European Commission

# ElderSafe

*Risks and countermeasures for road traffic of elderly in Europe*

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# ElderSafe - Risks and countermeasures for road traffic of the elderly in Europe

## Final report

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**Abstract:**
By 2050, one in four people will be aged 65 or over. The aging of the population coincides with an increase in older road users since far more elderly will actively participate in traffic. As a result, the road safety situation of the elderly will also change since the normal ageing process makes people more prone to experience functional declines that can make driving a car more difficult. The fatal accident risk for elderly cyclists and pedestrians is also many times higher than for elderly car drivers.

In the light of these challenges, this report has explored the road safety risks and main trends for older road user groups (drivers, passengers and pedestrians). Fragility, illnesses and functional limitations, urban roads, walking and medication appear to be the key risk factors of elderly road users. A comprehensive and proactive strategy is required to address these risk factors and meet the safety and mobility needs of elderly road users in the (near) future. This strategy will include all policy levels and needs to apply a “design for all” approach based on a package of interventions in the area of infrastructure, education & training, licensing & enforcement and vehicle & ITS technologies.

**Key words:** Elderly road users, Risk factors, Safety, Road design, Education, Training, Licensing, Vehicle and ITS technologies

**Résumé**:
En 2050, une personne sur quatre aura 65 ans ou plus. Le vieillissement de la population est associé avec une augmentation des usagers de la route âgés. Par conséquent, la sécurité routière changera aussi puisque le vieillissement rend les gens plus sensibles aux limitations fonctionnelles qui peuvent rendre la conduite d'une voiture plus difficile. Le risque d'accident mortel pour les cyclistes et les piétons âgés est aussi plus élevé que pour les conducteurs âgés.

A la lumière de ces évolutions, ce projet a exploré les risques de la sécurité routière et les tendances principales pour les groupes d'usagers de la route âgés (conducteurs, passagers et piétons). La vulnérabilité, des maladies et des limitations fonctionnelles liées à l'âge, les voies urbaines, le piétonnage et la consommation de médicaments ont été identifiés comme les facteurs de risque principaux. Donc, une stratégie globale et proactive est nécessaire pour répondre à ces facteurs de risque et pour rencontrer les besoins futurs des personnes âgées par rapport à la sécurité routière et la mobilité. Cette stratégie comprendra tous les niveaux politiques et doit appliquer une approche basée sur un ensemble d'interventions dans les domaines de l'infrastructure routière, l'éducation, l'entraînement, la réglementation relative au permis de conduire et la technologie des véhicules.

**Mots-clés**: Usagers de la route âgés, des facteurs de risque, la sécurité routière, la conception des routes, l'éducation, l'entraînement, la réglementation relative au permis de conduire, la technologie des véhicules.

# Preface

This report is the final report of the EU ElderSafe study, "Risks and countermeasures for road traffic of the elderly in Europe" (contract period: 2015) funded by the European Commission DG MOVE. The report is a state-of-the-art report that complements current knowledge with new insights about the safety and mobility of elderly road users.

The purpose of this study is to provide a clear view on the situation of elderly road users in traffic and to provide an action plan containing recommendations for the most promising measures to be taken at the EU-level in order to enhance the road safety of the elderly in the (near) future. This strategy is developed by:

- Assessing the main trends and road safety risks for all older road user groups (drivers, passengers, pedestrians),
- Providing an overview and analysis of various countermeasures, including ITS, aimed at increasing road safety for all older road user groups.

All ElderSafe consortium members contributed to the report by writing chapters of the report (authors), organizing the stakeholders' consultation process and/or commenting earlier versions of this report.

The ElderSafe consortium expresses its gratitude to all the participants to the workshop held in Brussels on the 5th of June 2015 for the active and fruitful discussions and wishes to thank all the respondents to the survey for their valuable inputs.

# Executive summary

In the coming years, Europe is facing a significant shift in the age distributions of populations. Currently, elderly make up 18% of the European population. However, due to the decline in birth rates, the ageing of the baby-boom generation and the increased longevity; 24% and 28% of the population will be aged ≥ 65 years in 2030 and 2050 respectively. Due to these demographic changes, more elderly will actively participate in traffic. An increased proportion of elderly road users in traffic will bring a significant increase in the number of elderly road users who are at risk of being involved in road accidents. While at the moment one road traffic fatality out of five is aged 65 or over in Europe, it is expected that by 2050 one road traffic fatality out of three will be an older person which is an increase of 13%. Therefore, the aim of the "Risks and countermeasures for road traffic for the elderly in Europe" project (in short: ElderSafe) funded by the European Commission DG MOVE is to provide an action plan containing recommendations for the most promising measures to be taken at the EU-level in the light of developing a proactive strategy to enhance the road safety of the elderly in the (near) future. This strategy is developed by:

- Assessing the main trends and road safety risks for all older road user groups;
- Providing an overview and analysis of various countermeasures, including ITS, aimed at increasing road safety for all older road user groups.

### The older road user

The following categories of older road users are identified in this study:

- Car drivers;
- Car passengers;
- Cyclists;
- Pedestrians;
- Powered two-wheelers (mopeds and motorcyclists) (PTW);
- Public transport users.

### Key safety issues of elderly road users

Risk factors can make a considerable contribution to crashes or injuries. The risk factor analysis revealed that the road safety problem of elderly road users has three dimensions, not independent of each other: exposure, accident risk and injury risk. Within these three dimensions, the following **thirteen risk domains for elderly** road users in Europe are identified:

1. Exposure
   - Urban roads;
   - Rural roads;
   - Transportation mode: car driver, car passenger, PTW-user, pedestrian, cyclist and public transport user.
2. Accident risk
   - Illnesses/functional limitations;
   - Medication;
   - Risk taking/distraction;
   - Self-regulation.
3. Injury risk
   - Fragility.

However, it is not always straightforward to reduce or eliminate the negative effects of certain risk domains since interventions in some risk domains may receive a strong public support or result in greater safety benefits. Therefore, the **following risk domains** require **prior attention** because they have the **strongest impact on the reduction of serious traffic casualties** among the elderly, and because they receive a strong support by the public in terms of countermeasures:

1. Fragility
2. Illnesses and functional limitations
3. Urban roads
4. Pedestrian (i.e. walking as a transportation mode)
5. Medication

### Policy recommendations to enhance the safety of the elderly

Unless there is a fundamental reconsideration of the road traffic system to guarantee that the safety and mobility needs of elderly road users are met, the risk associated with older road users will aggravate in light of the expected demographic changes. Therefore, measures targeting these risk factors are of great interest to the safety of elderly road users and should be a key priority of any policy. In order to meet the safety and mobility needs of elderly road users in the (near) future a **comprehensive and proactive strategy** is required which will encompass policy at EU, national, regional and local levels and includes **a package of measures** composed of:

- Infrastructural interventions;
- Education & training;
- Licensing & enforcement;
- Vehicle & ITS technologies.

The key policy priority in the (near) future is that this package of measures should be based on a **"design for all" approach**. This approach takes the specific needs, opportunities and limitations of different road users into account. As a result, these measures will not only enhance the road safety and mobility of the elderly; younger road users will also benefit from an age-friendly design.

### Infrastructural interventions

Creating and providing a **safe road environment** can significantly improve the safety and mobility of elderly road users. Additionally, improvements in infrastructure and road design can realize immediate **safety benefits and cost-effective results**. Several interventions in road design have the potential to improve the safety of elderly road users, however, only a handful seems to address the most important risk factors of elderly people. It is recommended:

- To separate vulnerable road users from motorized traffic and/or introduce low design speeds in areas with many vulnerable road users.
- To develop self-explaining and forgiving roads in urban and rural environments.
- To reduce conflicts between VRU's and vehicles and between vehicles at intersections in urban networks.
- To use protected-only operations at signalized intersections in urban areas.
- To develop standards in the area of age-friendly road design.

### Education and training

The safety benefits of educational and training programs are difficult to assess. However, **creating a better awareness** among the elderly of health and medical conditions and functional abilities that affect their driving, age-related vulnerability, and the adoption of self-regulation strategies will remain a **key policy priority** in the (near) future. Therefore, it is recommended to:

- Train elderly in recognizing their deficits and to adjust their behaviour accordingly which will result in more effective self-regulation of older road users and improved road user behaviour.
- Inform older road users about their increased age-related fragility and about the importance of using protection devices. These information initiatives should

be combined with a practical training aimed at the correct usage of these protection devices.

- Introduce standardized medical protocols to systematically assess the influence of age-related illnesses, functional limitations and prescribed medication on driving abilities. The results of these tests permit to design tailored-made educational and training initiatives to meet the individual needs and requirements of the older road user.

### Licensing and enforcement

As the number of elderly people will increase in the future, most will have a driving license, access to a car and will prefer to drive in old age. Therefore**, future older driver programmes should support continued driving for as long as drivers are capable to meet specific medical and safety criteria**. In that respect, programmes entailing **gradual license restrictions** provide promising prospects to fulfil the elderly's safety and mobility needs. Therefore, it is recommended to:

- Create a uniform arrangement across the Member States concerning the decision on fitness to drive. The decision with respect to driving cessation and/or restrictions should not be based on age nor on the diagnosis of any particular diseases, but on a judgement of health and functional abilities required for safe driving.
- Establish specialised and certified mobility centres with multidisciplinary professionals (driving instructors, psychologists, physicians,…) to perform medical and driving tests and to provide individually tailored trainings.
- Stimulate the development of a community-based referral system involving physicians, health care professionals, police, friends and families of older drivers and older drivers themselves to identify high-risk drivers, encourage them to test their driving abilities and provide tailored solutions.
- Inform (older) unfit drivers to participate in voluntary driver assessments such as online checklists or tests to raise awareness about the effects of functional limitations on driving abilities.
- Train licensing agencies to help maintain safe driving for as long as possible and assisting drivers in the transition to non-driving besides only focusing on identifying at-risk drivers.
- Provide guidelines for health care professionals, licensing agencies and law enforcers to refer/report drivers for license screening and testing and provide immunity for those reporting.
- Encourage research institutes to produce scientifically sound criteria (neuropsychological tests, medical tests and driving tests) to evaluate driving abilities (including compensation behaviour) and risks.

### Vehicle & ITS technologies

Interventions within the area of vehicle and ITS technologies provide potential to enhance the safety of elderly road users since **advanced vehicle technologies or driver assistance systems** can help the elderly to stay mobile in a safe way by assisting them to **compensate for their age-related functional declines**. Currently, these technologies are developed without applying a user-centered approach for older drivers. Therefore, it is time to design an **age-friendly vehicle**. It is recommended to:

- Develop better active vehicle safety standards for older and more vulnerable road users by including the elderly within the design process.

- Introduce a standardized testing procedure to systematically asses the usability and effectiveness of advanced vehicle technologies for older drivers. This should be done by including elderly safety in EuroNCAP testing.
- Educate and train older people on the correct usage of active safety technologies (elderly-adapted ADAS technologies).
- Encourage the further development of crash avoidance systems, such as intersection and lane change assistants and active pedestrian protection systems.
- Explore the potential benefits and drawbacks of (semi-) automated driving in extending the driving life of older road users by offering assistance to compensate for functional limitations.

