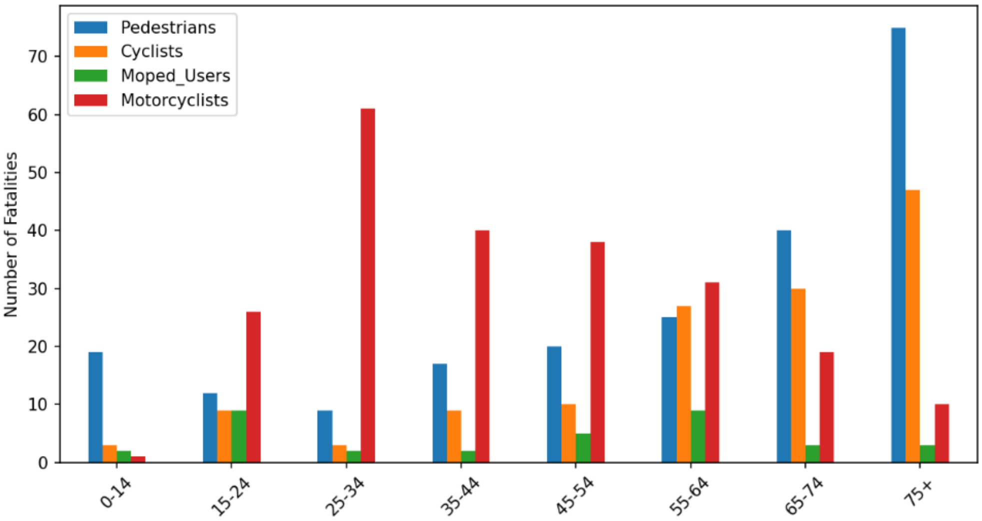

Figure 1: Distribution of the number of fatalities suffered by VRUs in Sweden, by age group and road user category, during the years 2014–2019. Figures for pedestrians are primarily a result of impacts with vehicles, i.e., falls are not included. Adapted from Eriksson et al. (2022).

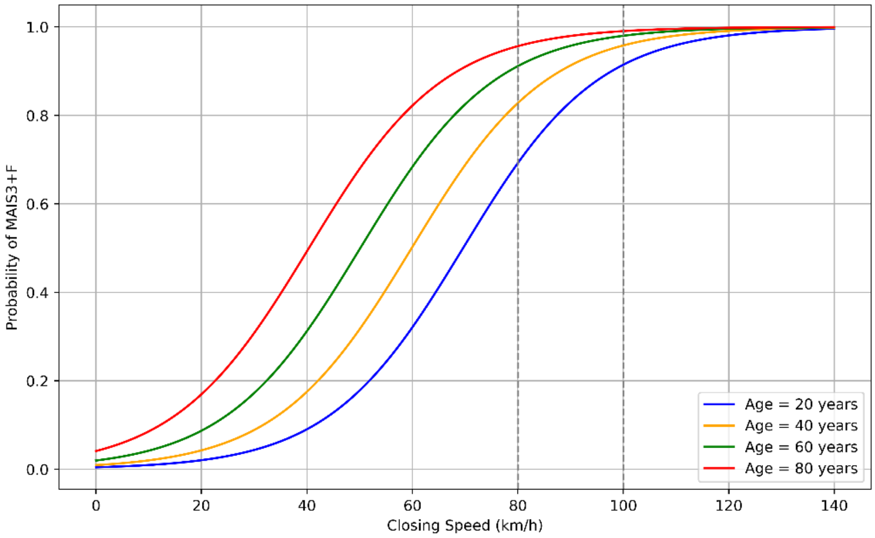

Figure 2: Probability of pedestrian MAIS3+F injury occurrence (at least serious injury or fatality) as a function of closing speed for different age groups. Adapted from Lubbe et al. (2022).

Studies have also shown that children, particularly those below the age of 10, have reduced ability to accurately perceive vehicle speeds and distances when crossing roads (Wann et al., 2011). Critically, this effect was investigated in terms of vehicle speed thresholds for detection of looming, i.e., whether or not an approaching vehicle is identified, with findings indicating that children may not be able to detect vehicles approaching at speeds higher than 32km/h (ibid.). These perceptual limitations impede their ability to detect oncoming vehicles, and estimate the time required for a vehicle to reach them, increasing their risk of being involved in a collision. In addition, children's greater susceptibility to distraction may further undermine their attention to traffic while crossing the road (Tapiro et al., 2018). Therefore, design solutions that may be considered 'relatively safe' for adults, e.g., multi-stage at-grade passages with refuge islands, are not necessarily safe and suitable for children without adult company. This is especially relevant for young people as public transport is often their only way to get to school and other social activities.

Similar considerations should also be made for the elderly since they are also disproportionally represented in collision statistics in Denmark (Jensen, 1999), and Sweden (Eriksson et al. (2022) - Figure 1), and the disabled, e.g., while graded footbridges and underpasses with stairs or ramps virtually eliminate collision risk, they can be challenging for people with mobility impairments.

2.3 THE NEED FOR ADVANCED WARNING ON HIGH-SPEED ROADS

Vision Zero accepts vehicle-pedestrian interactions on roads with speeds to a maximum of 40km/h, with a division of responsibility for speed reduction from active vehicle safety systems of -30km/h, and injury reduction from passive vehicle safety systems for the remaining 10km/h. Therefore, scenarios involving pedestrians crossing roads with speed limits of up to 100km/h is considered quite unacceptable under the Vision Zero paradigm.

When travelling at high speeds, vehicles have a longer braking distances, and therefore, drivers require advanced warning time to come to a stop with a safe braking deceleration. The stopping distance of a vehicle is influenced by a combined effect of multiple factors, including speed, reaction time, road conditions, gradient, vehicle condition, and load weight. However, as a demonstration, a simplified stopping distance plot is shown in Figure 3 for initial vehicle travel speeds between 0 and 110km/h, and a spectrum of hypothetical deceleration rates around 0.5g (a threshold for what can be considered 'hard-braking'). It can be noted that it is a direct proportionality relationship between the square of the initial velocity and the stopping distance ($s \propto u^2$), i.e., any change in the initial velocity will result in a squared change in the stopping distance. Furthermore, there is a scaled inverse proportionality relationship between stopping distance and deceleration rate ($s \propto {}^{1}/_{2a}$), i.e., a decrease in the deceleration value will cause the stopping distance to increase at twice the rate.

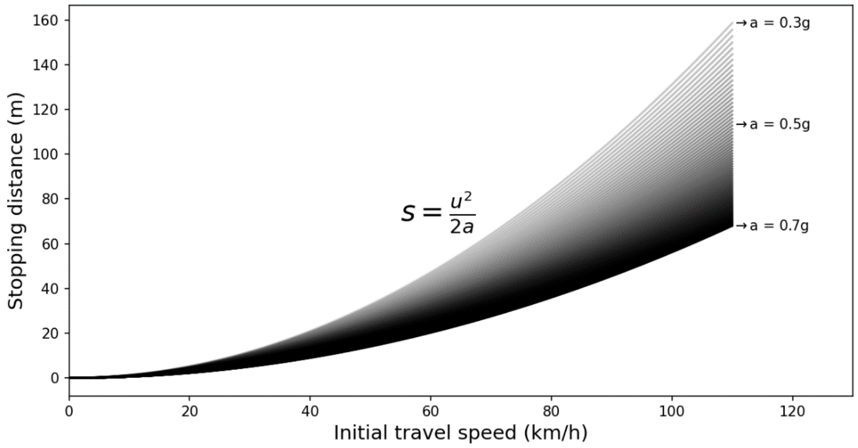

Figure 3: Vehicle stopping distance estimates for initial vehicle travel speeds between 0 and 110km/h, and a spectrum of hypothetical deceleration rates around 0.5g.

The practical implications are twofold. Firstly, stopping distances increase dramatically as initial speed increases, and secondly, the effect of deceleration rate is magnified at higher initial speeds. For example, with $a = 0.5g$, the stopping distance for an initial speed of 50km/h would be 20m, compared to 79m for an initial speed of 100km/h.

