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# Secondary roads – road safety challenges

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# Foreword

With the Strategic Action Plan for Road Safety for the 2021-2030 period, the European Union (EU) committed itself to halving the number of fatalities and serious injuries (MAIS 3+) when compared to the 2019 baseline. Considerable emphasis and concerns are put on improving road safety in urban areas, as well as reducing fatal and serious injuries on motorways and primary interurban roads. This is not surprising since these are also the roads that carry the bulk of traffic volumes in the EU. Notably, the publication of Directives 2008/96/EC and 2019/1936/EC set the stage for EU Member States (MS) to develop a comprehensive set of road infrastructure safety management (RISM) procedures that are applicable to these specific categories of roads. However, the Directives are not applicable to the remainder of the rural road network which provide a vital access and distribution function to road users. These secondary roads support crucial short to medium range journeys, often on long but low trafficked roads.

This paper aims to help meeting the ambitious road safety targets of the EU by showing the important contribution of these secondary rural roads to the burden of road traffic injuries and fatalities, emphasizing the corresponding need for addressing specific road safety challenges, and highlighting various opportunities for advancing safety created by new technologies and consistent research and innovation.

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# 1. Introduction

Road networks typically consist of a primary road network, providing high-speed long-distance connections between regions or major cities, supported by secondary interurban roads and roads providing connections between the interurban network and properties. The primary network (motorways and primary roads) is generally well developed, of a high geometric standard, financially well supported and maintained, and therefore relatively safe. In the European Union (EU), this was strengthened at the regulatory level, by the implementation of Directives 2008/96/EC and 2019/1936/EC on road infrastructure safety management (RISM).

At the macro scale, the length of motorways and primary roads represents significantly fewer kilometres than lower order roads (Meijer et al., 2018). Trans-European transport network (TEN-T) core network roads represent only about 1% of all paved roads in the EU (European Court of Auditors, 2020). Europe has a road network totalling some 6,992,685 km of which 85,974 km (1.2%) are motorways and 435,979 km (6.2%) primary roads (IRF, 2023). Lower order roads (non-motorways and non-primary roads) make up the difference and are classified by exclusion from these main categories rather than by specific attributes. This is partly due to the broad diversity in their design and layout and the low standing of these roads in public and decision makers' attention. There is no general international agreement on the classification of lower order roads, as can be concluded when comparing international databases, such as IRF (2023) and Openstreetmaps (2023). For instance, for Portugal IRF includes only state operated roads, whereas Openstreetmaps categorises some secondary roads as primary.

Roads are important for an equitable (passenger) accessibility and supporting logistics (goods transport). They facilitate the largest part of freight movement in the EU (Eurostat, 2023), with approximately 13,700 million tons, out of a total of 32,900 million tons moved by all modes – including seaports haulage, rail, inland waterways, and air (2021 annual data). Freight journeys of less than 50 km represent only 6% of the annual ton-kilometres but corresponded to almost half (48%) of the total moved freight (Eurostat, 2023). This shows that short distance logistics are important, and so is the lower order road network used in the corresponding journeys; similar conclusions apply to short and medium range passenger accessibility, especially in non-urban areas. Cars are the predominant vehicle type, with an average traffic share of 64%, and 54% of short-distance trips (less than 300 km) are made by private cars in most Member States. The average distance travelled per day (all transport modes) is 34.8 km (Armoogum et al., 2022).

Thus, lower order roads are important for road transport and there is no indication they will not remain so in the future.

The importance of the lower order road network's performance is recognised by the Conference of European Directors of Roads (CEDR), which in its 2021 position paper on road safety lists the following high priority safety actions (CEDR, 2021):

- Funding safety measures on secondary routes,
- Implementing RISM procedures on all roads,

- Segregating the most vulnerable road users (VRU) from road-based transport modes that create greatest risk, and
- Delivery of safe speeds through design on two-lane roads.

These are recognised as challenges that need to be overcome and delivered. The current paper contributes to overcoming the safety challenges of secondary roads by highlighting some of the main safety issues and possible opportunities for advancing safety, including those created by new technologies. The work is supported by various analyses of data from Czechia, Netherlands, and Portugal.

The paper is organized as follows: First, the notion of 'secondary roads' is introduced (Section 1), then the formal definitions are presented (Section 2) and the main infrastructure characteristics of these roads examined (Section 3). Subsequently, by example of results from three Member States from different regions of the EU (Czechia, Portugal, and The Netherlands), the key safety challenges are highlighted (Section 4). Section 5 discusses the key principles for effective interventions for improving safety on these roads, and sources for viable good practice examples. Section 6 discusses the potential contributions as well as challenges from ITS and Connected Automated Driving (CAD) for the safety of secondary roads and Section 7 lists several promising road safety research areas. Finally, Section 8 presents the main conclusions and recommendations for next steps towards higher safety levels of secondary roads.

## 2. Definitions

A frequently used classification of the road network identifies three main categories: urban streets, interurban roads, and motorways.

This is the approach taken in the EU's CARE road crash database, which is the main source of harmonised crash data for international crash analysis at European level. According to the CARE Glossary (see terms R-11 and R-12 in EU's Directorate-General for Mobility and Transport, 2021):

- Motorway – "Public road with dual carriageway and at least two lanes each way. All entrances and exits are signposted, and all interchanges are grade separated. Central barrier or median present throughout the road. No crossing is permitted, while stopping is permitted only in an emergency. Restricted access to motor vehicles, prohibited to pedestrians, animals, pedal cycles, mopeds, agricultural vehicles. The minimum speed is not lower than 50 km/h and the maximum speed is not higher than 130 km/h (Except Germany where there is no speed limit defined)".
- Urban road – "Road inside urban boundary signs".
- Interurban road – "Non-motorway road outside urban boundary signs (remaining elements of the public road network)".

Although relatively simple and straightforward, this classification is too coarse to be usefully applied when addressing road safety on the last category, the interurban roads. These roads are diverse in terms of function, form and use with road characteristics being determined according to their role within each Member State's network of primary and secondary roads. These roads are operated by a diversity of road administrations – such as national, regional and local authorities and private concessionaires. In some Member States it also happens that roads operated by regional and national road administrations include small stretches within urban areas (often small villages) but are not yet operated as urban roads; these through roads (see *Figure 1*) serve both local and through traffic.