Furthermore, fully automated vehicle technologies will create safety benefits for older drivers as the sensory, cognitive and psychomotor abilities of the driver can be compensated for by these vehicles. As a result, elderly will stay mobile. Furthermore, driving automation technologies encompass six levels ranging from no automation to full automation. In that respect special attention should be paid to the older driver when the technology is situated in the intermediate level of market introduction (i.e. level 2 'partial automation' and level 3 'conditional automation') since these technology levels still require that the driver is capable to intervene if necessary. Therefore, it needs to be carefully analyzed and monitored to what extent older drivers are still capable to quickly intervene in the driving task if this is required.

### Preserve and enable lifelong mobility

Infrastructural interventions, education & training initiatives, licensing restrictions and vehicle & ITS technologies can only compensate for reduced fitness to drive to a certain degree. Furthermore, mobility, health and well-being are intertwined since the **loss of mobility is connected with declines in life quality, functional independence and physical and mental health**. Therefore, elderly safety and mobility should be balanced equally in the development of an elderly transport safety strategy. Thus, maintaining the mobility of elderly who quit or are forced to cease driving will be a **key policy priority** in the (near) future. This should be realized by **providing alternative transport options and services**. These measures must be taken now in order to cope with the expected increases in the elderly population. Therefore, all policy levels and key stakeholders must work together to support the elderly by:

- Expanding and improving conventional public transport services adapted to the elderly's travel patterns.
- Offering safe, affordable, reliable, accessible transportation alternatives to elderly people before they are forced to cease driving.
- Training and informing elderly people about how to use these alternative transport options and services.
- Health care workers, licensing agencies, friends and families of older drivers should help the older driver to prepare the transition from car driving to life-after-car.

Finally, the older road user himself should have an open mind about his life-after-driving and should also consider life-decisions that can positively affect mobility into old age such as relocating to urban areas.

## Recommendations for action

Additional to the specific actions by countermeasure area, the ElderSafe project formulates the following recommendations for action with respect to the overall road safety policy for elderly road users. A multi-actor approach is necessary to keep older road users safe and mobile.

**Health care workers**

- To increase their own knowledge and awareness about age-related deficits or medication that may have an impact on road user safety;
- To pro-actively share information and discuss about such risks with the older road user;
- To offer possibilities and motivate the participation in self-assessment and voluntary testing for the early detection of driving deficits;
- Train elderly in recognizing their deficits and to adjust their behaviour accordingly which will result in more effective self-regulation of older road users and improved road user behaviour;
- Inform older road users about their increased age-related fragility and about the importance of using protection devices. These information initiatives should be combined with a practical training aimed at the correct usage of these protection devices.

**Vehicle technology and manufacturing sector**

- To design and inform older road users about effective vehicle safety technologies to better protect the (older) vulnerable road user;
- To design smart vehicle safety technologies adapted to the needs and individual characteristics of different driver groups, such as the higher physical vulnerability of the older driver and passengers (i.e. design for all);
- Educate and train older people on the correct usage of active safety technologies (elderly-adapted ADAS technologies);
- To systematically assess the usability of advanced vehicle technologies for older drivers.

**Local and regional governments**

- To design education and awareness campaigns aimed at improving the awareness of age-related, illness-related deficits and prescribed medication and their potential effects on road user safety;
- To provide safe, easy-to-use and comfortable transportation alternatives for (older) road users who are no longer able to drive;
- To create self-explaining and forgiving road infrastructure, both in urban and rural environments;
- To organize and promote possibilities for voluntary driver self-assessment and training;
- To formulate guidelines to separate vulnerable road users from motorized traffic and/or introduce low design speeds in areas with many vulnerable road users. Clear regulations should also be developed and applied in situations where this is not possible;
- To inform and train elderly road users in refresher courses on (new) traffic rules and modern road infrastructure concepts such as shared space, self-explaining and forgiving roads;
- To establish specialised and certified mobility centres with multidisciplinary professionals (driving instructors, psychologists, physicians, etc.) to perform medical and driving tests and provide individually tailored trainings;
- To develop a community-based referral system involving physicians, health care professionals, police, friends and families of older drivers and older drivers

themselves to identify high-risk drivers, encourage them to test their driving abilities and provide tailored solutions;
- To implement fitness-to-drive issues in the formal medical training of physicians and other health professionals;
- To provide standardized training and education for health care professionals, law enforcers and licensing personnel on fitness-to-drive;
- To provide guidelines for health care professionals, licensing agencies and law enforcers to refer/report drivers for license screening and testing and provide immunity for those reporting.

**Research institutes**
- To better understand the accident circumstances in which older road users are involved and propose effective countermeasures;
- To produce scientifically sound criteria (neuropsychological tests, medical tests, driving test) to evaluate driving abilities (including compensation behaviour) and risks;
- To explore the impact of innovative transportation means such as electric vehicles, pedelecs (e-bikes) and intelligent bikes on elderly safety;
- To explore the exposure patterns of elderly road users;
- To evaluate the effectiveness of countermeasures to improve older road user safety;
- To explore the prediction of non-fitness to drive in order to establish testing standards by differentiating safe from at-risk driving.

**Insurance sector**
- To stimulate older road users to participate in awareness raising, educational and/or driver training activities, e.g. by offering financial incentives.

**European Commission**
- To create additional awareness about older road user safety at different governmental levels (EU, national, regional, local);
- To stimulate Member States to address older road user safety in their national mobility plans;
- To exchange information on best practice countermeasures to increase older road user safety;
- To stimulate scientific research in the area of older road user safety;
- To include (older) vulnerable road user safety in vehicle safety testing standards;
- To monitor that interventions aimed to increase the safety and mobility of elderly road users are not discriminatory;
- To promote urban road safety policies within sustainable urban mobility plans;
- To develop stronger policies for traffic safety of pedestrians and other VRUs;
- To explore the potential benefits and drawbacks of (semi-) automated driving for older road users;
- To increase the importance of (elderly) road safety elements in the guidelines for holistic urban management;
- Add a recommendation to the Driving License Directive to include education/training/ awareness initiatives within the national licensing policies;
- To encourage health programmes that help reduce fragility;
- To introduce a standardized testing procedure to systematically asses the usability and effectiveness of advanced vehicle technologies for older drivers. This should be done by including elderly safety in EuroNCAP testing;
- To create a uniform arrangement across the Member States concerning the decision on fitness to drive. The decision with respect to driving cessation and/or restrictions should not be based on age nor on the diagnosis of any

particular diseases, but on a judgement of health and functional abilities required for safe driving;
- To create a uniform arrangement across the Member States with respect to license renewal policies;
- To introduce standardized medical and driving protocols with respect to license restrictions, license renewal and license screening and testing.

**The older road user himself**
- To be aware about the potential problems and increased accident risks associated with ageing;
- To (learn to) compensate for potential age- or medical related perceptual-motor deficits that may affect one's safety;
- To have an open mind about possibilities offered for self-assessment or voluntary driver testing, or to discuss one's personal situation with family and/or health care professionals (doctor, occupational therapist, pharmacist);
- To prepare the transition from driving to life-after-car.

# Résumé analytique

Dans les années à venir, l'Europe va se voir confrontée à un changement significatif en ce qui concerne sa répartition d'âge des populations. Actuellement, les personnes âgées représentent 18% de la population européenne. En raison de la baisse des taux de natalité, le vieillissement de la génération du baby-boom et l'accroissement de la longévité ; 24% de la population aura un âge ≥ 65 ans en 2030 et 28% en 2050. A cause de ces changements démographiques, les personnes âgées occuperont une place de plus en plus importante dans les transports routiers. Le vieillissement de la population ira de pair avec une croissance du nombre des usagers de la route courant le risque d'être impliqué dans un accident routier. De nos jours, la mortalité des personnes âgées (>65 ans) en accident de la route est de une sur cinq en Europe. Il est prévu que d'ici 2050, cette proportion passe à une sur trois. Ce qui représente une augmentation de 13%. C'est pourquoi l'objectif du projet, "Risks and countermeasures for road traffic for the elderly in Europe" (Projet : ElderSafe) subventionné par la Commission européenne DG MOVE est de pourvoir un plan d'action contenant des recommandations portant sur les mesures les plus prometteuses à mettre en place au niveau de l'Union européen en vue de développer une stratégie proactive pour l'amélioration de la sécurité routière des personnes âgées dans le futur. Cette stratégie est développée sur la base de :

- l'estimation des principales tendances et des risques majeurs en sécurité routière pour les personnes âgées dans chaque catégorie d'usagers de la route;
- la provision d'un aperçu et d'une analyse des différentes contre-mesures, y compris les technologies de transport intelligentes ayant pour but l'augmentation de la sécurité routière pour chaque catégorie d'usagers de la route.

## Les personnes âgées usagers de la route

Les catégories d'usagers de la route suivantes sont identifiées dans cette étude:

- Conducteurs automobiles;
- Passagers automobiles;
- Cyclistes;
- Piétons;
- Deux-roues motorisés (vélomoteurs et motocyclistes) (2RM);
- Usagers des transports en commun.

## Principales problématiques pour les personnes âgées usagers de la route

Les facteurs de risque peuvent considérablement influencer le risque d'accident ou de blessure. L'analyse de ces facteurs de risque a révélé que le problème de la sécurité routière des usagers âgés contient trois dimensions, dépendantes l'une de l'autre: exposition, risque d'accident et risque de blessure. En Europe, au sein de ces trois dimensions, les **treize domaines de risque suivants pour les usagers âgés de la route** ont été identifiés:

1. Exposition
    - Routes urbaines;
    - Routes rurales;
    - Mode de transport: conducteur automobile, passager automobile, usager de deux-roues motorisé, piéton, cycliste et usager des transports en commun.
2. Risque d'accident
    - Maladie/limitations fonctionnelles ou handicape;
    - Traitement médical;
    - Prise de risque/distraction;
    - Autorégulation.
3. Risque de blessure

- Fragilité.

Cependant, ce n'est pas toujours simple de réduire ou d'éliminer les effets négatifs de certains domaines de risque étant donné que des interventions dans certains domaines de risque peuvent recevoir un support public très fort ou résulter en des bénéfices de sécurité plus grands. Ceci explique pourquoi, les **domaines de risque suivants** demandent une **attention prioritaire** puisqu'ils ont **l'impact le plus important sur la réduction des victimes les plus gravement atteintes** parmi les personnes âgées, et parce qu'ils reçoivent un support public très fort en termes de contre-mesures:

1. Fragilité
2. Maladies et limitations fonctionnelles
3. Routes urbaines
4. Piétons (i.e. la marche comme mode de transport)
5. Médication

## Recommandations de politique générale pour améliorer la sécurité routière des personnes âgées

Sauf si l'on reconsidère fondamentalement le trafic routier afin de garantir que la sécurité et les besoins de mobilité des personnes âgées usagers de la route sont atteints, le risque qui leur est associé augmentera aux vues des changements démographiques attendus. C'est la raison pour laquelle des mesures ciblées sur ces facteurs de risque sont d'un intérêt capital pour la sécurité des usagers de la route âgés et devraient être une priorité pour toute politique générale. Afin de répondre aux besoins en sécurité et mobilité des usagers de la route âgés dans un avenir proche, une **stratégie compréhensive et proactive** est requise et se doit d'englober la politique générale au niveau de l'Union européenne ainsi qu'au niveau national, régional et local, incluant **un ensemble de mesures** composé de:

- Aménagement des infrastructures;
- Education & Formation;
- Attribution des permis de conduire & respect des règles de circulation;
- Technologies des véhicules et de transport intelligent.