Furthermore, at higher initial speeds, driver reaction time or detection delay becomes a more critical factor. For example, with a 2 second delay a vehicle at 50km/h will travel an extra 28m, compared to 56m at 100km/h. In total, for $a = 0.5g$ and a delay of 2 seconds, the stopping distance of a vehicle travelling at 50km/h will be 47m, compared to 134m at 100km/h. This effect is plotted in Figure 4 for $a = 0.5g$ and braking delay (t_{delay}) between 0 and 5 seconds.

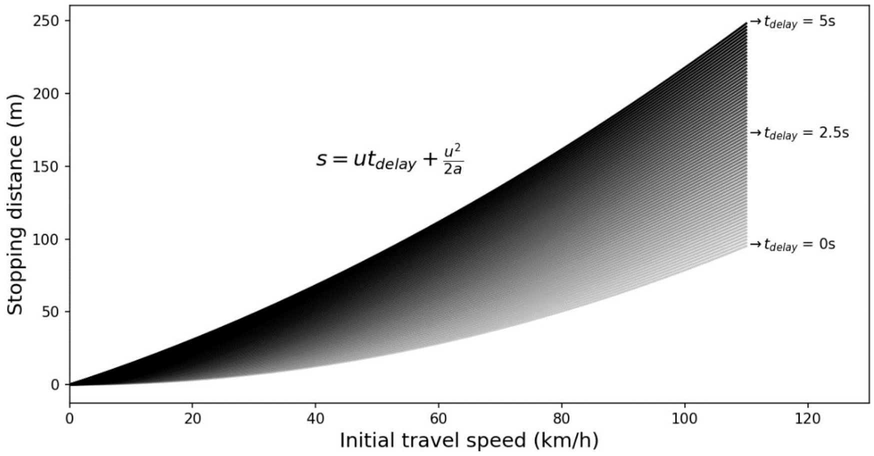

Figure 4: Vehicle stopping distance estimates for initial vehicle travel speeds between 0 and 110km/h, and a spectrum of hypothetical driver reaction/detection delay times, for a deceleration rate of 0.5g.

Evidently, for any intervention that requires driver intervention to come to a stop, a significant amount of advanced warning is typically necessary. For instance, an initial guideline might suggest that in the region of 200m on a 100km/h road, or 150m on an 80km/h road, could be needed. However, these are indicative figures. The actual warning distance necessary can vary significantly based on factors such as vehicle type/weight, vehicle braking capability, or road/visibility conditions. Factors like road layout, weather conditions, and time of day can affect visibility/line of sight, while human factors such as distraction, fatigue, or low pedestrian salience on rural roads can further influence driver reaction time. Additionally, vision algorithms in Advanced Driver Assistance Systems (ADAS) may also struggle in low-visibility conditions. Therefore, these figures should be considered within the context of the specific situation and road environment, and they may need to be adjusted upward based on the most adverse combination of these variables. In any case, it is clear that concerted efforts are needed to provide advanced warning in real-world conditions to ensure speed reductions that are compliant with Vision Zero.

2.4 STUDY AIMS

Accordingly, the aim of this project is to deliver a catalogue of ideas and approaches for facilitating safe crossings for pedestrians. Both existing/traditional measures as well as innovative/hypothetical measures are investigated. These potential solutions are considered in the context of Vision Zero and the Safe System approach, i.e., to reduce the risk and severity of crashes, separate pedestrians from motor vehicles, and create a forgiving transport system that is less reliant on individual driver or pedestrian behaviour.

3 METHODS

A mixed-methods approach was taken. Firstly, a spatial and descriptive analysis of a representative sample of pedestrian impacts that had occurred in the vicinity of bus stops on high-speed rural roads. This allowed for insights into the underlying patterns and contributing factors to these collisions. We also undertook a thorough review of existing design guidelines in Sweden. We then issued a 'call for information' to a variety of road safety networks across Europe. This step broadened our scope and provided an international perspective on the issue, opening doors for collaboration and knowledge sharing with various professionals and experts in the field. Finally, as a result of knowledge sharing, we developed an ‘idea catalogue’ that includes both existing and hypothetical solutions.

3.1 SPATIAL AND DESCRIPTIVE ANALYSIS

Our investigation utilised a basic spatial analysis approach, focusing on STRADA data (Swedish Traffic Accident Data Acquisition) to identify a subset of pedestrian impact incidents occurring within a 50-meter radius of bus stops. Due to some cases lacking geolocation data, we also conducted a manual review of the cases, leading to a final sample of 66 cases for further analysis. Our selection criteria included incidents that occurred on roads with a speed limit between 80 and 100km/h and instances where the pedestrian was crossing the road, regardless of whether or not this action was explicitly stated as being associated with access to a bus stop or not.

3.2 CALL FOR INFORMATION

A 'call for information' was sent to various traffic safety-related networks, including ICTCT (International Co-operation on Theories and Concepts in Traffic Safety) and NVF (Nordisk Vejforum), as well as numerous individuals with relevant expertise in the field. This effort generated a significant number of responses, both nationally and internationally. The feedback received highlighted various initiatives, design guidelines, potential solutions, and technical documentation from different countries. To further enhance understanding of the problem and foster collaboration, a series of follow-up brainstorming meetings were held. The responses we have received indicate two key points: firstly, the challenges surrounding pedestrian safety at rural bus stops are not unique to Sweden, but are experienced in many other countries; and secondly, the issue has no commonly accepted solution.

4 SPATIAL AND DESCRIPTIVE ANALYSIS

Figure 5 illustrates the geographical distribution of vehicle-pedestrian impacts in Sweden as recorded in the STRADA system. The selected data represents incidents occurring between 2015 and 2022 within close proximity of bus stops, specifically at distances of 10, 25, or 50 meters, on roads where speed limits ranged from 80km/h to 100km/h. Two key insights can be gleaned from this visual representation. Firstly, the overall number of such incidents is relatively low. Secondly, these collisions exhibit a fairly even spread across the populated regions of Sweden.

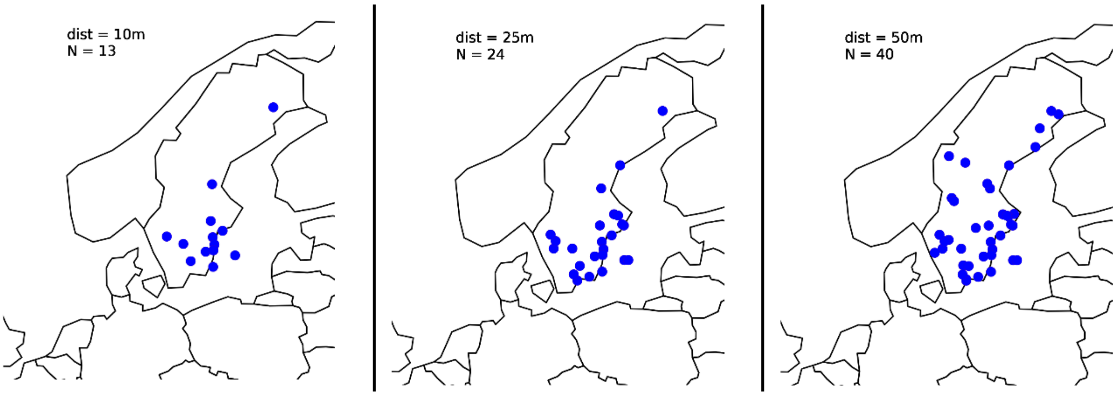

Figure 5: Vehicle-pedestrian impacts in STRADA between 2015 and 2022 which occurred within 10, 25, or 50m of a bus stop on a road with a speed limit of between 80km/h to 100km/h.

Figure 6 below provides a visualisation of the distribution of injury severity across different age groups. The data presents the frequency of various levels of injury severity, which include no injury, minor injuries (Injury Severity Score, ISS 1-3), moderate injuries (ISS 4-8), serious injuries (ISS 9 and above), and fatal injuries. It is worth noting that the predominance of minor injuries can be attributed to the nature of the impacts, which often involved partial engagement, such as impact between the front of the vehicle and a pedestrian's leg, or sideswipe impacts, where the side of the vehicle or the wing mirror makes contact with the pedestrian during an avoidance maneuver. It is difficult to discern whether a specific age category is disproportionately represented. However, it appears that there may be a higher prevalence of younger pedestrians involved in these incidents. This observation aligns with findings from the study by Eriksson et al. (2022) (Figure 1).