The EU Directive 2019/1936 of the European Parliament and of the Council, amending Directive 2008/96/EC, regulates the delivery of road infrastructure safety management (RISM) at the European level. The procedures set out in this Directive apply to roads which are part of the trans-European road network (TEN-T), essentially the motorways and high order primary roads of the road networks in EU Member States, but also to interurban roads which do not serve properties bordering on them and which are completed using EU funding (excluding roads that are not open to general motor vehicle traffic and roads that are not designed for general traffic). Under the current regulation, TEN-T roads do not serve bordering properties. According to the RISM Directive, "primary roads" belong to the highest category of road below "motorway" and they connect major cities and regions. In some jurisdictions these roads are also referred as "trunk roads", and most likely, seldom serve bordering properties. In summary, the RISM Directive tools are applied to the motorway network, to the primary interurban network, and to those other interurban roads which do not serve bordering properties (see *Figure 1*). In this document, the two last sets of roads are designated as non-motorway RISM roads (NM_RISM)

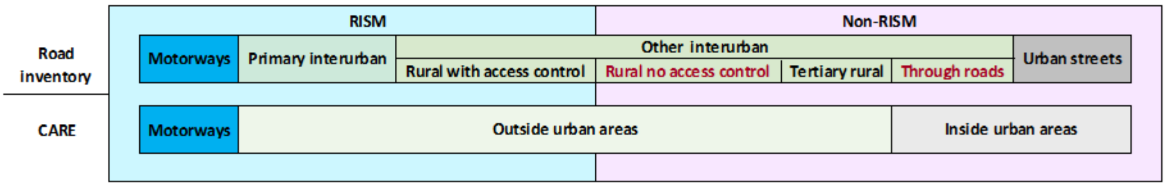


Figure 1. *Road characteristics data (Road Inventory) vs. crash data (CARE) and the scope of "secondary roads" safety. RISM roads are surrounded by the blue ribbon; the pink one surrounds non-RISM roads*.

In general, roads not serving bordering properties have some sort of access control, with frontage or alternative roads for collecting local traffic and for road users not allowed on the main road. In most cases access to these roads is provided by high order at grade intersections. Operating speeds of more than 70 km/h are possible. Often, these roads are within the scope of RISM, as EU funding is used for constructing new stretches or reconstructing existing ones.

In this document, interurban public roads falling outside of the RISM Directive categories and having regional relevance are grouped under the designation "secondary roads" (red-brown labelled sets in Figure 1). Besides urban streets, this excludes from the secondary roads category, e.g., all tertiary rural roads in Czechia and forest roads in Portugal.

# 3. Interurban secondary road characteristics

Geometric and other design characteristics of primary interurban roads are standardised in each EU Member State; however, in most Member States these guidelines are slightly less strict than those for motorways. Secondary interurban roads are much more diverse in their design, the characteristics depending on the role (function) they have within the respective road network (e.g., regional, local collector, and access), and the responsible administrative authority (e.g., National versus local authority). Often the directional and vertical alignment of secondary roads results from successive historical developments and its design parameters are not appropriate for the prevailing operating speed. In the case of reconstructions, many exceptions to current design standards are permitted, often due to difficulties in land acquisition. As a result, differences can be found in secondary road network elements, as shown in *Figure 2*.


Figure 2. *Examples of road environment variety in secondary road networks in Czechia, Netherlands and Portugal.*

In most Member States, all levels of road authorities have some secondary roads in their networks and are responsible for their design, construction and operation. This results in varying design standards, operational features and maintenance programmes within the same Member State, as national and regional/local authorities may develop and apply their own guidelines to their networks.

These differences relate to several characteristics such as physical separation of travel directions, type of access control from adjacent properties, prevailing type of intersections (roundabout, priority, signal, grade separated), design characteristics (e.g., design speed) and the allowed types of road users (in some cases bicycles or agricultural vehicles are not allowed). Often, due to their mixed function, these roads have direct access from bordering properties. They are also diverse in what refers to roadside characteristics (paved/non-paved shoulders and clear zone dimension).

Similarly, operational conditions on secondary roads are varied, as local and regional authorities have their own practices regarding important aspects, such as speed limit setting and traffic control devices. Road maintenance quality of secondary roads also differs considerably over road authorities. This is related to the considerable length of these roads, the relatively low traffic volumes, low design standards and the capacity and skill levels available at the road authority. *Figure 3* shows an example in Portugal of different levels of maintenance on two similar bridges, constructed during the same period.

Figure 3. *Example of maintenance conditions of contemporary (and same type) bridges on secondary local (left) and national (right) roads.*

Finally, secondary roads may have regional or local relevance, which impacts the motorised traffic volumes and the proportion of local traffic. More importantly, these roads also differ in terms of the environment they pass through. Some roads may include short stretches through small built-up areas, adding a new dimension to their diversity. These through-village road stretches serve both local (access function) and through traffic (traffic function). However, the relatively low traffic volumes and village population size generally do not justify constructing an interurban bypass and it is foreseeable that they will keep this dual function in future.

# 4. Current safety challenges

It is difficult to assess the importance of the road safety burden and challenges on non-primary roads outside of urban areas. For instance, the main source of harmonised crash data for international crash analysis at the European level – the CARE road crash database – only covers three road classes: motorways, urban roads (streets) and interurban roads (see *Figure 1*). The last class includes all non-motorway roads outside designated urban areas and does not distinguish the primary network from the secondary and lower-level networks (CARE, 2012). This is the classification used in a recent European Transport Safety Council (ETSC) report on improving the safety of rural roads (Carson et al., 2024). The same type of classification is used in the IRTAD database.

Due to the coarse nature of the CARE road classification, comparative analysis of road safety on secondary roads at the European level is only possible after careful analysis of national crash databases and the application of suitable data harmonisation procedures. This not only involves identifying all relevant secondary road stretches and selecting the crash data corresponding to occurrences on those stretches, but also ensuring that road classes between countries are similar. Nevertheless, direct comparisons must consider that there may exist differences between countries regarding, in particular, traffic composition, traffic culture, speeds and regulations.