La priorité pour la politique générale dans le futur (proche) est de baser cet ensemble de mesures sur une approche **"conception universelle"**. Cette approche tient compte des besoins, opportunités et limitations de divers usagers de la route. Ainsi, ces mesures accroîtront non seulement la sécurité routière et la mobilité des personnes âgées mais également celles des usagers plus jeunes qui profiteront également d'une telle conception.

## Interventions infrastructurels

La création et la mise à disposition d'un **environnement routier sûr** peut améliorer significativement la sécurité et la mobilité des usagers de la route âgés. De plus, l'amélioration de l'infrastructure et de la conception des routes peut conduire à **un gain immédiat en sécurité tout comme des résultats rentables**. Plusieurs interventions sur la conception des routes ont le potentiel d'accroître la sécurité des usagers âgés, néanmoins, seulement un nombre limité semble adresser les facteurs de risque primordiaux des personnes âgées. Il est recommandé de:

- Séparer les usagers de la route vulnérables de la circulation motorisée et/ou imposer des vitesses réduites pour des zones à forte densité d'usagers vulnérables.
- Développer des routes auto-explicatives et des routes « pardonnantes » dans des environnements urbains et ruraux.

- Réduire le nombre de conflits entre les usagers vulnérables et les véhicules et entre véhicules en intersection en agglomération.
- Utiliser des zones protégées en intersection signalée dans des environnements urbains.
- Développer des standards adaptés aux personnes âgées dans le domaine de la conception routière.

### Education et formation

Les bénéfices en sécurité des programmes éducatifs et des formations sont difficiles à estimer. Cependant, **la mise en place d'une meilleure prise de conscience** chez les personnes âgés au sujet des risques liés à l'état de santé, la médicalisation et l'influence de leurs compétences fonctionnelles sur leur aptitude de conduite, leur vulnérabilité en rapport avec l'âge et l'adoption de stratégies d'autorégulation restera **une priorité de politique générale** dans un avenir proche. C'est pourquoi il est recommandable de:

- Former les seniors à la reconnaissance de leurs déficits et à l'ajustement correspondant à leur comportement ce qui résultera en une autorégulation plus efficace des usagers âgés et un comportement routier amélioré.
- Informer les usagers de la route seniors de leur fragilité accrue caractéristique de leur l'âge et de l'importance de l'utilisation de dispositifs de protection. Ces initiatives d'information devraient être combinées avec une formation pratique visant l'emploi correct de ces dispositifs de protection.
- Introduire des protocoles médicaux standardisés pour estimer systématiquement l'influence de maladies typiquement liées à l'âge, des limitations fonctionnelles et des prescriptions médicales sur les compétences de conduite. Les résultats de ces tests permettent de développer des initiatives éducatives et des formations sur mesure afin de répondre aux besoins individuels et aux exigences des usagers de la route séniors.

### Permis de conduire et respect des règles de circulation

Vu que le nombre de personnes âgées augmentera dans l'avenir, la plupart aura un permis de conduire, accès à une voiture et préférera conduire à un âge avancé. C'est pourquoi**, des programmes futurs pour des personnes âgées devraient inclure la poursuite de la conduite aussi longtemps que les conducteurs seront capables de satisfaire aux critères médicaux et de sécurité spécifiques**. A cet égard, les programmes contenant des restrictions graduelles d'attribution de permis de conduire offrent des perspectives prometteuses quant à la satisfaction des besoins de sécurité et de mobilité des personnes âgées. C'est pourquoi il est recommandable de :

- Créer un arrangement uniforme à travers les Etats Membres par rapport à la décision sur l'aptitude de conduire. La décision sur la cessation de la conduite automobile et/ou des restrictions ne devrait pas être basée sur l'âge ou sur le diagnostic d'une quelconque maladie particulière, mais sur un jugement d'aptitudes de santé et d'aptitudes nécessaires à la conduite automobile en toute sécurité.
- Créer des centres de mobilité spécialisés et certifiés avec des professionnels multidisciplinaires (moniteurs de conduite, psychologues, médecins, …) pour la réalisation d'examens médicaux et de conduite et pour offrir des formations personnalisés.
- Stimuler le développement d'un système de référencement communautaire incluant des médecins, des professionnels de la santé, la police, des amis et des familles de personnes âgées tout comme les âgés eux-mêmes afin

d'identifier des conducteurs à fort risque, et les encourager à faire évaluer leurs aptitudes de conduite et de pourvoir des solutions sur mesure.

- Informer les conducteurs âgés inaptes afin qu'ils participent à des examens de conduite volontaires comme des listes de contrôle en ligne ou des tests ayant pour but d'augmenter la prise de conscience par rapport aux effets de limitations fonctionnelles sur les aptitudes de conduite.
- Former les agences auto-écoles à entretenir une conduite sécuritaire aussi longtemps que possible et assister les conducteurs âgés pendant la transition d'arrêt de la conduite au lieu de se concentrer exclusive sur l'identification des conducteurs à fort risque.
- Pourvoir des consignes pour les professionnels de la santé, les préfectures et les agents des forces de l'ordre pour qu'ils rapportent/renvoient les conducteurs vers un examen théorique et pratique du permis de conduire et attribuer l'immunité pour les « rapporteurs ».
- Encourager des instituts de recherche à proposer des critères scientifiquement solides (tests neuropsychologiques, tests médicaux et tests de conduite) pour l'évaluation des aptitudes de conduite (y compris le comportement d'adaptation) et des risques.

### Véhicules et Technologies intelligentes de transport

Les développements dans le domaine de la technologie des véhicules et des transports intelligents offrent un potentiel d'amélioration significatif en sécurité pour les usagers de la route âgés car **plusieurs technologies de véhicule avancées ou systèmes d'assistance à la conduite** peuvent aider les personnes âgées à prolonger leur mobilité en toute sécurité en les assistants à **compenser leurs déclins fonctionnels liés à leur âge**. Pour le moment, ces technologies sont développées sans appliquer une approche axée sur l'utilisateur pour les conducteurs âgés. Ceci explique pourquoi il est temps de concevoir **un véhicule adapté à l'âge**. Il est recommandable de:

- Développer de meilleurs critères standards de sécurité active automobile pour des usagers de la route plus âgés et vulnérables en incluant les personnes âgées dans le processus de conception.
- Mettre en place une procédure d'évaluation standardisée afin d'examiner systématiquement la praticité et l'efficacité de technologies automobiles avancées pour des conducteurs âgés. Ceci devrait être réalisé en incorporant la sécurité des personnes âgées dans le test EuroNCAP.
- Eduquer et former des personnes âgées dans l'emploi correct de technologies de sécurité active (technologies ADAS adaptées aux personnes âgées).
- Encourager le développement ultérieur de systèmes de prévention de collisions, comme les systèmes d'évitement de collisions en intersection et d'aide au changement de voie et des systèmes de protection active des piétons.
- Etudier les potentiels avantages et inconvénients de la conduite semi-automatisée qui permettrait de prolonger la conduite automobile des usagers de la route âgés par l'offre d'une assistance compensatrice de leurs limitations fonctionnelles.

De plus, les technologies de la conduite automatisée apporteront un gain en sécurité routière pour les conducteurs plus âges car leurs limitations sensorielles, cognitives et psychomotrices pourront être compensées par ses technologies. La conduite automatisée comprend six niveaux allant de l'absence d'automatisation à l'automatisation complète. Dans ce cadre, une attention particulière devrait être accordée aux conducteurs plus âges quand la technologie est situé dans les niveaux intermédiaires d'introduction sur le marché (par exemple niveau 2 'automatisation partielle' et niveau 3 'automatisation conditionnelle') car ces niveaux exigent encore que le conducteur intervient lors de phases de conduite. Par conséquent, il est important de bien appréhender ce que les personnes âgées sont encore en mesure de faire si elles se doivent d'intervenir rapidement lors d'une reprise en main de la tâche de conduite dans un véhicule automatisé.

## Préserver et permettre la mobilité tout au long de la vie

Les aménagements d'infrastructures, les initiatives d'éducation & de formation, les restrictions d'attribution du permis de conduire et les technologies automobiles et de transport intelligent ne peuvent compenser la diminution des aptitudes de conduite qu'à un certain degré. De plus, la mobilité, la santé et le bien-être sont interdépendants étant donné que **la perte de mobilité est en relation avec le déclin de la qualité de vie, l'indépendance fonctionnelle et la santé physique et mentale**. Voilà pourquoi, la sécurité et la mobilité des personnes âgées devraient être développées à parts égales dans une stratégie de sécurité de transport les concernant. Alors, le maintien de la mobilité de personnes âgées qui s'arrêtent ou qui sont forcées de cesser la conduite sera **une priorité** de la politique générale dans un proche avenir. Ceci devrait être réalisé **en offrant des options et des services de transport alternatifs**. Ces mesures doivent être prises maintenant pour que l'on puisse faire face aux augmentations attendues dans la population des personnes âgées. C' est pourquoi, tous les niveaux politiques et parties intéressées doivent coopérer afin de supporter les personnes âgées en :

- Etendant et en améliorant les services de transport public conventionnels adaptés aux modèles de mobilité des personnes âgées.
- Offrant des alternatives de transport sûres, abordables, fiables et accessibles aux personnes âgées avant qu'elles soient obligées de cesser la conduite automobile.
- Formant et informant les personnes âgées sur la façon d'utiliser ces options et services de transport alternatifs.
- Incitant les professionnels de santé, les préfectures, les amis et familles des conducteurs âgés à aider le conducteur âgé à préparer la transition de la conduite automobile vers la vie après la voiture.

Finalement, l'usager de la route âgé lui-même devrait adopter un esprit ouvert envers sa propre vie succédant la conduite automobile active et devrait aussi prendre en considération des décisions de vie qui peuvent affecter positivement leur mobilité comme le déménagement vers des environnements urbanisés.

## Recommandations d'action

En plus des actions spécifiques par domaine de contre-mesure, le projet ElderSafe formule les recommandations suivantes pour une prise en compte adaptée à la politique générale de sécurité routière des usagers de la route âgés. Une approche multi-acteurs est nécessaire afin de garantir la sécurité et la mobilité des usagers de la route âgés.

### Professionnels de la santé

- Approfondir leur connaissance et développer leur prise de conscience par rapport aux déficits liés à l'âge ou à la médication qui pourrait influencer la sécurité routière;
- Echanger pro-activement des informations et discuter de tels risques avec l'usager de la route âgé;
- Offrir la possibilité et motiver la participation à l'auto-évaluation et l'examination volontaire ayant pour but la détection précoce de déficits de conduite;
- Former les personnes âgées dans la reconnaissance de leurs déficits et l'ajustement correspondant de leur comportement ce qui résultera en une

autorégulation plus efficace pour les usagers de la route âgés et un comportement routier amélioré;
- Informer les usagers de la route âgés sur leur fragilité augmentée liée à l'âge et sur l'importance de l'emploi de dispositifs de protection. Ces initiatives d'information devraient être combinées avec une formation pratique ciblée sur l'emploi correct de ces dispositifs de protection.