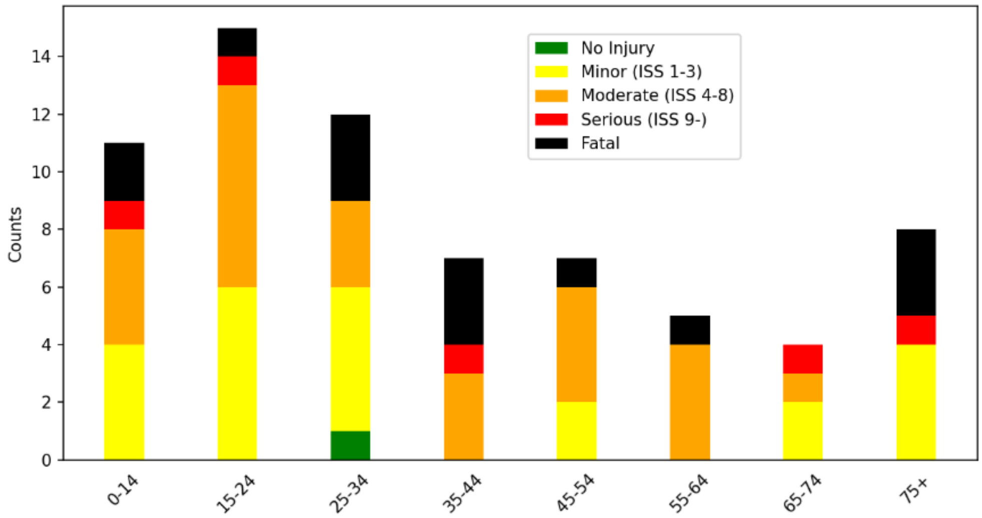

Figure 6: Distribution of injury severity among different age groups, depicting the frequency of various levels of injury severity - no injury, minor (ISS 1-3), moderate (ISS 4-8), serious (ISS 9-), and fatal.

Figure 7, presented below, outlines the monthly distribution of collisions. There is an observable increase in collisions into the winter months. It is noteworthy that this pattern aligns with the broader statistics for vehicle-pedestrian impacts resulting in fatalities in Sweden, as found in the study by Eriksson et al. (2022).

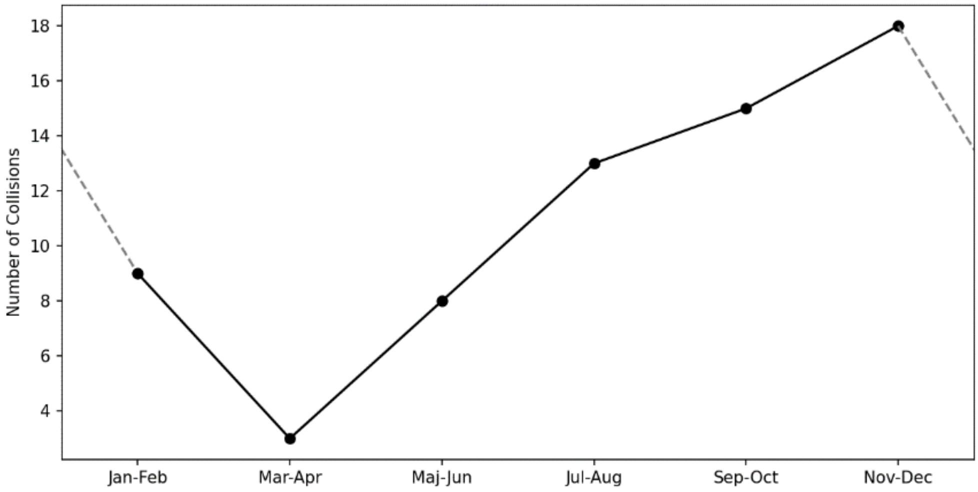

Figure 7: Monthly distribution of collisions.

This trend could be attributed to multiple factors such as reduced visibility, inclement weather conditions, or even behavioural changes in pedestrian or vehicular movement during these months. However, Figure 8 shows that a relatively high proportion of cases (48.5%) occur in darkness. These findings highlight the potential safety issues that increase during winter months and the need for targeted interventions during this period, and the general need to address the issue of reduced visibility.

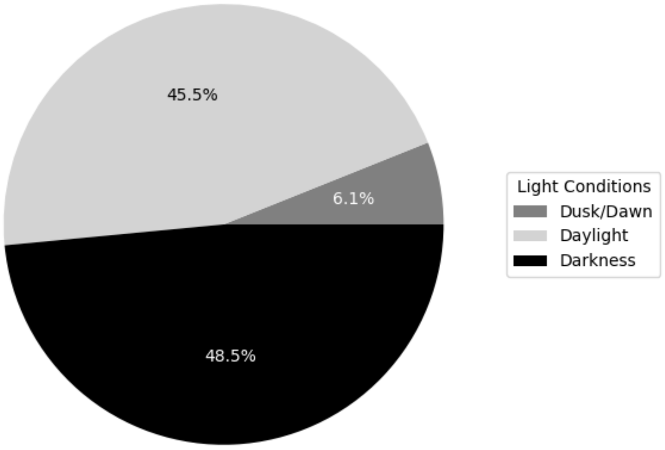

Figure 8: Distribution of collisions according to lighting conditions.

Figure 9 contains an analysis of pedestrian road crossing scenarios by age group. The data illustrates that unspecified road crossing incidents account for the majority of the events (N=30, 45%). However, when specific actions leading up to the incidents are identified, crossing the road after alighting from a bus is significantly represented (N=18, 27%). Notably, children in the '0-14' age group are prominently affected in this category, constituting 50% of such incidents (N=9). This suggests a potential vulnerability of younger pedestrians in road crossing situations, particularly following alighting from buses.

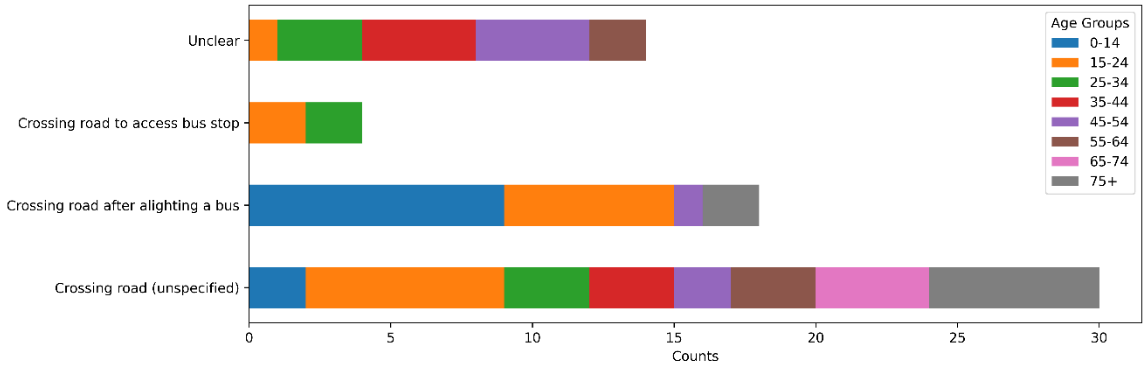

Figure 9: Distribution of pedestrian crossing scenarios by age group.

5 CURRENT DESIGN GUIDELINES

5.1 INFRASTRUCTURAL LAYOUT

The Vägar och Gators Utformning (VGU) guidelines are developed by the Swedish Transport Administration for the design of roads and streets[1]. The VGU guide is comprised of several documents, two of which outline the design process for state roads in Sweden, stipulating and differentiating between design requirements ('Krav' - Swedish Transport Administration (2022a)), and design advice ('Råd' - Swedish Transport Administration (2022b)). Furthermore, an additional document offers supporting knowledge on road and street design which is not included in VGU's Krav or Råd documents (Swedish Transport Administration, 2022c).