## 4.1 Crashes and crash rates

Usually, secondary roads correspond to a major proportion of the road length, requiring efficient priority allocation of maintenance and redesign activities, to provide their enhanced operation. For instance, in Portugal, secondary roads (11,919 km) accounted for 64% of the National Road Network (NRN) length, administered by the national authority. However, the length of the NRN is only a fraction of the total Portuguese road network length. The local (municipal) interurban roads are eight times the length of the NRN secondary road network and correspond to 517% of the total NRN length. In the Czech Republic, only 12,7% of roads are classified as motorways and primary roads, others are secondary or tertiary roads (local roads – streets – in urban areas are excluded). In 2022 the Netherlands had a road network totalling 141,820 km of road (CBS, 2024). Of these 5,571 km fall under national roads, 7,802 km under provincial roads and 128,315 km under local authority roads. Secondary rural roads in the Netherlands fall into all three categories. However, about 46% of these roads are rural with some 50,000 km being 60 km/h roads (in this paper referred to as secondary rural roads) and 12,000 km of 80 km/h roads (NM_RISM roads in this document) (Schermers & Van Petegem, 2013 and 2015; Gebhart, Wijlhuizen & Dijkstra, 2022)

Crash data from Czechia (2019-2022), The Netherlands (2019-2021) and Portugal (2015-2019) shows that injury crashes and related injuries on secondary roads account for a sizeable proportion of all registered occurrences. As shown in *Figure 4*, injury crashes (all severities) on secondary roads corresponded to more than 20% of the Czech and Portuguese registered totals, and 12% of the Netherlands' registered total. Regarding fatalities, the importance of secondary roads is even higher: 21% of all cases in the Netherlands, 25% in Czechia and 48% in Portugal.

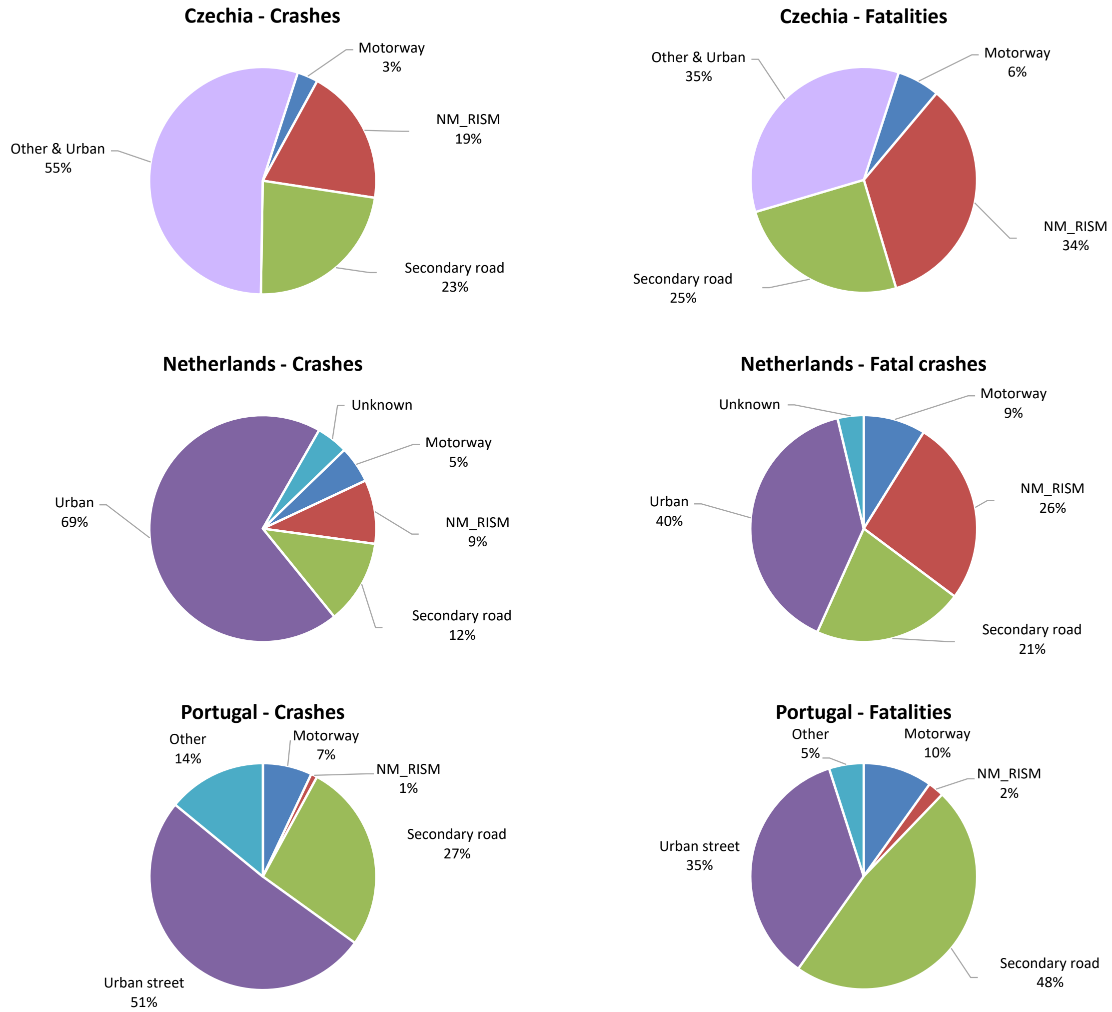


Figure 4. *Distribution of injury crashes (all severities) and fatalities per road category (Czechia, 2019-2022, the Netherlands, 2019-2021, and Portugal, 2015-2019).*

In Portugal, most of the secondary road crashes (55%) and injuries (60% of fatalities and serious injuries) occurred on the National Road Network, the rest having occurred on municipal interurban roads.

When considering travelled distance as the exposure measure, injury crash risk is higher on Czech and Portuguese secondary roads, than on the non-motorway RISM roads (NM_RISM). Results from the analysis of total crash data (fatal, severe, slight, and property damage only crashes) in Czechia during the period 2017-2021 show that the crash risk (crashes per million vehicle×km) is higher on the lower order roads than on other road categories (Andrášik & Bíl, 2022). This is most noticeable for risk rates in the higher percentile categories (*Table 1*). In Portugal this type of crash risk analysis can be done only for the secondary roads belonging to the National Road Network, as there are no regular traffic counts on municipal roads. While dual carriageway NM_RISM and secondary roads in Portugal have similar crash rates (both around 0.11 crashes per million vehicle×km), NM_RISM single carriageway roads have half the crash rate of secondary undivided roads (0.15 vs. 0.30 crashes per million vehicle×km).