**Technologie des véhicules et secteur industriel**
- Concevoir et informer les usagers de la route âgés sur des technologies automobiles de sécurité efficaces afin de mieux protéger l'usager de la route (âgé) vulnérable;
- Concevoir des technologies automobiles de sécurité intelligentes adaptées aux besoins et caractéristiques individuels de différents groupes de conducteurs, comme la vulnérabilité physique plus élevée du conducteur et du passager plus âgé (i.e., conception universelle);
- Eduquer et former les personnes âgées dans l'usage correct des technologies de sécurité actives (technologies ADAS adaptées à l'âge);
- Evaluer systématiquement la praticité de technologies automobiles avancées pour des conducteurs âgés.

**Autorités locales et régionales**
- Concevoir des campagnes d'éducation et de prise de conscience ciblées sur l'amélioration de la prise de conscience des déficits liés à l'âge, aux maladies, aux médications prescrites et leurs effets potentiels sur la sécurité des usagers de la route;
- Pourvoir des alternatives de transport sûres, d'utilisation facile et confortables pour des usagers de la route (plus âgés) qui ne sont plus à même de conduire;
- Créer une infrastructure auto-explicative et pardonnante, dans les environnements urbanisés ainsi que ruraux;
- Organiser et promouvoir des possibilités d'auto-évaluation et de formation volontaires;
- Formuler des directives pour la séparation des usagers de la route vulnérables de la circulation motorisée et/ou introduire des zones de circulation à vitesse réduite dans des zones avec beaucoup d'usagers de la route vulnérables. Des règles claires devraient être également développées et appliquées dans des situations où cela n'est pas possible;
- Informer et former les usagers de la route âgés moyennant des cours de recyclage sur les (nouvelles) règles de circulation et des conceptions d'infrastructure routière moderne comme les espaces partagés et routes auto-explicatives et pardonnantes;
- Etablir des centres de mobilité spécialisés et certifiés avec des professionnels multidisciplinaires (instructeurs de conduite, psychologues, médecins, …) pour la réalisation d'examens médicaux et de conduite et ainsi que pour offrir des formations personnalisées.
- Développer un système de référencement communautaire incluant des médecins, des professionnels de la santé, la police, des amis et des familles de personnes âgées tout comme les personnes âgées elles-mêmes afin d'identifier des conducteurs à risque, et de les encourager à faire estimer leurs aptitudes de conduite et de pourvoir des solutions sur mesure.
- Mettre en place les problématiques liées à l'âge et aux aptitudes à la conduite dans la formation des médecins ainsi que des autres professionnels de la santé;
- Pourvoir des programmes de formation et d'éducation standardisés pour les professionnels de la santé, les auto-écoles et les forces de l'ordre sur l'aptitude à la conduite;

- Donner des consignes pour les professionnels de la santé, les préfectures et les agents des forces de l'ordre pour qu'ils rapportent/renvoient les conducteurs vers un examen théorique et pratique du permis de conduire et attribuer l'immunité pour les « rapporteurs ».

**Instituts de recherche**

- Mieux comprendre les circonstances des accidents dans lesquels sont impliqués les personnes âgés et proposer des contre-mesures efficaces;
- Proposer des critères scientifiquement valables (tests neuropsychologiques, tests médicaux et tests de conduite) pour l'évaluation des aptitudes de conduite (y compris le comportement d'adaptation) et les risques.
- Explorer l'effet de moyens de transport innovants comme les véhicules électriques, Pedelecs (vélos électriques) et les vélos intelligents sur la sécurité des personnes âgées;
- Explorer les modèles d'exposition des usagers de la route âgés;
- Evaluer l'efficacité de contre-mesures visant l'amélioration de la sécurité des usagers de la route plus âgés;
- Explorer la prédiction de l'inaptitude à la conduite afin de pouvoir établir des normes d'examen ayant pour but de séparer la conduite en sécurité de la conduite à risque.

**Secteur des assurances**

- Encourager les usagers de la route âgés à participer à des activités de prise de conscience, éducatives et/ou de formation de conduite, par exemple moyennant l'offre d'incitations financières.

**Commission européenne**

- Accélérer et améliorer la prise de conscience sur les besoins en sécurité routière des personnes âgées aux différents niveaux gouvernementaux (Union européenne, national, régional, local);
- Stimuler les Etats Membres à prendre en compte la sécurité des usagers de la route âgés dans leur plans de mobilité nationaux;
- Echanger des informations sur les meilleures pratiques en matière de contre-mesures visant à augmenter la sécurité des usagers de la route plus âgés;
- Stimuler la recherche scientifique dans le domaine de la sécurité des usagers de la route âgés;
- Inclure la sécurité des usagers de la route vulnérables (plus âgés) dans les normes d'évaluation de la sécurité des véhicules;
- Surveiller à ce que des développements ayant pour but d'augmenter la sécurité et la mobilité des usagers de la route âgés ne soient pas discriminatoires;
- Promouvoir des politiques générales de sécurité routière urbaines au sein de plans de mobilité urbaine durable;
- Développer des politiques générales plus solides pour la sécurité routière des piétons et d'autres usagers de la route vulnérables;
- Explorer les bénéfices et les désavantages potentiels de la conduite (semi-) automatisée pour les usagers de la route plus âgés;
- Augmenter l'importance des éléments de sécurité routière (des personnes âgées) dans les directives pour la gestion urbaine holistique;
- Ajouter une recommandation à la Directive sur le Permis de Conduire afin d'inclure des initiatives d'éducation/formation/prise de conscience dans les politiques générales d'attribution des permis de conduire nationaux;
- Encourager des programmes de santé qui supportent la réduction de la fragilité;
- Introduire une procédure de test standardisée pour l'évaluation systématique de la praticité et de l'efficacité des technologies automobiles avancées pour les

conducteurs plus âgés. Ceci devrait être fait par l'inclusion de la sécurité des personnes âgées dans le test EuroNCAP;
- Créer un arrangement uniforme entre les différents Etats Membres au sujet de la décision de l'aptitude à la conduite. La décision par rapport à la cessation et/ou aux restrictions ne devrait se baser ni sur l'âge, ni sur le diagnostic de quelconque maladie particulière, mais sur un jugement des aptitudes de santé et de fonctionnalité nécessaires à la conduite en sécurité;
- Créer un arrangement uniforme entre les différents Etats Membres par rapport à la politique générale de renouvellement des permis de conduire;
- Introduire des protocoles médicaux et de conduite standardisés par rapport aux restrictions, renouvellement, évaluation et examen du permis de conduire.

**L'usager de la route âgé lui-même**
- Etre conscient des problèmes potentiels et des risques d'accident plus élevés associés au vieillissement;
- (Apprendre à) compenser les déficits de perception et de mouvement potentiels liés à l'âge qui pourraient affecter la sécurité personnelle;
- Avoir un esprit ouvert envers les possibilités offertes pour l'auto-évaluation ou l'examen de conduite volontaire ou discuter de sa situation personnelle avec la famille et/ou des professionnels de santé (médecin, ergothérapeute, pharmacien);
- Préparer la transition de la conduite active à la vie après la voiture.

# Glossary

| | |
|---|---|
| Fatality rate | Number of fatalities per million inhabitants. Calculated as the number of fatalities in a certain country or region divided by population size of this region or country and multiplied by 1 million. |
| EU-19 | Belgium, The Czech Republic, Denmark, Germany, Ireland, Greece, Spain, France, Italy, Luxemburg, The Netherlands, Austria, Portugal, Romania, Slovenia, Finland, Sweden, The United Kingdom. |
| EU-27 | Belgium, The Czech Republic, Denmark, Germany, Ireland, Greece, Spain, France, Italy, Luxemburg, The Netherlands, Austria, Portugal, Romania, Slovenia, Finland, Sweden, The United Kingdom, Cyprus, Croatia, Hungary, Latvia, Poland, Bulgaria, Estonia, Malta, Slovakia. |
| Young elderly | People within the age group of 65-74 years. |
| Older elderly | People aged 75 years or older. |
| Relative Risk | The ratio of the probability of an event occurring (for example, crash involvement, being injured) in an exposed group to the probability of the event occurring in a comparison, non-exposed group. |
| Population Attributable Risk | The size of the contribution that a risk factor makes to the total number of accidents or killed or injured road users. |
| Vulnerable road user | Pedestrians, cyclists, motorcyclists and moped riders. |

# List of abbreviations

| | |
|---|---|
| ACC | Adaptive Cruise Control |
| ADAS | Advanced Driver Assistance Systems |
| AEBS | Advanced Emergency Braking System |
| AHP | Analytic Hierarchy Process |
| ASL | Advanced Stop Line |
| BSD | Blind Spot Detection |
| CI | Confidence Interval |
| DRP | Driver rehabilitation program |
| DSD | Decision sight distance |
| DSL | Dynamic speed limits |
| ESP | Electronic Stability Control |
| ETSC | European Transport Safety Council |
| FCW | Forward Collision Warning |
| FHWA | Federal Highway Administration |
| GPS | Global Positioning System |
| HDAD | Headway Detection and Alerting Device |
| HUD | Head-up Display |
| ICU | Intensive Care Unit |
| ITS | Intelligent Transport Systems |
| LCA | Lane Change Assist |
| LDW | Lane Departure Warning |
| LED | Light-Emitting Diode |
| LKA | Lane Keeping Assist |
| LTAP | Left turn across path |
| MRVD | Minimum Required Visibility Distance |
| NCHRP | National Cooperative Highway Research Program |
| NHTSA | National Highway Traffic Safety Administration |
| OD | Opposite Direction |
| OECD | Organization for Economic Co-operation and Development |
| PAR | Population Attributable Risk |
| PCM | Perceptual countermeasures |
| POI | Point Of Interest |
| PRT | Pedal Release Time |
| PT | Public Transport |
| PTW | Powered Two-Wheelers |

| | |
|---|---|
| RR | Relative Risk |
| TH | Time Headway |
| VMS | Variable Message Sign |
| VRU | Vulnerable Road User |

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# Introduction

In most European countries, older adults comprise the fastest growing segment of the population, and in many, one in four people will be aged 65 or over in 2050. This demographic change is primarily driven by declining birth rates and a higher life expectancy. This increase in the older population coincides with an increase in older road users since far more elderly people will use the road. This means that the traffic safety situation of elderly people will also change. As people grow older, they are however more likely to experience functional declines that can make driving a car more difficult. At the same time, the risk of a fatal accident for elderly cyclists and pedestrians is many times higher than for elderly car drivers. These are some of the challenges that the ageing of society brings for the policy area of transport.

Proactive and thoughtful planning is thus necessary to ensure senior citizens' safe, lifelong mobility. This report seeks to address this challenge by providing an overall transport safety strategy for the elderly within the EU.