Generally, guidelines for pedestrian crossings on rural roads vary depending on the road type and traffic conditions balancing safety with efficiency, considering road speeds and traffic flows. Advisory design guidelines on pedestrian access to/from bus stops on mötesfri roads, i.e., separated/meeting-free roads (a type of road design to prevent head-on collisions, e.g., 2+1 roads) are provided in VGU-Råd section 10.3.9, which refers to mandatory common design requirements for GCM (Gång, Cykel, Moped) traffic, i.e., VRUs in VGU-Krav section 5.17. In terms of advised guidelines, the VGU-Råd provides three example designs for 2 stage at-grade crossings (Figure 10).

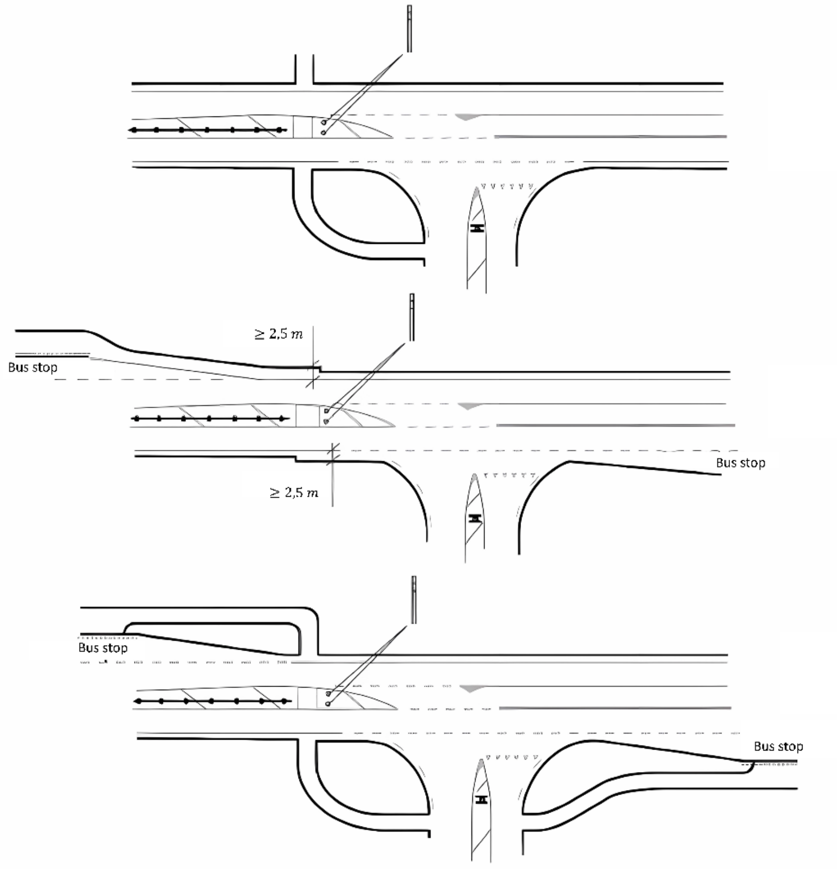

Figure 10: Example designs for pedestrian crossings. Adapted from Swedish Transport Administration (2022b).

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[1] https://bransch.trafikverket.se/for-dig-i-branschen/vag/Utformning-av-vagar-och-gator/vagar-och-gators-utformning-vgu/

On freeways and motorways, pedestrian crossings are strictly prohibited, and bus stops must be separated from the road. However, in rural areas with low traffic flows, high speed limits (up to 100 km/h), and low pedestrian footfall, there is an acceptance for at-grade crossings. The preferred approach is to have pedestrians cross at intersections with lower speed limits where they can cross in two stages, i.e., crossing one lane at a time. In some cases, crossings without securing lower speeds have been accepted, including on 2+1 roads. The guidelines state that for roads with speed limits of 100 km/h and above, larger traffic flows and pedestrian footfall, graded or two stage at-grade crossings with reduced speed limits are required. For roads with speed limits of 70 km/h and 80 km/h, larger traffic flows may require graded crossings or two stage at-grade crossings with a reduced speed limit of up to 60 km/h. In cases where there are more pedestrians and cyclists, a passage in two stages is preferred, particularly when the road is wide. For roads with smaller traffic flows and pedestrian footfall, no action is required.

While VGU-Krav section 5.17 mandates that the road speed limit, and pedestrian/vehicular traffic flow must be considered when deciding on how extensive/protected a crossing is to be installed (e.g., 1 or 2 stage at-grade, graded), exact values for the latter are not specified. This ambiguity leaves the requirements open to interpretation, and may lead to inconsistencies across the road network, and unsafe environments. Interestingly, this section of VGU-Krav also refers to stricter regulations for cyclist crossings, requiring vehicle speeds of 30 km/h for at-grade crossings, or the implementation of graded crossings. As previously discussed in section 2.3, given that Vision Zero does not condone the mixing of pedestrians and vehicles at speeds well in excess of 40 km/h, the current guidelines appear to be in conflict with this principle.

5.2 VISIBILITY AND LIGHTING

Visibility is an important factor in road and street design, particularly for at-grade crossings. The supporting knowledge document of the VGU specifies that for at-grade crossings, the sight distance must be sufficient for pedestrians to cross the road (for 1-stage crossings) or a stage (for 2-stage crossings), and to consider a slow walking speed of 1 m/s in the calculations. Furthermore, the Vägbelysningshandboken (road lighting manual) acts as an additional supplement to VGU in planning road lighting installations (Swedish Transport Administration, 2023c). The Vägbelysningshandboken discusses pedestrian safety in the context of high-speed roads in dark rural conditions, as well as pedestrian access to bus stops. It specifically highlights the need for site-specific lighting solutions at bus stops outside urban areas, considering the availability of electricity. If an electrical connection is within 199 meters, the cost is considered reasonable.

Section 6.3.1 of the document discusses the challenges and potential solutions for lighting at bus stops. It is recommended that lighting should be designed to illuminate the entire waiting area, the bus stop sign, and the road section where the bus stops. The section emphasises the importance of considering the surrounding environment when designing lighting for bus stops, as too much light can cause glare for drivers and too little light can make it difficult for bus drivers to see waiting passengers.

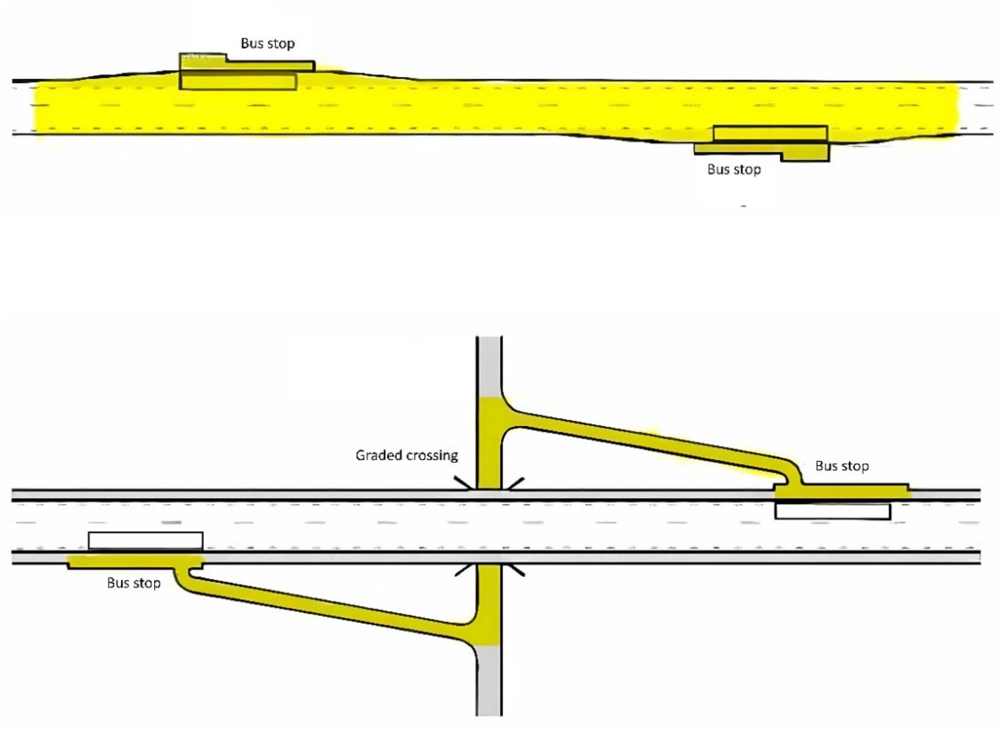

Figure 11: Examples of illuminated regions at graded and at-grade pedestrian crossings at bus stops. Adapted from Swedish Transport Administration (2023c).