Table 1. *High order percentiles of crash rates (per travelled distance) in Czechia per road category (2017-2021) (adapted from Andrášik & Bíl, 2022).*

| Percentile[1] | Motorways | NM_RISM roads (divided) | NM_RISM roads (undivided) | Secondary roads | Third order roads |
|---|---|---|---|---|---|
| 95% | 1.71 | 7.14 | 2.81 | 4.77 | 3.10 |
| 90% | 1.11 | 4.01 | 1.89 | 2.80 | 1.93 |
| 85% | 0.93 | 2.43 | 1.51 | 2.09 | 1.49 |
| 80% | 0.79 | 1.83 | 1.27 | 1.75 | 1.21 |

[1] Percentiles reflect the value that is not exceeded by that percentage of roads, so the 95th percentile means that 5% of roads have a value higher than the threshold and 95% lower.

## 4.2 Crash characteristics

Crash characteristics on secondary roads are quite different from those on NM_RISM roads, on both single and dual carriageway roads, as shown in *Figure 5*, for the three example countries. This figure displays the distributions of crashes and fatalities by type of crash. The percentages of run-off-road crashes (ROR), collisions with pedestrians (Hit_Ped), frontal collisions (Fr_col), rear-end crashes (Rear-end), lateral collisions (Lat_Col), collisions with obstacles (Col_Obst), and other types of collisions (Col_other) are shown for primary interurban roads as defined by RISM (single and dual carriageway, non-motorway) and for secondary roads.

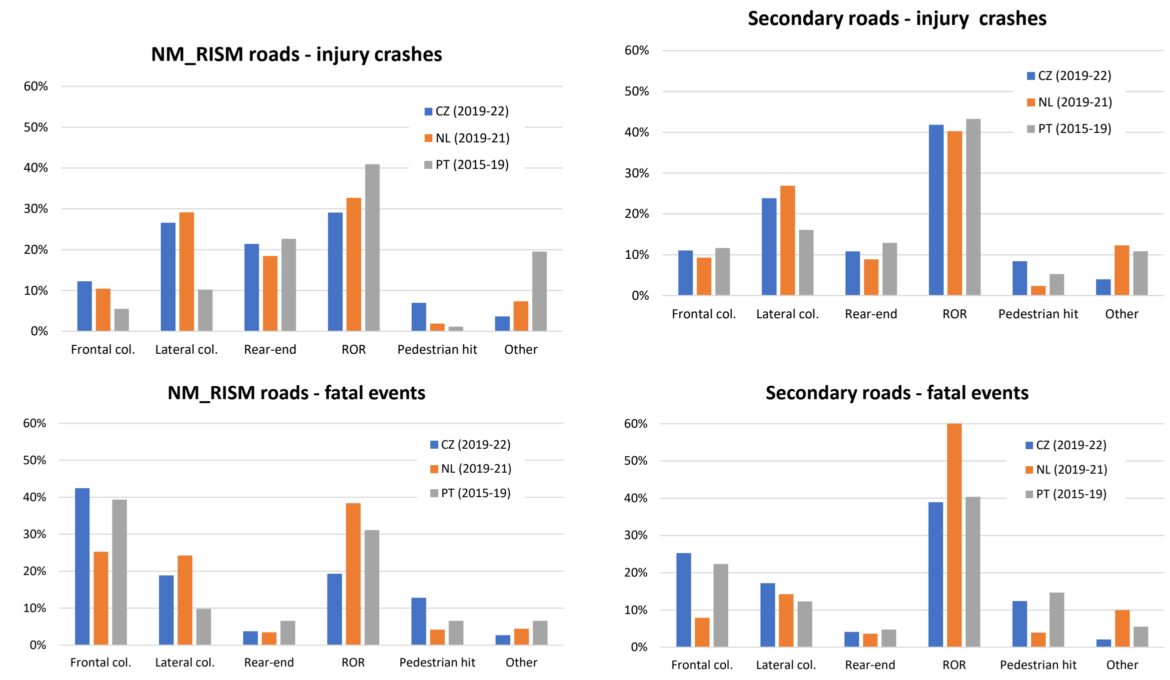


Figure 5. *Distribution of crashes per type, on primary and secondary roads in Czechia (CZ), the Netherlands (NL), and Portugal (PT).*

Overall, ROR crashes are the most important crash type in all three countries, on both NM_RISM and secondary roads. However, on secondary roads the proportion of this type of crash is higher (and similar for all three countries) than on NM_RISM roads (where Portugal has the higher share). Lateral collisions are the next most important crash type in Czechia and the Netherlands on both road categories; in Portugal, rear-end collisions are more important on NM_RISM roads, as compared to lateral collisions on secondary roads. This is partially explained by access control being generally applied on Portuguese NM_RISM roads, but not on secondary roads – which also explains why the percentage of collisions with pedestrians is much lower on NM_RISM roads in Portugal.

The distribution of fatal events (fatalities in Czechia and Portugal, and fatal crashes in the Netherlands) on secondary roads by type of crash has similar percentages in Czechia and Portugal (ROR, frontal collisions and pedestrians hit) and higher percentages of lateral collisions in Portugal. The Netherlands shows an especially high percentage of ROR fatal events and very low percentages of fatalities related to frontal collisions and pedestrians being hit.

Globally, albeit a preponderance of ROR crashes and fatal events, there are differences between countries concerning the relative importance of different crash types on secondary roads.

*Figure 6* depicts a comparison of the distributions of injury crashes and fatal events on NM_RISM and secondary interurban roads in Czechia, the Netherlands and Portugal.