### Age classifications

International literature defines an older person as a person aged 65 or over (CONSOL, 2013a; Eby, Molnar, & Kartje, 2009; OECD, 2012; Shinar, 2007; Whelan, Langford, Oxley, Koppel, & Charlton, 2006). Furthermore, literature makes a distinction between young elderly (65-74) and older elderly (≥ 75) because mobility decreases around the age of 75 (CONSOL, 2013a; Kubitzki & Janitzek, 2009; Orimo et al., 2006). This drop in elderly mobility patterns can also be observed in the accident data statistics. Therefore, this report uses both age classes to describe the risks of elderly people in road traffic.

This definition maybe perceived as subjective, but the age of 65 years is in many European countries the official retirement age. However, it is important to note that these age classes do not take the individual differences of the elderly into account. The ageing process does not necessarily start at 65 years and progresses differently for each individual. For example, it can be possible that some 80 year olds are in better shape than certain 65 year olds. As such, significant differences in traffic skills, physical and mental abilities emerge between elderly of the same age.

# 1. The ageing population in Europe

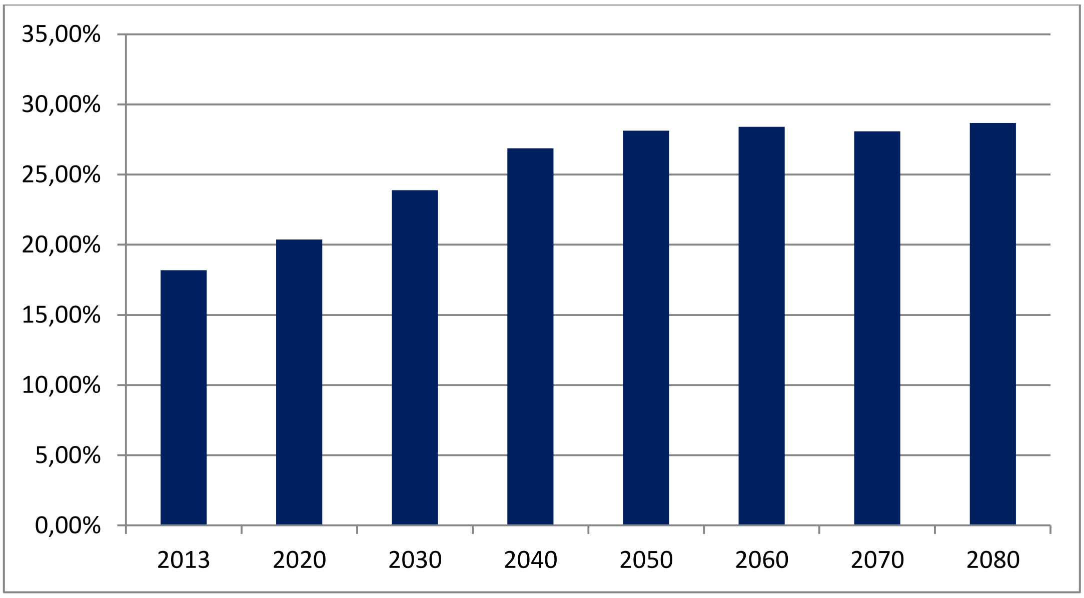
## 1.1 Demographic change

In the coming years, Europe is facing a significant shift in the age distributions of populations. By **2050,** more than 147 million people aged 65 or over will be living in the European Union. This is a substantial increase compared to the 92 million in this age group in 2013 (Eurostat, 2015b).

Figure 1 illustrates the predicted increases in the population aged 65 years or older till 2080 for all European Member states. As shown in figure 1, a gradual increase in the proportion of older people is expected **by 2050**, approximately **28% of the European population will be 65 years or older**. After 2050, the proportion of older people is expected to level off.

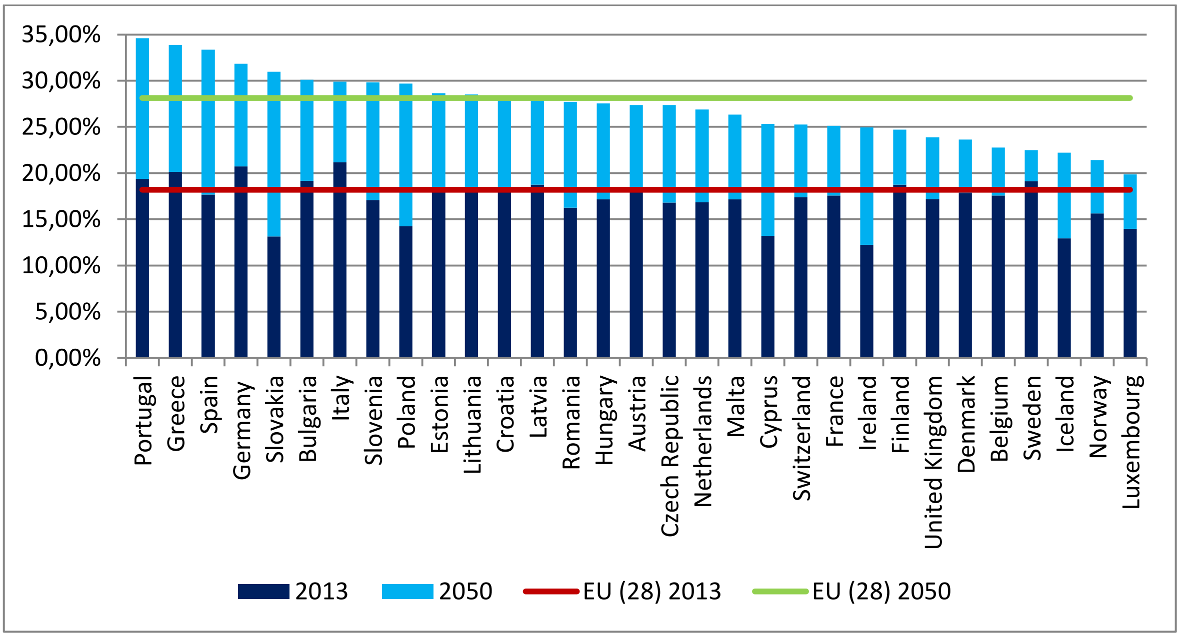
The actual and predicted percentage of the population aged ≥ 65 years for individual European countries for 2013 and 2050 is shown in figure 2. While the proportion of elderly people is expected to increase with an average of 10% in the EU-28 by 2050, countries like Cyprus, Germany, Greece, Ireland, Poland, Portugal, Romania, Slovenia, Slovakia and Spain will experience a higher rise (11-15%) in the proportion of elderly people. In comparison, countries such as Austria, Belgium, Denmark, Finland, France, Iceland, Italy, Latvia, Luxemburg, Malta, Norway, Sweden, Switzerland and the United Kingdom will be confronted with lower increases (3-9%).

**Figure 1: Percentage of population aged 65 or more for all European Member states, predicted for 2013-2080**




Source: (Eurostat, 2015b)

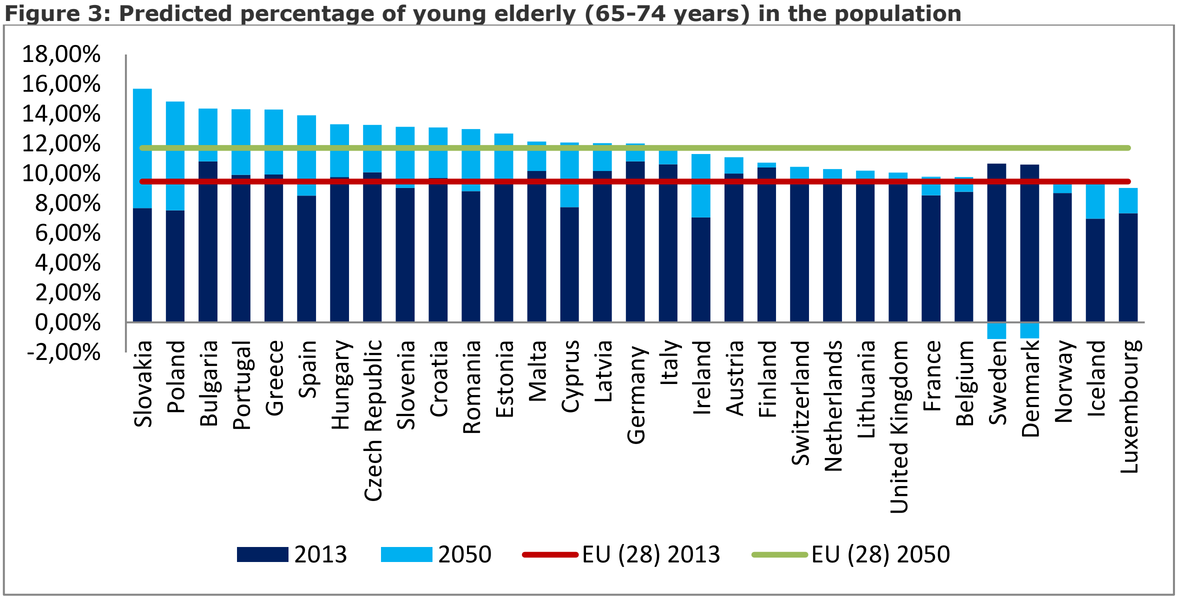
**Figure 2: Predicted percentage of older people (≥ 65 years) in the population**




Source:(Eurostat, 2015b); EU 28: average of the 28 member states of the European Union

**The expected increase in the number of elderly people is different for the younger (65-74 years) and the older elderly (≥ 75 years)**. Figure 3 illustrates the predicted increases in the population of young elderly for all European Member States. The increase will be the smallest in Malta, Latvia, Germany, Italy, Austria, Finland, Switzerland, The Netherlands, Lithuania, The United Kingdom, France, Belgium, Norway and Luxemburg while the greatest rise is expected in Slovakia, Poland, Portugal, Greece, Spain, Slovenia, Romania, Cyprus and Ireland. It is even projected that the proportion of young elderly in the population in Sweden and Denmark slightly decreases in 2050 compared to 2013.