Section 7.5 of the document highlights that while the purpose of lighting at pedestrian crossings is to make pedestrians visible to motorists and illuminate the road for pedestrians, achieving this in practice can be complex due to various factors such as the pedestrian's size, contrast against the background, and the driver's position and visual ability. The manual emphasises that there is no standard solution for lighting design at crossings, as it must be adapted to the specific conditions of the location. The document suggests that lighting should be arranged to make pedestrians visible both when they are on the road and when they are about to cross it. It is recommended that lighting should be arranged to illuminate the area where pedestrians wait to cross the road. The importance of high vertical illuminance, which could be beneficial in rural areas where there may be less ambient light. For example, if a pedestrian is standing at a crossing, the light that falls on the front of their body (a vertical surface) is what makes them visible to an oncoming driver. If the vertical illuminance is high, the pedestrian will be well lit and easily visible. However, in section 7.5.7 it is recommended that lighting pedestrian crossings on unlit roads may be appropriate when pedestrian footfall is high in low-light conditions, or the footpath leading up to the crossing is already illuminated. Under these conditions, the recommendation is to illuminate around 50 m before and 50 m after the pedestrian crossing, and if possible, 5 m from each side of the carriageway (Figure 12).

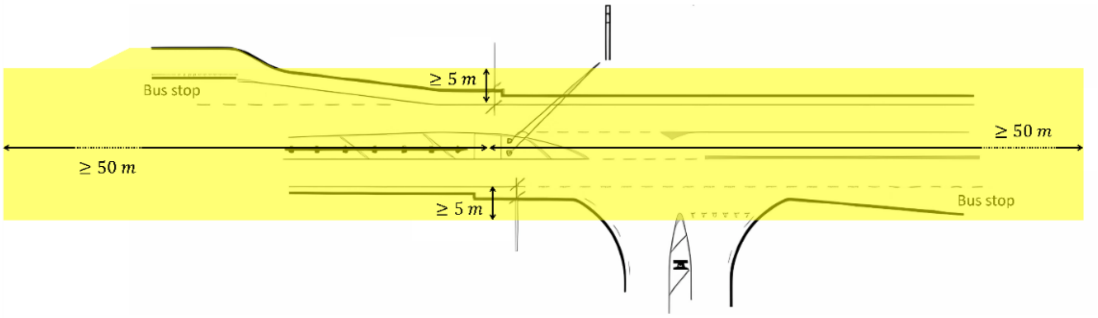

Figure 12: Example of recommended illuminated region for an at-grade pedestrian crossing on an unlit street. Adapted from Swedish Transport Administration (2023c).

6 IDEA CATALOGUE

The idea catalogue includes an array of existing and potential solutions, both in practice and in the conceptual phase, that address the challenges of pedestrian safety in the context of rural bus stops. These solutions span from infrastructural modifications to technological innovations.

6.1 GRADED AND AT-GRADE CROSSINGS

Graded/grade-separated crossings, which involve raising or lowering the road level to create a separate crossing space for pedestrians may be considered the optimal solution to the problem from a road safety perspective. Examples of grade-separated crossings for pedestrians include pedestrian bridges or tunnels. Pedestrian bridges, also known as footbridges, are elevated structures that allow pedestrians to cross over busy roads or highways without interfering with vehicular traffic. On the other hand, pedestrian tunnels, also known as underpasses, are passageways dug underneath roadways, providing a safe crossing for pedestrians beneath the traffic (e.g., Figure 13).

Figure 13: Examples of graded/grade separated crossings.

While these solutions offer a high degree of safety by physically separating pedestrians from vehicular traffic, they come with their own set of challenges. There are issues such as usability, feeling of security, extra distance to walk, potential accessibility issues for individuals with mobility challenges, and maintenance concerns, especially for tunnels which may be prone to flooding or other hazards. Moreover, the construction of these grade-separated crossings requires significant investment in terms of construction work and associated costs. Therefore, in areas where the cost of construction is not justified by the potential safety benefits, i.e., where vehicular traffic flows are small or occasional and pedestrian footfall is low, it is generally deemed unnecessary to invest in the construction of graded crossings (as detailed in section 5).

Design guidelines in Sweden recommend alternative approaches, such as at-grade passage in two stages (one direction of travel of the road at a time), or passage at intersections with reduced speed limits. These options can provide a reasonably safe crossing while considering the specific context and balancing the needs of pedestrians with other factors such as traffic efficiency and resource allocation. In rural environments, a variety of at-grade crossings can be implemented. Uncontrolled crosswalks, i.e., marked pedestrian crossings without any traffic control devices, are typically used in areas with low traffic volumes. In contrast, controlled crosswalks, regulated by traffic signals, pedestrian signals, or stop signs, can be used in areas with higher traffic volumes and speeds. Though no comprehensive survey has been performed, virtually all pedestrian crossings at bus stops on high-speed rural roads are uncontrolled (Figure 14). Pedestrian refuges or medians are sometimes used on wider roads to allow pedestrians to pause midway and deal with one direction of traffic at a time. Zebra crossings, flashing beacons or other warning signs are not used, however, user-activated retroreflective devices are common for flagging down busses (Reflexsnurra – section 6.4).

Figure 14: Examples of at-grade unsignalised crossings.

From a driver’s perspective encountering unexpected, signalised pedestrian crossings on high-speed roads can potentially compromise safety due to the longer distances needed to bring the vehicle to a stop. As previously explained, to prepare for a stop on roads with speed limits of 80 km/h or 100 km/h, drivers need an advanced warning distance of approximately 150m and 200m respectively. This requirement effectively poses a challenge in ensuring both pedestrian and driver safety, as the driver must have adequate time and distance to react and stop the vehicle safely upon approaching a pedestrian crossing. As discussed below, this particular problem can be tackled in a number of ways.

6.2 SPEED MANAGEMENT AND CALMING

6.2.1 SPEED LIMIT COMPLIANCE AND ATK

As previously described in section 2, speed limit compliance is a significant problem in Sweden (Hurtig et al., 2023). Compliance can be improved through enforcement strategies such as manual speed surveillance by the police, or automated traffic control (ATK: Automatisk TrafikKontroll). The ATK system is a fixed-spot speed enforcement solution[2]. It uses radar technology to measure the speed of each individual vehicle passing by, and if a vehicle exceeds the speed limit, the system can capture an image of the vehicle and its license plate. This evidence is then referred to the police for investigation (Figure 15). ATK has been shown to effectively reduce the average speed of vehicles and the proportion of speed limit violators (Vadeby & Howard, 2022). The findings indicate that between ATK systems there were rises in speed limit compliance of 11% for 70 km/h roads, 15% for 80 km/h roads, and 9% for 90 km/h roads. The study also found that the ATK system had a positive effect on traffic safety, i.e., a 39% reduction in fatalities and a 15% reduction in serious injuries. Accordingly, a targeted increase in ATK rollout has been included in recent national road safety action plans (Swedish Transport Administration, 2019, 2023b). As of the last estimate (end of 2022), there were roughly 2,390 installed ATK systems monitoring approximately 6,000km of roads (Swedish Transport Administration, 2023a), and between 2022 and 2025 roughly 400km will be added per year (Swedish Transport Administration, 2023b).