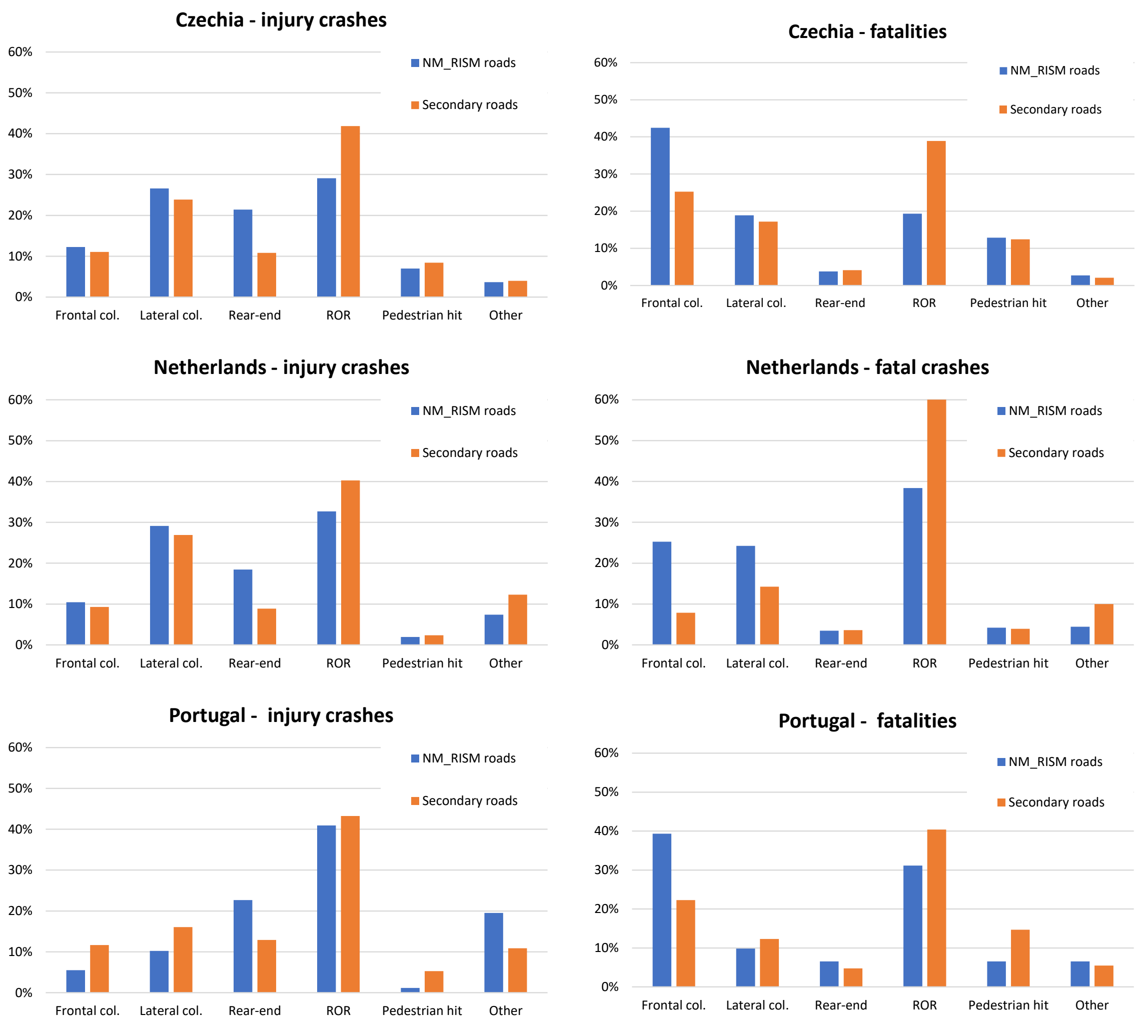


Figure 6. *Distribution of injury crashes and fatalities per road category and type of crash in Czechia, The Netherlands and Portugal.*

The percentage of ROR events is higher on secondary roads in all three countries, and more noticeable for fatal events. On secondary roads, the percentage of rear-end injury crashes and the percentage of frontal collision events are much lower than on NM_RISM roads. It is also interesting that fatal lateral collisions are less frequent on secondary roads in the Netherlands; and that in Portugal events involving pedestrians are more frequent on secondary roads.

It is also possible to detect differences in the relative importance of crash association with design elements. As shown in *Figure 7*, in Czechia NM_RISM roads are more likely to have crashes in straight sections, especially ROR crashes and head-on collisions, probably due to loss of control and excessive speed, while secondary roads are more likely to have crashes at horizontal curves or on the adjoining transition to straight sections.

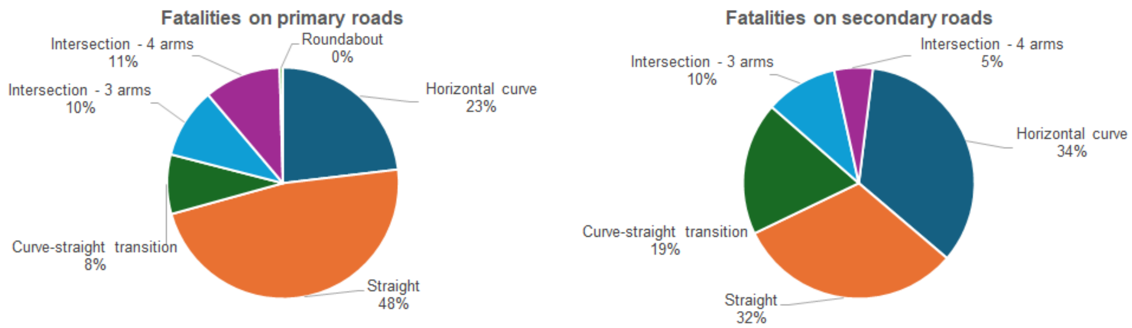


Figure 7. *Distribution of fatalities per type of horizontal alignment element in Czechia (2017-2022).*

## 4.3 Synthesis

In summary, the crash data show that ROR crashes are the most common type of crash on both the NM_RISM and the secondary road networks. Nevertheless, there are some differences between the crash occurrence phenomenon on NM_RISM and on secondary roads, allowing to infer that efficient safety interventions need to be tailored specifically for this latter road category. Data also show that crashes and injuries, and in particular fatal crashes, resulting from crashes on secondary roads are a major contributor to the burden of unsafety at the national levels, indicating that these roads also need road safety infrastructure management, even though the details may be different from the ones for trunk (RISM) roads.