**Figure 3: Predicted percentage of young elderly (65-74 years) in the population**

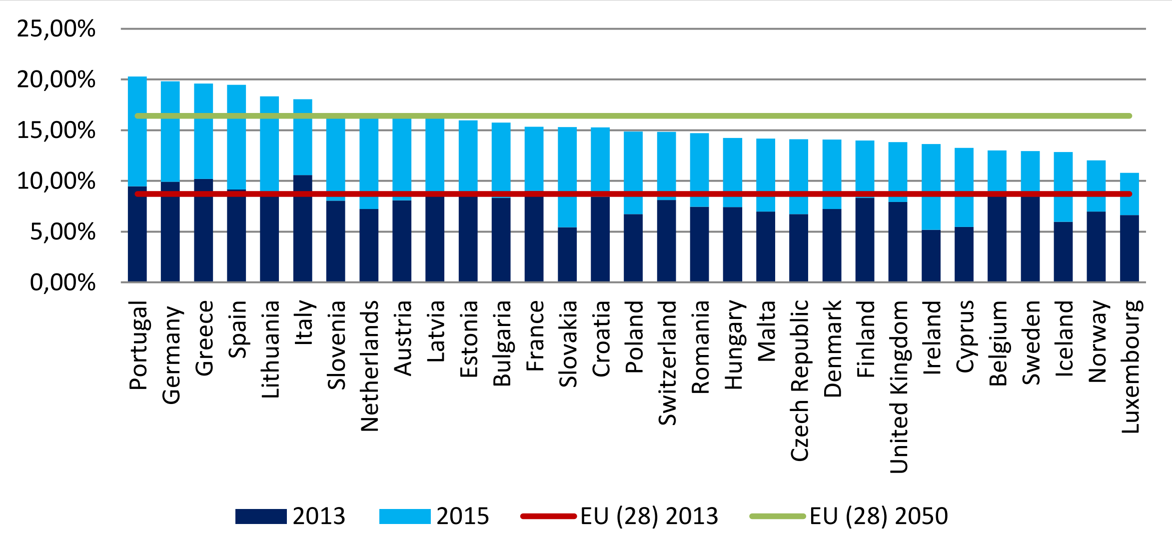



Source:(Eurostat, 2015b); EU 28: average of the 28 member states of the European Union

The **percentage of older elderly in the population will increase even more** and is expected to double by 2050 in almost all European Member States (figure 4).

Portugal, Germany, Greece, Spain, Lithuania, Slovenia, The Netherlands, Austria, Slovakia, Poland and Ireland will probably experience the greatest growth between 2013 and 2050, while the rise is expected to be smaller in Finland, The United Kingdom, Belgium, Sweden, Norway and Luxemburg.

**Figure 4: Estimated percentage of older elderly (≥ 75 years) in the population**




Source: (Eurostat, 2015c); EU 28: average of the 28 member states of the European Union

This demographic change can be attributed to three main factors:

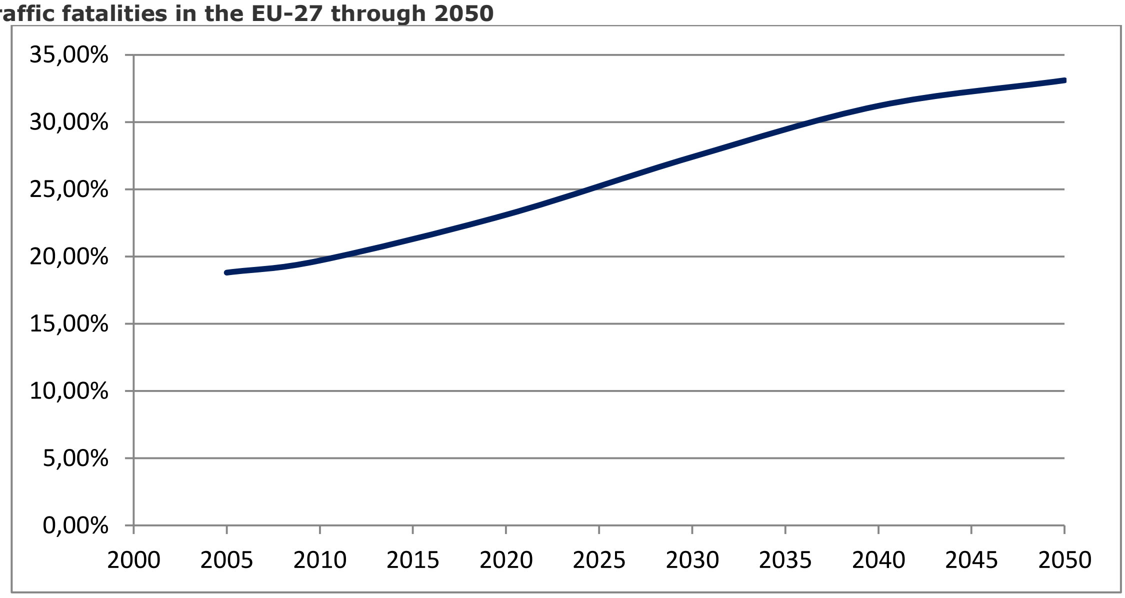
- ***Declining fertility***: since the second half of the 20th century, the average European fertility rate has increased from below 1.45 children per woman to 1.6 in 2009 (European Commission, 2011). Nevertheless, the fertility rate in all European countries has fallen below the replacement rate of 2.1 children per woman. Therefore, Europe will be confronted with an ageing population.
- ***Increasing longevity***: the life expectancy in Europe has also been increasing in an almost continuous and uniform trend at an average rate of 2-3 months every year since 1993 (European Commission, 2011). Furthermore, people do not only live significantly longer, but they also live longer healthier lives.
- ***Migration***: in most European Member States, migration is the main driver of population growth. The total population is rejuvenated since the majority of the immigrants are young adults (aged 25-34) (European Commission, 2011). As such, migration could postpone the population from ageing. However, population development forecasts predict that the migration processes may not be able to compensate for the declines in fertility rates and the increases in longevity (Malmberg, 2006, p. 134).

## 1.2 The effects of demographic change on road safety

Due to the demographic changes in the future, more elderly will actively participate in traffic. An increased proportion of elderly road users in traffic will bring a significant **increase in the number of elderly road users who are at risk of being involved in road accidents**. The European Traffic Safety Council (ETSC) (2008a, 2008b) estimated the effects of an increased proportion of elderly within the population on the number of road traffic fatalities until 2050. This estimation is based on the assumption that the mortality rate over time for the age groups of 65+ and ≤64 remains constant or evolves in the same direction (Eksler, 2007). The results are presented in figure 5. While at the moment **one road traffic fatality out of five is aged 65 or over** in Europe, it is expected that by **2050 one road traffic fatality out of three** will be an

**older person** if the risk rates of older people and younger age groups decline at the same pace. So by 2050, the share of elderly road traffic fatalities will increase with 13%.

**Figure 5: Estimated road traffic fatalities among the elderly (≥ 65 years) as a percentage of all traffic fatalities in the EU-27 through 2050**

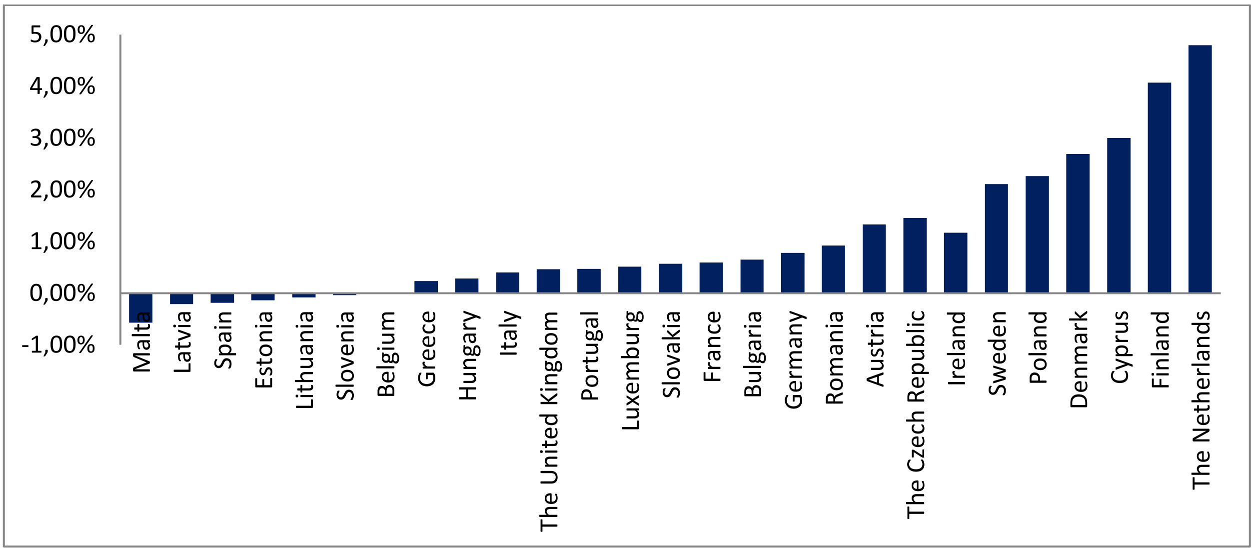



Source: (Eksler, 2007; ETSC / European Transport Safety Council, 2008a, 2008b)

Following the variability of the estimated increases in the population aged ≥ 65 years and the mortality rates across individual countries, the impact of the changing proportion of elderly people in the population on future traffic fatalities will also vary.

According to figure 6, the rise of elderly people in the population will lead to an increase in the number of road traffic fatalities in 21 countries. As a result, the ageing population will have a negative effect on the road safety level of these countries in 2020. The effect will be the highest in The Netherlands. Due to the increase in the number of elderly people and their higher mortality rate, **a 5% increase in the total number of road traffic fatalities is expected by 2020**. Furthermore, it is estimated that the total number of road traffic fatalities will increase by more than 1% in 8 European countries. For 6 European countries, the ageing population will most likely lead to a slight reduction in road traffic fatalities. To summarize, these projections suggest that **the ageing population will have a significant impact on the road safety situation, even in European countries with an impeccable road safety score**.

**Figure 6: Estimated road traffic fatalities among the elderly (≥ 65 years) as a percentage of all traffic fatalities in individual countries by 2020**




Source: (ETSC / European Transport Safety Council, 2008b)

### 1.2.1 Driving licenses

The elderly are also becoming more mobile due to their increased longevity and better health (CONSOL, 2013a; INFAS & DLR, 2010). Furthermore, previous research has indicated a **notable increase in licensing rates and car access** in the older population during recent decades (Hjorthol, Levin, & Sirén, 2010; Ottman, 2010). This increase is and will be mainly attributable to significant increases in the number of older female drivers (DaCoTA, 2012a; Holland, Handley, & Feetam, 2003; OECD, 2001). The **new generations of older people will also be likely to keep their licenses into old age** (Hakamies-Blomqvist, Henriksson, Anund, & Sörensen, 2005; Hjorthol & Sagberg, 2000). As such, **by 2030 a quarter of all drivers will be older than 65** (DaCoTA, 2012a).

**Table 1: Percentage increase in licensed drivers to 2030 for selected countries**

| Country | Percentage of total number of licensed drivers aged 65+ in 2000 | Percentage of total number of licensed drivers aged 65+ in 2030 | Percentage increase in licensed drivers aged 65+ |
|---|---|---|---|
| Finland | 14.9 | 26.7 | 79 |
| France | 16.1 | 25.8 | 60 |
| The Netherlands | 13.7 | 26.5 | 93 |
| Norway | 15.3 | 23.5 | 53 |
| Spain | 16.8 | 26.1 | 55 |
| Sweden | 17.2 | 24.1 | 40 |
| The United Kingdom | 15.7 | 23.5 | 49 |

Source: (DaCoTA, 2012a; OECD, 2001)

## 1.3 A 'Silver Proof' traffic safety policy

Mobility is a fundamental prerequisite for the quality of life of older persons (Farquhar, 1995). Several studies have revealed that mobility and the opportunity to leave home is associated with longevity, physiological well-being, social integration, independence, health benefits and the sense of being empowered at old age (Bonnel, 1999; Christiaens et al., 2009; CONSOL, 2013a; Dugan & Lee, 2013; Fonda, Wallace, & Herzog, 2001; Gabriel & Bowling, 2004; Marottoli et al., 1997; OECD, 2001; Ragland, Satariano, & MacLeod, 2005). As such, mobility in the form of driving, use of public transport, cycling and walking will be increasingly important for the elderly (Kocherscheid & Rudinger, 2005).