The roads targeted for ATK rollout are precisely the ones we are focusing on in the current study. The strategic positioning of ATK systems in areas with rural bus stops could potentially enhance safety by ensuring speed limit compliance in these zones.

Figure 15: An automated traffic control camera (ATK: Automatisk TrafikKontroll). Image from Swedish Transport Administration (2023a).

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[2] https://www.sensysgatso.com/solutions-road-safety-enforcement/speed-enforcement-equipment-systems/fixed-speed-enforcement/

6.2.2 SPEED LIMITS

As outlined in section 2.3, even with complete speed limit compliance, there is a clear need for measures which would temporarily secure vehicle speeds far lower than posted speed limits of 80-100km/h in the vicinity of bus stops. Since formal legal requirements for enforcement of a speeding offence includes the need for evidence that sufficient warning/notification was provided to the driver, it may not be feasible to specify lower legal speed limits for relatively short road sections around bus stops. The concept of speed limit consistency should also be considered, i.e., abrupt changes in speed limits, especially over short distances, can lead to confusion and non-compliance. Therefore, while it is essential to ensure the safety of pedestrians around bus stops, it is also important to consider the overall traffic flow and speed limit consistency on these roads.

A recent study by Lubbe et al. (2022) highlighted that current practice of allowing high speeds on rural roads is considerably unsafe for VRUs, and that speed limit reductions may warrant consideration (similar to the move towards 30 km/h limits in urban settings). Such reductions in speed limits could potentially enhance safety by providing drivers with more time to react to unexpected situations, and reduce both the occurrence and severity of collisions. Estimated potential benefits of reducing speed limits on high-speed rural roads are shown in Table 1. One of the most compelling arguments in favour of such reductions is the substantial decrease in the risk of MAIS3+F injuries, particularly for the elderly (calculated using risk models from Lubbe et al. (2022) - Figure 2). Furthermore, stopping distances decrease markedly with reduced speeds (as estimated in section 2.3 - Figure 4). At 100 km/h, the stopping distance ranges from 78.65-217.54m. When the speed is reduced to 80 km/h, this range drops to 50.34-161.45m, and further decreases to 28.32-111.65m at 60 km/h.

While there are trade-offs, primarily in terms of travel time, the potential to save lives makes a strong argument for re-evaluating speed limits on high-speed rural roads. For longer journeys, such as those spanning 100 km, reducing the speed limit from 100 km/h to 80 km/h results in a 15-minute increase in travel time. Further reducing it to 60 km/h adds another 25 minutes to the journey. For shorter distances, the impact on travel time is less pronounced. For instance, on a 25 km stretch, the travel time increases by just 3 minutes when reducing the speed from 100 km/h to 80 km/h, and by an additional 7 minutes when further reducing it to 60 km/h. Importantly, considering the possibility of introducing temporary reductions in speed limit only on sections of road with bus stops, the impact on travel time would be minimal.

Table 1: Comparative analysis of speed limits, balancing travel time, stopping distances, and MAIS3+F risks on rural roads.

Speed (km/h)	Time to travel:				Stopping Dist. (m)	MAIS3+F (65 yo)
	100km	75km	50km	25km		
100	01:00	00:45	00:30	00:15	78.65-217.54	0.98
90	01:06	00:50	00:33	00:16	63.71-188.71	0.96
80	01:15	00:56	00:37	00:18	50.34-161.45	0.92
70	01:25	01:04	00:42	00:21	38.54-135.76	0.85
60	01:40	01:15	00:50	00:25	28.32-111.65	0.72

It's important to note that speed limit reductions alone may not be sufficient. An ongoing study in the UK has found that while speed limit reductions on rural roads achieve the intended effect of reducing collision rates, speed choice is also influenced by the road environment (The Road Safety Trust, 2022). Furthermore, as discussed previously, speed compliance is low in Sweden. Therefore, speed enforcement (e.g., ATK – section 6.2.1), and calming measures should accompany any speed limit reductions in rural environments.

6.2.3 SPEED CALMING

Strategically positioned speed calming signs can also play a role in managing speed in these areas. For advanced driver warning before at-grade signalised pedestrian crossings, signposts can be placed significant distances before the crossing to alert drivers. These signposts may also have active elements, i.e., flashing lights or a display, which are activated either manually by a pedestrian using a pushbutton at the crossing, or automatically with a pedestrian detection system. For example, sensors at the pedestrian crossing can detect the presence of pedestrians and activate advanced driver warning signs hundreds of meters prior. In terms of speed calming, these signs can also prompt drivers to temporarily reduce their speed. As previously described, while these signs may state a recommended speed, this is not legally enforceable. Nonetheless, they serve as a visual reminder for drivers to adjust their speed in the interest of safety.

Signposts are considered ‘soft’ measures which rely on driver compliance and attention. ‘Hard’, or physical speed management measures are preferred under the Safe System paradigm. These include the implementation of traffic calming measures such as rumble strips, speed bumps/humps, or chicanes, i.e., alternating curves or bends in the road, which have a direct effect on drivers, and are difficult to ignore. Although speed bumps/humps are designed to slow down traffic, they are better suited in low-speed urban environments, as they pose a risk on high-speed roads. On 80-100 km/h roads they are generally considered unsafe, especially if not clearly marked or unexpected. Chicanes are considered a particularly useful speed calming measure because they force drivers to slow down and pay closer attention to their surroundings. A recent report by Lunds Tekniska Högskola (LTH) indicate their potential effectiveness in rural environments (Hammad et al., 2023). While speed calming measures have been widely implemented and studied in urban contexts, their application and effectiveness in rural environments, particularly on high-speed roads, is less well understood. The rural context presents unique challenges, including higher travel speeds, longer distances, and different road user behaviours. Further research is therefore required to establish their effectiveness and identify best practices.

6.3 ROAD LIGHTING

Since a relatively high proportion of pedestrian casualties at rural bus stops occur in darkness (Figure 8 - 48.5%), improvements to street lighting should be prioritised at locations where pedestrians are expected to cross. This is considered a high-impact intervention for pedestrian safety and has been shown to reduce pedestrian fatalities by as much as 50% (Elvik et al., 2009; Jensen, 1999). As detailed in section 5, guidelines often recommend that in rural environments the road should be illuminated from 50 meters before to 50 meters after the crossing, and if possible, 5 meters from each side of the carriageway (as depicted in Figure 12). However, it is worth noting that this is not common practice in many rural areas, likely due to a lack of electricity supply. The lack of adequate lighting at bus stops and pedestrian crossings in these regions can significantly compromise safety during hours of dusk/darkness. Therefore, it is recommended that lighting be prioritised around rural bus stops. This could involve the installation of additional streetlights or the upgrading of existing lighting systems to ensure that they provide sufficient illumination, with a particular focus on providing vertical illuminance (see section 5).

6.4 VISIBILITY AIDS

High-visibility clothing can significantly increase the visibility of pedestrians to drivers in both daylight and darkness (Kwan & Mapstone, 2009). Other kinds of visibility aids can include reflective armbands, or bags. There are also various types of lights that pedestrians can carry, such as flashlights or blinking LED lights. These can be particularly effective in rural areas with insufficient street lighting. However, relying on pedestrians to carry high-visibility equipment is not entirely in line with the Vision Zero or Safe System approach. This means that while high-visibility clothing can enhance safety, it should not be the primary solution, and the system should be designed to be safe even for those who are not using such equipment.

The Reflexsnurra, also known as "Reflecthor", is a rotating reflector designed to enhance pedestrian visibility, particularly for bus users in the dark[3]. This device is manually activated (the pedestrian spins it) and does not require an energy source, making them inexpensive and easy to install (Figure 16). The device is intended for two use-cases: firstly, the device can be installed on the bus stop pole for flagging a bus driver to stop, and secondly, installed at a pedestrian crossing on an unlit rural road to act as a visibility aid. The device has been shown to be effective in this context (VTI, 2020). Reflexsnurra is commonly used for flagging down busses, however, it is not commonly used for pedestrian crossings. While this may present as an simple and effective visibility aid for pedestrian crossings on rural roads, it still relies on the pedestrian's action to spin the disk. Therefore, it aligns with the Safe System approach only to a certain extent, as it shifts some responsibility from the individual road users to the system designers.