# 5. Effective safety interventions in the road life cycle

There are several effective safety interventions that fit the stages of the road life cycle: planning, design, construction, and operation. Clearly, these interventions would need to be in line with the Safe System design principles – supporting safe road-user behaviour, preventing exposure to forces above human body tolerance, and combining several protecting layers (ITF, 2016; ITF, 2023). The Safe System design principles are applicable to all roads. However, their implementation needs to be specifically tailored to each road category, more so to secondary roads due to their general non-conformity to a limited range of characteristics and to their normally low traffic volumes. Due to the latter, the most efficient practice on secondary roads may differ from practice on main trunk (primary) roads and motorways. Priority evaluation for designing new secondary roads or retrofitting parts of the existing network is important, and will depend on costs and benefits, as well as on characteristics such as speed limits compliance to safe speed practice, carriageway separation, the allowed road user mix, the type of access control from marginal properties, and land use.

## 5.1 Self-explaining roads and forgiving roadsides

Generally, the configuration of the road environment (the road geometric design and its median and roadside characteristics) should be set to facilitate the correct perception of the appropriate speed by drivers and other road users, by means of the application of self-explaining roads, forgiving roadsides and safe and credible speed concepts.

The concept of "self-explaining roads" involves designing a road system in which road users' expectations created by each road environment are implicitly in line with the safe, appropriate behaviour for the road. To this end, different (function) classes of roads should be distinctive in features and design characteristics; whilst consistent features should exist in all roads within a class (Theeuwes & Godthelp, 1995; Aarts & Davidse, 2007). The systematic selection of distinguishing lane and shoulder widths, shoulder paving, type of junction (e.g., grade separated or roundabout) and the application of consistent signing colours and markings specific to each class of road, are frequent elements selected to foster an almost automatic recognition of a road category and the adoption of the appropriate speed on each road (e.g., Cardoso, 2010). On through road stretches, issues such as land use, public transport, area-wide traffic calming, and transition zones are key aspects to consider (Greibe et al., 1999). Alignment design consistency is embedded in self-explaining roads, except on transitions between different road categories, where design discontinuities (e.g., gates) are used to alert drivers to the required changes in driving behaviour.

Self-explaining roads may be designed to hinder the choice of undesirable road user behaviour (such as non-compliant operating speeds), in which case they are sometimes designated as "self-enforcing roads".

"Forgiving roadside" means that the roadside environment (and median, on dual carriageway roads) does not contain dangerous elements (such as trees, poles and steep embankment or cut slopes) that will seriously injure or kill road users in the case where the vehicles have unplanned trajectories off the carriageway (ETSC, 1998; SWOV, 2002). This concept can be extended to the whole road, in which case road characteristics nudge road users to non-dangerous behaviour, for example by means of low speeds at intersections (e.g., at roundabouts) or at locations of motorised vehicle-vulnerable road user conflicts (e.g., traffic calming in through roads).

## 5.2 Safe speeds

The concept of a safe speed is an important aspect of the Safe System approach and is directly related to the biomechanical tolerance of humans, to prevalent injuries in typical crashes on likely traffic interactions. These tolerances depend on the affected human organ and the direction, intensity, and duration of the impact forces, these being related to change in velocity or to the acceleration, principal directions of impact and type of vehicle and object involved. Typical criteria for setting safe speeds correspond to the impact speed where the chance of death is less than 10%; alternatively, the point on fatality risk curves where this changes from shallow to steep can be used (OECD, 2006; Aarts et al., 2010; SWOV, 2018). This should be considered when integrating traffic modes and explains the need for segregating vulnerable modes from motorised traffic at speeds above 30 km/h. It also provides ground for considering speed tolerance in lateral collisions for roads with medium to high density of accesses to farms and adjacent properties, and at intersections. Dutch data show the benefits of progressive adoption of roundabout intersections, as regards lateral and frontal serious crashes (SWOV, 2022).

## 5.3 Selecting and prioritizing suitable interventions

In general, there are several useful sources for selecting effective engineering road safety interventions, such as The Handbook of Road Safety Measures (Elvik et al., 2009), EU's SafetyCube project's Road Safety Decision Support System (Martensen et al., 2019), FHWA's CMF Clearinghouse (2023), iRAP's Safer Roads Investment Plans (2023) and PIARC's Road Safety Manual (2015). However, due to the low traffic on secondary roads and the non-linear variation of crash frequencies with traffic volumes, caution is advised when benefit-cost analysis is used to support prioritising decisions (Roque and Cardoso, 2014).

The benefits of correcting design inconsistencies in interurban roads have been demonstrated (e.g., Cardoso, 2005; and Ambros & Valentová, 2016). These can be identified using crash data (Elvik et al., 2009) or state of the art a priori methods such as road geometric indexes (Andrášik & Bíl, 2016), driver workload, unimpeded speed profiles and required speed variation in the approach to horizontal curves (Cardoso, 2001), or floating car data (Ambros et al., 2022). In case of consistent horizontal alignment, floating car data will show that differences in driving speed of drivers are small (Ambros et al., 2017, Ambros & Valentová, 2016).

Segregating vulnerable road users from motorised traffic, posting correct, safe speed limits, and providing forgiving roadsides are standing aspects to improve secondary rural roads. Prioritizing suitable interventions depends on traffic volumes and prevailing traffic speeds. Regarding directional separation, the right balance should be pursued, between investment for installing physical provisions (e.g., a median, a barrier or a double continuous centre line) and costs to expected traffic volumes resulting from lowering to a safe speed limit. This will depend on the amount of expected traffic volumes and the average journey length. For example, lowering the limit from 90 km/h to 70 km/h could result in an increase of 5 minutes (out of 20) in the journey time required for a 30 km point to point trip. Experience from Flandres (Belgium) showed that lowering the speed limit on single carriageway interurban roads (with a length of 116 km) from 90 km/h to 70 km/h was accompanied by a reduction of 33% in fatal and serious injury crashes (De Pauw et al., 2014). In France, following the reduction of speed limit for cars on single carriageway from 90 km/h to 80 km/h, the average speed diminished 3.1 km/h (to 83.3 km/h) and a 12% reduction in the number of fatalities was obtained (389 out of 3238 fatalities). More than 400,000 km of rural roads were affected by this intervention (CEREMA, 2020). Experience from Portugal shows that lowering the speed limit must be supported by other measures on the infrastructure, enforcement, and campaigns for improved effectiveness (Cardoso, 2011).