As the elderly will represent a substantial part of the European population in the future, it is expected that this rise will also affect the dynamics of the total traffic system (OECD, 2001). The mobility needs of the elderly will grow in the future. As a result, **elderly road users will transform from a minority group with special needs and habits to one of the largest road user groups**. This evolution will not only affect the elderly but also the behaviour of road users of other age groups who interact with them. Therefore, the challenge lies in making the European traffic safety policy and the transportation system '**silver proof**' (Moerdijk, 2013). More specifically, efforts need to be made proactively to provide comfortable, safe and lifelong mobility for the future generations of elderly.

## 1.4 Structure of this document

The overall structure of this report takes the form of six chapters, including this introductory chapter. Chapter two is concerned with the methodology used for this study. The third chapter begins by laying out the risk factors of elderly road users, and looks at generic areas of improvement that would be effective in reducing – the severity of – elderly road user accidents. The fourth section presents prospects to enhance the safety of elderly road users by identifying countermeasures within the areas of infrastructure, education & training, licensing & enforcement and vehicle & ITS technologies. The fifth chapter begins with the selection of most promising countermeasures from the perspective of elderly road users and identifies suitable policy actions for each promising countermeasure. Chapter 6 summarizes the most important findings and recommendations from this study. Finally, this final report is complemented by an Annex report which contains all additional information, tables and figures referred to in this report.

# 2. Methodology

This study seeks to formulate recommendations that can be used to develop a policy strategy to **increase road safety for the elderly** in traffic. Therefore, the purpose of this study is threefold:

1. To identify the **dominant risk factors** or safety issues for different elderly road user categories (elderly car drivers, elderly car passengers, pedestrians, powered two wheelers, cyclists, and public transport users);
2. To identify and evaluate **road safety and ITS countermeasures**;
3. To provide **policy recommendations** (a road safety strategy towards elderly road users) to the European Commission.

The following sections provide an overview of the applied methodology.

## 2.1 Risk factor analysis

### 2.1.1 Identification of risk factors

The road safety of elderly road users has three dimensions, not independent of each other (Rumar, 1999):

- **Exposure:** the number of 'opportunities' a certain group of people has of becoming a road accident casualty. It can be expressed as the size of a certain group (population data), by the number of kilometres travelled or trips made by that group, or by the time spent in traffic (or any variable that can serve as a proxy).
- **Accident risk:** the probability of an accident occurring.
- **Injury risk:** (or: injury severity) the probability of sustaining a certain level of injury (often a fatality) when involved (or injured) in an accident.

Within this framework, the risk factors were determined by reviewing relevant literature and policy documents to identify risk figures, differential risks and risk factors concerning older road users. Additionally, data from the European accident database CARE (European Commission, 2015a) were used to develop suitable indicators to address both the total numbers of fatally injured people and the three aforementioned decomposing dimensions (exposure, accident risk and injury risk).

**The accident analysis of the CARE-data was only based on the number of fatally injured road users to rule out the possibility of unreliable accident data.** First of all, the number of fatally injured road users is the most reliable indicator to describe the evolution of a road safety situation because the underreporting rate is very low for this variable. Secondly, the definition of a fatally injured road user is consistent in each European country. Furthermore, for each European country the number of fatally injured road users within the last three years (for which data were available for) were combined **to minimize the influence of random variation** in the accident data. For most European countries, this means that the number of fatally injured road users in the period 2011-2013 are jointly analysed. Some countries are characterised by a significant amount of unknown values for some variables. In order to allow reliable comparisons between countries, it was decided to only discuss the road safety situation of countries with no to limited unknown values (≤5% unknown) in the report. An overview of the reliability of the consulted CARE-data can be found in Annex 1.

A limitation of this study is the **lack of exposure data** dedicated to elderly road users in terms of the number of trips, vehicle kilometers and person kilometers travelled. Indeed, research demonstrated a big lack of statistical data on exposure of elderly road users. Instead, **population figures are used as an exposure measure** to estimate the risk of elderly road users. The advantage is that population figures are quite accurate compared to other exposure measures. However, this measure cannot capture the regional and temporal variations in the accident process (Yannis et al., 2004).

As a result, the risk factors were identified and classified as follows:

- Factors increasing the exposure to risk;
- Factors increasing the accident risk (accident involvement);
- Factors increasing accident severity (and post-accident severity outcome).

### 2.1.2 Analysis of risk factors

After the identification of the relevant risk factors, the results of the different studies and policy documents were compared, combined and contrasted in order to identify patterns, common parameters or other interesting relationships that will assist in the identification of best practices and the development of recommendations for measures to be taken at EU level. Since road safety problems are multidimensional, the different risk factors were analyzed by describing each particular risk problem (depending on the availability of data) in terms of the following eight dimensions (Elvik, 2008):

- **Magnitude:** the size of the contribution a risk factor makes to the total number of accidents or killed or injured road users, sometimes also described as the population-attributable risk (PAR).
- **Severity:** a road safety problem is severe if it makes a greater contribution to fatalities and serious injuries than it makes to slight injuries or property damage.
- **Externality:** when travel performed by one group of road users imposes an additional risk on another group of road users, i.e. risk that would not exist if the travel giving rise to it did not take place. It can be estimated by looking at the injured road users according to the combination of parties involved in an accident.
- **Inequality:** to which extent those who benefit the most of the transport system (usually measured by those groups who travel the most) also have the highest level of risk, and vice versa. Based on exposure data for different road user groups and elderly in particular and accident data for these groups, it can be measured to what extent the principle of 'equality' holds for elderly road user groups.
- **Complexity:** some road safety problems are more difficult to attack because they are attributable to a multiplicity of risk factors instead of a single one. In that case, multiple policy interventions or measures are necessary to improve the safety problem.
- **Spatial dispersion:** some road safety problems have a distinct geographic dimension, some do not. Based on accident statistics, it can be determined whether certain attributable risks related to elderly are geographically dispersed or not.
- **Temporal stability:** stability of a certain road safety problem over time. It can be examined by looking at trends or sudden jumps in a series of accident counts.
- **Perceived urgency:** a problem which is not seen as a problem may be less amenable to treatment than a problem that everybody sees as a problem and for which stronger action to reduce the problem is supported. It can be examined in different ways, e.g. by looking at the level of support for stronger policy interventions.

Unfortunately, it was not possible to describe all risk factors based on the eight aforementioned dimensions due to insufficient quantitative information in the existing literature. Nevertheless, a "**qualitative" assessment**" of the risk factors on the eight road safety dimensions is made in and summarized in table A9.27 in Annex 9.

In that respect the **quantitative analysis** and prioritization of the risk factors is based on a two-dimensional approach based on two of the eight dimensions of road safety problems (Elvik, 2008):

- **<u>Magnitude:</u>** The population attributable risk (PAR) is estimated as follows:

$$PAR = \frac{PE\ (RR-1)}{\left(PE\ (RR-1)\right)+1)}$$

  Where:
  PE is the proportion of exposure in the presence of the risk factor
  RR is the relative risk associated with it

  In terms of road safety, the result of this calculation is the number of accidents that is attributable to a particular risk factor, and therefore the expected decrease in the number of accidents that would be achieved if the risk factor were to be eliminated. The result is a value between 0 and 1.

  **The estimations of PE and RR were obtained through a literature review of different studies addressing the risk factors for elderly road users.** In case multiple studies provided an estimation of the PE and RR of a specific risk factor, the average value is calculated. These average values are then used to estimate the PAR.

- **<u>Perceived urgency or public support:</u>** Public attitude towards the road safety problem or risk factor. Does the public perceive the risk factor as a problem? Do they find the risk factor important?

  **Estimations for the public support for implementing measures to address a certain risk factor in order to enhance road safety for older road users were based on the results of the stakeholder's questionnaire** (ElderSafe, 2015).

The result of this analysis is a **typology of risk factors for the elderly** in which the risk factors are classified for each road user type and ranked according to their overall importance. The calculations for identifying the magnitude and public support of each risk factor can be consulted in Annex 9. The final outcome of the risk identification analysis is shown in figure 7 in chapter 3.

## 2.2 Identification and analysis of countermeasures

### 2.2.1 Identification of countermeasures

The current state-of-the-art of road safety and ITS countermeasures which can contribute to a better road safety for older road users was obtained by applying both a top-down approach and bottom-up approach. The results of the top-down approach are presented in chapter 3 while the outcomes of the bottom-up approach can be consulted in chapter 4.

The **top-down approach** begins from an identification of the dominant safety issues for each of the identified older road user categories (pedestrians, cyclists, car drivers, PTW, PT users) and searches for information on conceivable countermeasures on these issues:

- From the specifics of accidents **generic areas of improvement** are identified and qualitatively described, that would be effective in reducing – the severity of – traffic accidents.
- The identified areas of improvement may directly lead to **applications or countermeasures** in the areas of:
  - Infrastructure;
  - Vehicle & ITS technologies;
  - Education/training;
  - Licensing/enforcement.

The **bottom-up approach** starts from information on reported impacts of existing and/or experimental countermeasures on road safety, and consequently filters on relevance to older road users:

- For each countermeasure area (infrastructure, vehicle & ITS technologies, education/training, licensing/enforcement), **potentially interesting countermeasures** are addressed with their proven (or potential) impact.
- Each **countermeasure is** described (and where possible quantified) on the following criteria:
  - Proven or potential safety impact on older road users (pre, during or post-crash and impact on exposure, risk or severity);
  - Cost of implementation;
  - Public support;
  - Level of implementation: from experimental to proven, if possible an expected timeline (e.g. for vehicle & ITS technologies).

By applying both approaches, European project reports and international literature were consulted to provide an overview of best practices and infrastructure, vehicle & ITS technologies, education/training, licensing/enforcement related measures to enhance the safety of older road user groups. The identified countermeasures for each countermeasure area where then classified based on the **Haddon matrix** (Haddon, 1980) which identifies risk factors before the crash, during the crash and after the crash, in relation to person, vehicle and environment. This Haddon matrix can be consulted in tables A10.1-A10.7 in Annex 10.

### 2.2.2 Analysis of countermeasures

The **road safety and vehicle & ITS countermeasures are structured, compared and ranked** in order identify the most promising countermeasures to enhance the safety of elderly road users. The calculations with respect to the countermeasure scoring can be consulted in Annex 12 while the final outcome of the scoring process is discussed in chapter 5.