Figure 16: The Reflexsnurra device for visibility aiding at pedestrian crossings on unlit rural roads.

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[3] https://reflexsnurra.se/

6.5 SMART SPEED CONTROL MEASURES

6.5.1 SEEME

SeeMe[4] is a product developed under the SAFEWAY2SCHOOL project[5], designed to enhance the visibility and safety of children around bus stops. Initially, the system relied on a tag worn by each child. As the child neared a bus stop equipped with the SeeMe system, this tag would trigger flashing lights to warn drivers, which would stop once the child boarded the school bus (Figure 17). A more recent iteration of the system has adopted automatic radar technology, eliminating the need for children to wear tags, and opening up the possibility for broader applications, i.e., not just for children.

This advanced version has shown promising results, with studies indicating an average increase of 14% in yielding rate when the radar-based SeeMe system is active (Høye & Laureshyn, 2019). However, there were concerns in terms of detection accuracy. The study revealed that the proportion of detected crossing pedestrians varied between 70% and 97% for those crossing within the crosswalks. Such variability, especially at the lower end, indicates concerning false negative rates. Missing a pedestrian detection could have dire consequences, potentially leading to a fatality. This is especially true for any similar implementations on high-speed rural roads. On the other hand, 43% of all alarms (times when SeeMe was flashing) were false alarms, i.e., false positives. While it's always preferable for a vehicle to make an unnecessary stop than to hit a pedestrian, it's also important to address and reduce the rates of false positives; if they are excessive it can lead to driver desensitisation or distrust over time, causing them to disregard the system's warnings. Furthermore, frequent unnecessary stops can disrupt traffic flow and potentially cause rear-end collisions. Thus, for a system like SeeMe to be effective and reliable, especially on high-speed rural roads, both false negatives and false positives need to be minimised.

Figure 17: The tag-based SeeMe system for child visibility aiding at rural bus stops.

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[4] https://www.occas.se/seeme/

[5] https://cordis.europa.eu/project/id/233967

6.5.2 ACTIBUMP

Actibump[6] is an innovative smart speed bump system. The mechanism operates by using radar technology to measure the speed of oncoming vehicles. Drivers adhering to the speed limit will traverse the Actibump experiencing no disruption. Those exceeding the limit will encounter a module that descends into the road, serving as a reminder for the driver to slow down. The system has been primarily tested and approved for use in urban environments with lower speed limits, such as in Uppsala (Nilsson & Börefelt, 2015), Linköping (Börefelt & Nilsson, 2016), and now Stockholm.

These evaluations showcased its effectiveness in reducing speeds and enhancing driver yielding behaviour towards VRUs in urban environments. However, the system's applicability and performance on high-speed rural roads remain uncertain. A promising avenue for future research could be the integration of Actibump with variable speed limit signs. In this proposed setup, the Actibump would only be activated when the speed limit is temporarily lowered. The speed limit, in turn, would only be reduced when a pedestrian is detected in the vicinity of the bus stop. This approach could offer a dynamic and responsive solution. While his idea hasn't been tested yet, but it's a promising option for future research.

Figure 18: The Actibump system for dynamic urban speed control.

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[6] https://www.actibump.com/

6.6 COOPERATIVE, CONNECTED AND AUTOMATED MOBILITY

Cooperative, connected, and automated mobility (CCAM) describes a progression of the transportation system, where vehicles will be able to communicate with each other and with infrastructure[7]. Through Cooperative Intelligent Transport Systems (C-ITS), it aims to enhance road safety and streamline traffic flow through communication between vehicles/road users and infrastructure. While most existing C-ITS solutions target Vehicle-to-Vehicle (V2V) communication, its potential to enhance the safety of VRUs is gaining traction and will likely present significant opportunities for VRU safety in the coming years.

6.6.1 P2I, V2P, AND V2I COMMUNICATION

In the context of pedestrian safety, C-ITS systems could facilitate communication between intelligent vehicles, roadside infrastructure, or other road users. Three key communication paradigms are Pedestrian-to-Infrastructure (P2I), Vehicle-to-Pedestrian (V2P), and Vehicle-to-Infrastructure (V2I).

1. P2I communication refers to the exchange of information between pedestrians and the surrounding infrastructure, such as traffic lights, sensors, or bus stops. This can alert the infrastructure about their presence, in turn triggering warning signals or other safety measures. As previously discussed for the SeeMe system (section 6.5.1), the precision of these systems is important, i.e., minimising both false negatives and false positives.
2. V2P communication involves direct communication between intelligent vehicles and pedestrians, often facilitated through devices carried by the pedestrian, like smartphone apps or wearables. This kind of approach may be more applicable in the context of pedestrian safety on high-speed rural roads, as it would be particularly suited to challenging visibility conditions, and situations where a significant degree of advanced warning is required.
3. V2I communication enables vehicles to interact with roadside infrastructure like traffic lights, road signs, and sensors. This can be particularly useful for alerting drivers about pedestrians detected by the infrastructure. As with V2P communication, this paradigm may provide a significant degree of advanced warning to drivers.

For pedestrian safety when crossing high-speed roads in rural environments, P2I or V2P, or V2I C-ITS could be used to alert vehicle drivers to the presence of a pedestrian ahead and their intention to cross the road. For these systems, communication could involve existing cellular networks, dedicated short-range communication (DSRC) technology, or roadside infrastructure equipped with sensors. Building on these modalities, a number of potential systems could be envisioned. For example:

- Smart crosswalks: Using both V2I and P2I communication, crosswalks can be equipped with sensors that detect the presence of pedestrians waiting to cross. Upon detection, the system would send signals via DSRC to approaching vehicles, alerting drivers of the pedestrian's intention to cross. The V2I component ensures that vehicles are aware of the pedestrian's presence and can take appropriate action in time.
- Smartphone safety app: In a V2P scenario, pedestrians could use a dedicated road safety app that communicates their location and movement to nearby vehicles using cellular networks. When a pedestrian intends to cross the road, the app could send an alert to approaching vehicles, giving drivers advanced warning.

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[7] https://transport.ec.europa.eu/transport-themes/intelligent-transport-systems/cooperative-connected-and-automated-mobility-ccam_en

Scholliers et al. (2017) provides a detailed prospective discussion of requirements for VRU-based C-ITS, and below, these points are adapted to the specific use-case of pedestrian crossings in rural environments. Accurate positioning is important for C-ITS applications, and the position accuracy issue is more challenging for VRU devices than for vehicles. For instance, smartphones used for positioning might face challenges in achieving the desired accuracy. One of the potential major benefits of cooperative safety systems is the early detection and communication of dangerous situations, so the potential conflict should be relayed in time to warn one or both of the road users to take corrective action. The warning time depends on the Time To Collision (TTC) and should account for user reaction time, communication latency, and other factors. As a guideline, Scholliers et al. (2017) proposed a minimum TTC threshold of 5 seconds, corresponding to a range requirement of roughly 150-200 meters for pedestrian crossing scenarios in rural environments, aligning with our calculations in section 2.3. For Vehicle-To-Vehicle (V2V) communications, the range can be roughly 500-1000 meters using ETSI ITS-G5, i.e., the European standard for wireless C-ITS communication (5.9 GHz). While infrastructure-based V2I systems with intelligent pedestrian detection may also be fitted with such a communication system, smartphone-based V2P solutions which may have more relevance for applications in rural environments are not currently compatible. Jutila et al. (2017) highlighted that current limitations and challenges of using smartphone-based systems for V2P communication in terms of antenna performance are particularly important to consider for potential crossing scenarios on high-speed rural roads. Latency is also an important consideration. ETSI ITS-G5 allows for a latency of less than 1ms, whereas smartphones allow for 100ms or more (Scholliers et al., 2017). These limitations, particularly in terms of smartphone-based V2P communication latency and antenna performance, are important to overcome in order to fully harness the potential of C-ITS systems for enhancing pedestrian safety on high-speed rural roads.