Czech experience shows that road markings can be used to influence the driving trajectory and speed selection. Speeds decreased following both edgeline and centreline application; regarding lateral positions, edgelines were associated with driving trajectories nearer to the centre of the road, and the centrelines were associated with shifting the driving trajectories towards the road edges (Havránek et al., 2020). Examples of road markings for motorcycles and other safety interventions on rural roads stemming from Safe System principles are described in a ETSC report (Carson et al., 2024).

## 5.4 Preventing injuries from run-off-road crashes

Preventing serious and fatal injuries from run-off-road (ROR) crashes is important on secondary rural roads, as evident from *Figure 5*. This entails reference to the forgiving roadside concept: a roadside environment which does not contain dangerous elements (such as large trees, poles, or steep side slopes) that will seriously injure or kill road users if their vehicles inadvertently leave the roadway (ETSC, 1998). Fatality data analysis shows that obstacles in the roadside and the lack of obstacle-free zones are dangerous issues (especially for ROR crashes in curves). Due to low traffic volumes and space restrictions, it is not practical to envisage the widespread provision of operating speed compatible obstacle-free zones. Where it is not possible to remove or relocate dangerous obstacles, traffic vehicles should be protected by CEN/EN 1317 compliant safety barriers. However, it should be recognised that these barriers are a factor significantly correlated with severe and fatal powered two-wheeler (PTW) riders' injuries, as shown by Portuguese data (Ananou-Johansson, 2024), even though in Portugal these barriers are mostly equipped with motorcyclist shielding devices. Ensuring adequate pavement surface evenness and skid resistance at critical locations (e.g., curves, roundabouts, and intersections) is also an important factor in motorcycle and moped safety levels.

Overall, guidance for preventing crashes involving lane departures (ROR crashes and head-on collisions) can be obtained in PROGReSS, a CEDR funded project in which a tool to self-assess and evaluate roadside design and management policies was developed (see Roadside risk assessment tool in https://cedrprogress.eu/). Likewise, this tool allows to gain insight into issues of current roadside design practices. The study also provides recommendations to improve the quality of roadside safety design, operations, and maintenance, thereby increasing the effectiveness of the road infrastructure safety management (Weber et al., 2019).

## 5.5 Some remaining issues

There are a number of remaining issues that need to be tackled.

First, a benefit-cost evaluation of introducing high energy absorbing passive safe poles (CEN EN 12767 compliant) should be sought and non-standardized safety barriers, terminals and transitions should be progressively upgraded to CEN EN 1317 compliant restraint systems.

Furthermore, space restrictions and quality of detour routes (due to shortage of alternative roads) pose special safety problems to maintenance and reconstruction roadworks, as well as to emergency services accessibility and incident management. A long-term persistent stepwise approach to improvement is needed, due to the length of secondary road networks eligible for improvement, and the diversity of road characteristics involved and the number of design guidelines to update.

Overall, RISM tools are also applicable to the design and redesign of secondary roads (road safety impact assessment and road safety audits) as well as to the existing networks (network safety assessment and road safety inspections). However, adaptations are required, due to low traffic, coarse road characteristics inventory, and low budget availability. Network-wide road safety assessments should be done on the whole network of the secondary roads, the reactive approach being especially suitable for prioritizing interventions. In the simplest form crash rates or densities by road section can be used; other more sophisticated statistical approaches can be used, such as safety performance functions (Bíl et al., 2013; Schermers et al., 2011). In the case of intersections, the Empirical Bayes approach can be used, the riskiest sections and intersections (e.g., 20% of the worst evaluated) being targeted for roads safety inspections. Cost-effective decisions can be supported using cost-benefit analysis and statistical models, for instance to address roadside safety (Roque & Cardoso, 2015).

# 6. Impact of ITS

There is a widespread expectation that ITS and connected and automated driving (CAD) have the potential to improve road safety by reducing driver errors that are associated with a large proportion of crashes (Singh, 2015) and by quickly disseminating crowd-sourced information on critical hazards and road conditions to other road users (Eriksson et al., 2014). Eventually, this could of course also affect the safety of secondary roads, even though current developments mainly concern the primary road network.

FERSI (2018) summarized the broad aspects deserving to be conveniently addressed for CAD and ITS to significantly advance road safety on European roads. This includes the conditions for securing the most likely positive contributions for safety, the recognition that some issues will likely not be solved, the identification of what new issues may be caused, as well as developing knowledge on how testing and certification can assist in identifying ITS best practices and regulating its application.

Levels of sustained automation (from 0 to 5) and the operational design domain (ODD) are key and intertwined aspects in driving automation systems for on-road motor vehicles (SAE, 2018), the latter term designating the conditions under which a given driving automation system or feature is specifically designed to function. ODD includes aspects such as environmental conditions, geographical constraints, time-of-day restrictions, the presence or absence of specific traffic or roadway characteristics, and other conditions required for the automatism to take control of a vehicle at the designated automation level.

Already, current automation systems, such as Adaptive Cruise Control (ACC) and Lane Keeping Assist – individually (Level 1 automation) or in combination (Level 2 automation) – can reduce driver workload. There are indications that these systems can contribute to a safer operation, by means of increased headway and less harsh manoeuvres (Kessler et al., 2012); there are also indications that some drivers may become complacent while using these systems and engage in secondary task activities, paying less attention to the driving task than under fully manual driving or fail to react at system limits (Banks et al., 2018; Endsley, 2017; Morando et al., 2020; Hu et al., 2022). In addition, these systems still have their technical limitations: present-day Lane Keeping Assist systems struggle to maintain lane position in sharp curves (Reagan et al., 2018), and ACC may fail to detect a preceding vehicle in the same travel lane, or mistakenly detect a vehicle in an adjacent travel lane (Miyata et al., 2010). At system limits of assistance systems (up to Level 2) drivers may fail to control their vehicle as intended (Wiggerich, 2021). Studies have also shown that drivers tend to deactivate systems issuing high rate of false positive warnings especially on roads with narrow lanes (Alkim et al., 2004; Schermers et al., 2005; Reagan et al., 2018). Currently, decisions concerning the activation of key automation systems rest on drivers, who must study and understand these systems based on description of the various systems ODD in vehicle user manuals. Drivers must then assess if prevailing conditions correspond to the descriptions they are provided with and retain the required situational awareness to timely respond when system limits threaten to be exceeded or are reached.