In addition to these technical considerations, other challenges include the need for market penetration to ensure widespread adoption by both vehicles and pedestrians. There are also concerns about non-users or those with incompatible devices, particularly during the transitionary phase before full market penetration. Furthermore, the potential for behavioural adaptation, where road users might take riskier behaviours due to the existence of these systems, should also be considered for the long-term success of C-ITS in pedestrian safety.

6.6.2 GEOFENCING AND ISA

Along similar lines, geofencing, a technology that uses GPS or RFID to define geographical boundaries, can be integrated with Intelligent Speed Assist (ISA) systems. By creating virtual perimeters around specific areas, such as school zones or bus stops on high-speed rural roads, geofencing can trigger the ISA system when a vehicle enters these zones. The ISA system, which combines information from the vehicle's onboard systems with current speed limit data, can then provide warnings to the driver or take corrective actions, such as limiting the fuel supply or applying brakes. In the context of this project, these spatial boundaries could be temporally activated based on bus locations or the bus timetable.

Several projects are underway investigating the applications of geofencing for ISA in urban environments, e.g., the Smart Urban Traffic Zones project[8]. In this project, geofencing and other sensor technologies are used to create smart urban traffic zones that prioritise safety. The project's demonstrations, especially in Hornsgatan, Stockholm[9], showcase the potential of geofencing in regulating vehicle speeds based on pedestrian activity. This project represents a practical demonstration of how geofencing and ISA systems can be integrated to improve urban traffic safety, however, there are challenges associated with applying similar smart solutions in rural environments, e.g., limited infrastructure and inconsistent network connectivity. With this in mind,

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[8] https://closer.lindholmen.se/en/project/smart-urban-traffic-zones

[9] https://closer.lindholmen.se/en/innovation-zone-hornsgatan

the Svenska Cellulosa Aktiebolaget (SCA) and Swedish Transport Administration's 'Geofencing in Rural Areas' project is particularly relevant[10]. It is using geofencing to reduce the speed of timber trucks in rural areas with road safety concerns, e.g., school zones. Four towns/sections of road in Sweden have been selected for this project, ranging from 500 meters to 2.2 km, and the programmed speeds within these zones will be between 30-50 km/h. The project is ongoing, and results are not yet published, but the findings will have broad implications as a proof-of-concept for potential similar systems in passenger cars.

6.7 PROACTIVELY TARGETING AND TREATING RISK

In the context of Vision Zero, a proactive approach signifies a departure from the traditional method of identifying and addressing black spots or high-risk areas based on historical collision data. Instead, the emphasis is on implementing safe solutions uniformly across the entire road network. However, given the large scale and dispersed nature of the rural road network in Sweden, a strategic approach should be taken. Road safety assessments play a role in identifying potential risks and implementing proactive measures to mitigate them. One relevant initiative in this regard is the International Road Assessment Programme (iRAP), which develops proactive road safety assessment methodologies for various regions, e.g., EuroRAP[11]. This is a global initiative that provides a standardised methodology for assessing the safety performance of roads and identifying potential infrastructural improvements to reduce road crashes and fatalities. In the context of pedestrian safety, iRAP assessments take into account various influential factors, such as the presence and quality of pedestrian crossings, sidewalks, lighting, and traffic calming measures. By evaluating these factors and assigning safety ratings to road sections, this allows road authorities and policymakers to prioritise safety interventions. However, while the methodology inherently considers pedestrian safety as part of the overall road safety assessment, a more tailored assessment framework may be required to adequately address the specific issue of pedestrian safety around rural bus stops. Furthermore, as detailed in section 5, while current Swedish guidelines accept that road speed limits and pedestrian/vehicle traffic flows should be considered when deciding the the level of pedestrian protection needed, exact values are not specified.

Spatial correlation techniques have been used to identify correlations between bus stop locations and pedestrian-involved road traffic collisions. For example, in Florida, USA, Ulak et al., (2021) found a statistically significant relationship between bus stop locations and the pedestrian crashes. Hot spot analyses are commonly used to identify clusters of crashes on road networks. While spatial correlation is used to investigate the degree to which two or more variables are related in space, i.e., pedestrian crash locations, and bus stop locations, hotspot analysis can be used to identify areas with high collision numbers. The locations of these clusters can then be compared to bus stop locations. While this approach can be effective in urban areas, its application in rural environments is limited by several factors. Other than the slow, reactive nature of this kind of approach, one primary challenge relates to the lower frequency of crashes in rural areas (as demonstrated in section 4 - Figure 5), which can result in fewer instances of significant concentrations of crashes. This, in turn, can make it difficult to identify hot spots, or establish/assess the relationships between factors and collision risk. For example, Grauers (2019) conducted an analysis of the effects of infrastructural, human, and environmental factors on collision risk at railway level-crossings in Sweden using logistic regression modelling. While the findings highlighted the importance of the level of protection, i.e., the extensiveness of the warning system (with or without light/sound signals), and the roadway type as significant predictors, it was difficult to identify clear relationships for other variables with expected effects, e.g., road speed limit, traffic flows.

In line with the proactive approach of Vision Zero and the Safe System paradigm, the integration of Trafikverket's traffic safety classification for GCM crossings can further refine the risk assessment

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[10] https://www.sca.com/en/about-sca/innovation-and-research/forest/geofencing-speed-reduction/

[11] https://irap.org/partnering-to-save-lives/regional-raps/

and mitigation strategies around rural bus stops[12]. This classification system categorises pedestrian, bicycle, and moped crossings into three quality levels: green (good), yellow (moderate), and red (low). The criteria for these classifications are based on the principles of Vision Zero, focusing on reducing collision forces for unprotected road users. A safe GCM crossing is defined as one that is grade-separated or has effective speed reduction measures to ensure that 85% of drivers pass at a maximum of 30 km/h. Utilising this classification as part of the safety assessment for bus stops can aid in systematically identifying and prioritising upgrades to pedestrian facilities, thereby aligning with the proactive objectives of targeting and treating risk before incidents occur.

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[12] https://bransch.trafikverket.se/tjanster/trafiktjanster/trafiksakerhetsklassade-gcm-passager/

7 KEY RECOMMENDATIONS AND PROPOSED WORK

Based on this scoping study, the following key recommendations are outlined for improving pedestrian safety in accessing bus stops on high-speed rural roads:

1. **VGU Guidelines:**
   Conduct a comprehensive review of the VGU guidelines to address ambiguities and ensure they align with Vision Zero. Re-evaluate the design and placement of pedestrian crossings, especially in areas with high-speed limits. This includes considering the use of graded crossings, two-stage at-grade crossings, and other innovative solutions.
2. **Proactive Safety Assessment Frameworks:**
   Investigate and adopt proactive safety assessment frameworks tailored for rural environments. Prioritise interventions using Trafikverket's traffic safety classification for GCM crossings.
3. **ATK Expansion:**
   Continue to prioritise the rollout of Automatic Traffic Control (ATK) systems, especially on roads with bus stops. Integrating ATK can significantly enhance safety by monitoring speeds and enforcing speed limits in these zones.
4. **Speed Reductions:**
   Implement reduced speed limits or lower recommended speeds in the vicinity of bus stops, along with physical calming measures like chicanes. These could be paired with ATK systems for effective enforcement.
5. **Enhanced Road Lighting:**
   Prioritise improvements in street lighting around rural bus stops, especially considering the high proportion of pedestrian casualties occurring in darkness. The focus should be on providing vertical illuminance and ensuring that the entire area is well illuminated.
6. **Visibility Aids:**
   Promote the use of Reflexsnurra as a cost-effective, easy to install solution to enhance pedestrian visibility. Its manual activation, without the need for an energy source, makes it a practical "quick win" for improving safety.
7. **Smart Solutions and C-ITS:**
   Initiate pilot projects to test the effectiveness of innovative solutions like SeeMe, Actibump, and C-ITS in rural areas. This includes the potential use of smartphone-based systems for V2P communication, and geofencing integrated with Intelligent Speed Assist (ISA) systems. It's important to highlight that, in the long-term perspective, C-ITS and smart solutions hold the promise of being the most effective measures for ensuring safe speed interactions, even if the technology is currently in its nascent stages.

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