It is known that resuming vehicle control is more effectively done when drivers self-pace the transfer (Eriksson & Stanton, 2017). Therefore, it is important for drivers to learn at the navigation stage of a journey what type of ITS will likely be available on a given route; and once on the road to be informed (e.g., by timely nowcast warnings) if it is likely that prevailing traffic system conditions will be within the scope of the operational design domain (ODD) of their vehicles' ADAS. It would also be useful for the vehicle system to have information on the likelihood and frequency of absence of their ODD required conditions.

Like vehicles, road infrastructure elements (e.g., links and intersections) may be categorized according to their capabilities to support and guide CAD, depending on the type of digital information available to automated vehicles. In Inframix, an EU research project, a model for such categorization was offered, comprising five "Infrastructure Support for Automated Driving" (ISAD) Levels (CEN/TR 17828:2022).At the highest level of support (A), infrastructure can provide vehicles with digital mapping (e.g., static sign prescriptions and information), with variable message signing (e.g., warnings on incidents and abnormal weather conditions), real-time microscopic traffic situation characteristics, as well as real-time guidance information (e.g., speed and lane advice) allowing to optimise the overall traffic flow. The following two levels correspond to infrastructure capabilities to digitally support automated driving systems, by providing real-time complete information on microscopic traffic situations (Level B) or just information of its static and dynamic characteristics, such as signs, variable message signs (VMS) and signals (Level C). The two lower levels correspond to a conventional road infrastructure, with digital mapping of only static signs and regulations (Level D) or no digital information at all (Level E).

It is unlikely that secondary rural road administrators will deploy significant elements of digital infrastructure in the near future. If they do, they will most likely comprise level E and D elements. The latter level is compatible with ISA, and already allows alerting drivers to speed limits on critical sections such as horizontal curves (Doulabi et al., 2024). Driver support for safety decisions concerning reliance on automation systems while driving on secondary roads is needed, as well as ways to help drivers to remain engaged in the driving task on these roads, for them to successfully take over when the automation operational limits are reached (Reagan et al., 2019). More generally, it is necessary to provide context-oriented role-based-user-communication, as drivers need a clear understanding of their role when using an assisted or automated driving function (BASt, 2024). Ensuring appropriate levels of surface and landscaping quality, as well as traffic signs and road markings maintenance (optical characteristics) will continue to be a challenge for secondary road administrators.

# 7. Promising road safety research areas

The various road safety features of the current secondary road network discussed in this paper encourage a number of areas for research that could contribute to improving their safety level.

C-ITS technologies and decarbonizing road transport policy implementation are the main drivers of two emerging road safety challenges for secondary road administrators: the growing market penetration of advanced driver-assistance systems (ADAS) and intermediate levels of automation; and the upsurge of VRU traffic volumes in the spring and summer periods and when motorised traffic volumes are also higher. In many cases the proper functioning of these systems is dependent on key characteristics of the road infrastructure and environment.

Past and current planning, as well as space restrictions, challenge the implementation of widespread bicycle segregation. Prioritising methods for interventions that segregate or mitigate (lower speeds) need to be properly adjusted to meet local conditions, operating conditions (such as traffic volumes, speeds, etc.) and the needs of the local road operator (and asset management systems). Methods to effectively convey information to road users on prevailing conditions to nudge their appropriate awareness and behaviour need improvement as well.

Motorcycles have special needs regarding design consistency, skid resistance (e.g., road markings) and safety barriers. In Portugal, adherence to the current EN1317 technical specification on systems that reduce the impact severity of motorcyclist collisions has not prevented barriers from being a factor that adversely impacts motorcycle crash severity (Ananou-Johansson et al., 2024).

In the medium-term, secondary road networks will remain mostly a conventional infrastructure, not reaching ISAD levels higher than level D over most of the road length. However, secondary road administrations can benefit from advances in the integration of new-generation data sources for road condition and traffic operations assessments into their maintenance and safety management procedures. Conventional data updating will continue to rely on low frequency visual inspections and specialised probe vehicle surveys. However, data from road users (i.e., from their vehicles and their smartphones) is available with high update frequency and these need to be explored for further use. Furthermore, the road operators' vehicle fleets may be equipped with low-cost sensors capable of collecting road and roadside data. Appropriate data analytics and visualisation tools can support the development and standardisation of innovative and new performance indicators for road safety and road management. Sharing these indicators with local road administrators through the MS National Access Point (created under Directive 2010/40/EU on ITS), allows their combined use with current conventional technical specifications in technical evaluation of assets and roadwork procurement.

Besides supporting evidence based and data driven road safety management by secondary road administrators, these crowdsourced data allow mapping the likelihood of ADAS availability and providing road users with suitable expectations concerning their availability in alternative routes, contributing to improved ADAS performance and use on secondary roads.

# 8. Conclusions and possible next steps

RISM is making significant steps toward improving managing road safety on Europe's primary road network. Although this may contribute towards meeting the ambitious road safety targets set by the European Commission, it is doubtful whether these targets will in fact be met given the road safety burden on rural secondary roads and on urban roads. Based on road safety performance in three random Member States, this paper demonstrated that fatal and serious injury crashes on secondary rural roads are also a major concern. It also suggested that the secondary networks are ill equipped to deal with future technological demands from the vehicle sector. These roads need attention and at the very least steps need to be taken to ensure that these roads also meet Safe System requirements and are adapted to safe speed principles.

It is recommended that systems be developed indicating which roads are supportive of ADAS and related technologies and that use of such technologies is restricted to roads where they can be accommodated. Furthermore, consideration must be given to developing guidelines, strategies, and investment plans to redress the problems hampering road authorities in dealing with the road safety burden on secondary roads. A first step in this direction would be to scope the exact extent of the problem in Europe and to develop an action plan for implementing the most effective remedial treatments for secondary road infrastructure. Simultaneously, guidelines are required to assist road authorities in harnessing new developments to improve design standards, road inspections, maintenance, and road safety management. These should also include some form of assessment to indicate the state of C-ITS-readiness of secondary roads.

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