#### 2.2.2.1 Amenability to treatment

The '**amenability to treatment' method** (Elvik, 2008) was used to compare the different countermeasures. Amenability to treatment is a methodology to **compare different measures that can reduce a road safety problem**, or at best, eliminate the problem. It combines (1) information on the size of these problems and the extent to which measures can help to reduce the problem (effectiveness) with (2) information on the level of support for specific road safety measures. In addition, (3) costs are of major importance for policy decisions. Based on these three dimensions, the best and worst measures to reduce a road safety problem can be determined. Hence, **the**

**countermeasures** within the areas of infrastructure, vehicle & ITS, education & training and licensing & enforcement were compared on the following dimensions:

- **Effectiveness of the measure**: expressed as the degree to which the measure is effective in reducing the population attributable risk (i.e. number of killed or injured elderly road users or number of crashes with elderly road users).
- **Public support for the measure**: expressed as the percentage of the total population that would be in support for the measure.
- **Cost of the measure**: the cost of the measure.
- **Importance of the measure**: this is an extra dimension added by the consortium. It indicates whether or not the countermeasure addresses a key risk factor identified within the typology of risk factors for the elderly (see section 3.7).

Each **consortium member scored the countermeasures** within each countermeasure area on these four dimensions. Each dimension received a **score between 1 and 5**; with a score of 1 indicating that the measure scores very bad on a certain dimension. The scorings for the dimensions 'Effectiveness' and 'Costs' are based on a literature review of effectiveness and cost-benefit studies. The scorings for the dimension 'Public support' are based on a combination of expert judgements from members of the consortium and consulted stakeholders within this project (ElderSafe, 2015). Finally, the scorings for the dimension 'importance' are based on expert judgements from members of the consortium. The individual consortium member scorings were then summed up and averaged in order to calculate the final scores for each countermeasure.

#### 2.2.2.2 Countermeasure ranking

Once the countermeasures were scored on their effectiveness, public support, costs and importance, a **composite score** needs to be calculated for each countermeasure. For this purpose, the weighted geometric scoring method is applied. The following input is required to apply this method:

- The score of each countermeasure on the four dimensions, i.e. the averaged consortium member scores (see section 2.2.2.1); and
- The individual weights of each dimension.

The weight for each dimension is determined by using the **analytic hierarchy process (AHP) method**. The AHP method was developed in the field of decision theory (Haas & Meixner, 2006). The purpose of this method is to weigh different alternatives against each other, in order to select the best alternative.

The first step of the AHP method is a pairwise comparison of the four dimensions (Saaty, 2008). Each dimension is given a weight which represents the importance of the dimension in relation to the other dimensions (Haas & Meixner, 2006). Due to the lack of empirical research on this topic, **each consortium member assigned weights to the four dimensions based on their expert opinion**. Subsequently, the individual weights of each consortium member were summed up and averaged in order to obtain the **optimal weight for each dimension**. Subsequently, the final weights for the different dimensions are then pairwise compared by calculating an eigenvector (Saaty, 2008). To this end, the weights were placed in a matrix and are squared. The sums of the rows were then summed and normalized. This process was repeated until the eigenvector was the same as the eigenvector of the previous iteration. More information can be found in Saaty (2008). The calculations are described in Annex 12.

Secondly, the scores of the countermeasures on their effectiveness, pubic support, costs and importance (see section 2.2.2.1) were weighted with respect to the weights of each of the four dimensions in order to obtain a single score for each countermeasure. For this purpose, the **weighted geometric mean** (Saisana & Tarantola, 2002) is calculated. This results in a composite score for each measure by raising the score of the countermeasure on a certain dimension to the power of the corresponding weight of this dimension and multiplying these products:

$$\prod_{i=1}^{I} x_i^{w^i}$$

Where:
$X_i$ = countermeasure score on a certain dimension
$W_i$ = corresponding weight of each dimension

The calculations are described in Annex 12. Finally, these composite countermeasure scores are ranked to obtain a top four of most promising countermeasures by countermeasure area.

### 2.3 Stakeholders consultation workshop

The consultation round was divided into two phases: an online questionnaire (phase 1) was launched that prepared the ground for a physical stakeholders meeting (phase 2) in Brussels on June 5$^{th}$, 2015.

***<u>Phase 1</u>*****:** an **online survey** was launched targeted at a wide range of relevant stakeholders across Europe. The purpose of the survey was to obtain the stakeholder's attitudes, opinions and level of implementation regarding the following aspects:

- Identification of risk factors involving older road users;
- Identification of areas for improvement to increase the safety of older road users in Europe;
- Identification and implementation of effective countermeasures;
- Identification of relevant partners and their roles to realize the identified countermeasures.

The final questionnaire was sent out to a list of relevant stakeholders; out of 74 organizations were contacted and 50% responded to the questionnaire. As previously described, output from the online stakeholder consultation survey was used as an input for the analysis and ranking of countermeasures (section 2.2.2).

***<u>Phase 2</u>*****:** a physical **stakeholder consultation workshop** was organised in Brussels on Friday June 5$^{th}$ 2015. In total, 15 stakeholder organizations participated in the workshop. Based on the results obtained from the online survey (phase 1), 15 'provocative' statements were composed to start the discussion with the participants.

Participants were then divided into 3 groups (infrastructure, vehicle technologies and human behaviour) of five people in order to discuss the statements that they received previously. Each group discussed about 3-4 statements in two consecutive sessions:

- Session 1 on risks and areas for improvement, and
- Session 2 on effective countermeasures.

During each session, the participants were asked to rank the statements according to whether they agreed or disagreed with the statements. After the ranking, each statement was discussed in detail with the participants. The session leader of each group then reported the results of these individual group discussions to the entire group to obtain additional views and opinions.

Both the results of the on-line survey and of the stakeholders' workshop were included in a consultation report (Durso et al., 2015) submitted to the European Commission.

### 2.4 Synthesis and concrete actions

In this step, the **results of the top-down and bottom-up analysis** were combined to select the countermeasures that were identified as having the most positive impact on the safety of older road users. The approach to obtain the selection of most promising countermeasures was defined as follows:

1. Focus on the countermeasures that obtained the best scoring to increase the road safety of older road users according to the amenability to treatment methodology.
2. For each of these most promising countermeasures it was identified according to which of the available EU instruments (directives, recommendations, research, standards …) action can be taken by the EU.

Finally, an **outline of concrete actions** is provided in chapter 5 which focuses on the future needs and next steps to increase the road safety of older road users.

# 3. Risk factors of elderly road users

This chapter will provide a detailed overview of the current road safety situation of elderly road users in Europe. The risk factors will be identified and classified according to these three dimensions:

- Factors increasing the exposure to risk
- Factors increasing the accident risk (crash involvement)
- Factors increasing injury severity (and post-crash severity outcome)

Relevant risk factors are identified for different road user categories (elderly car drivers, elderly car passengers, pedestrians, powered two wheelers, cyclists, and public transport users). Table 2 provides a first general overview of the three risk dimensions and the different aspects that are related to these dimensions.

**Table 2: Overview of the road safety problem of elderly road users**

| | Exposure | Accident risk | Injury risk |
|---|---|---|---|
| Elderly road users | Kilometres travelled | Experience | Frailty |
| | Time of day | Low yearly mileage | Longer recovery period |
| | Gender | Functional limitations: cognitive, sensory, perceptual | |
| | Location | Age-related illnesses also comorbidity | |
| | Routes | Medication also polypharmacy | |
| | Circumstances | Risk taking behaviour | |
| | Trip purposes | Distraction | |
| | Mode | Self-regulation | |

By addressing the following aspects, these risk factors will be further discussed in the following sections to identify the road safety problem for each elderly road user category:

1. Accident statistics: This subsection provides information about the absolute or relative accident frequency in which a specific elderly road user category is involved, possible differences between European countries and information on fatality or injury rates.
2. Characteristics and causes of accidents: This section summarizes available information on the risk factors that influence the accident occurrence for a specific elderly road user category.
3. Possible areas of improvement: Based on the accident details and characteristics, generic improvement areas are identified that would be effective in decreasing – the severity of – elderly road user accidents.
4. Relevant countermeasures: The identified areas of improvement may directly lead to applications or countermeasures in the areas of:
    a. Infrastructure
    b. Vehicle and ITS technologies
    c. Education/training
    d. Licensing/enforcement

Finally, section 3.8 of this chapter gives a high-level synthesis of the identified risk. In this synthesis a typology of risk factors for the elderly is developed in which the risk factors are classified for each road user type and ranked according to their overall importance. The calculations for this ranking can be consulted in Annex 9.

### 3.1 Elderly road users

This section describes the current road safety situation of elderly road users in general in order to gain first insights in their road safety risks. For this purpose, the European accident database and relevant literature are consulted. The accident data extracted from the CARE database can be found in Annex 2.

#### 3.1.1 Accident statistics

According to the CARE database, **the elderly** (65+) accounted for **25% of all traffic fatalities** in 2013 in the EU (Table A2.1 & Figure A2.2 in Annex 2). There are however notable differences between Member States, ranging from values around 15-20% in Belgium, Bulgaria, Cyprus, Estonia, France, Croatia, Ireland, Luxemburg, Latvia, Poland, Slovenia, and Slovakia to over 30% in Austria, Denmark, Italy, The Netherlands and Portugal (Figure A2.2 in Annex 2). In the period 2000-2013, the total number of elderly fatalities fell by 33% in the EU-27 whereas the total number of fatalities has reduced by more than 53% (Figure A2.1 in Annex 2).

In the same period, the **proportion of all elderly fatalities even rose by 7.5%** (Figure A2.1 in Annex 2). Additionally, the number and proportion of elderly fatalities is higher for the older elderly (75+ years) than for the young elderly (65-74 years): approximately **15% of all traffic fatalities** in 2013 in the EU were **older elderly** while the **younger elderly** accounted for **± 11%** (Table A2.2, Table A2.3 & Figure A2.2 in Annex 2). There are also considerable differences between the member states, but in all member states the proportion of older elderly fatalities within the total number of elderly fatalities (65+) is significantly higher than for younger elderly. The Netherlands (24%), Austria (20%), Germany (18%), Spain, Finland and Italy (all 17%) have the highest proportions of older elderly fatalities while Sweden (15%), Portugal (14%) and Denmark (13%) have the highest proportions of young elderly fatalities (Table A2.2, Table A2.3 & Figure A2.2 in Annex 2).

The elderly are characterised by fewer fatalities than the younger adult age groups. Nonetheless, the **fatality rate strongly increases with a higher age**: from a small to medium increase in the younger elderly age group (65-74) to almost twice this value for the older elderly (75+) (Figure A2.3 in Annex 2). As a result, the fatality rates of the young and older elderly are amongst the highest after the fatality rate of the 20-24 year olds. The primary cause of this higher fatality rate is the **increased fragility of the elderly**. The fact that older people more often use **unprotected modes** also increases their risk of being seriously injured or killed in an accident (CONSOL, 2013a).

This higher fatality rate becomes even more apparent when the fatality rates of the young and older elderly are compared with the fatality rate of the middle-aged (45-64 years) and the entire population within a country (Table A2.4 in Annex 2). In Europe, the fatality rate of the young and older elderly is respectively 1.14 and 1.70 times higher compared to the middle-aged in 2013 (Table A2.4 in Annex 2). Furthermore, the ratios of the **young (1.10) and older (1.64) elderly** to fatalities of all ages also show that both elderly age categories have an **above average fatality risk** in most of the 27 EU Member States in 2013 (Table A2.4 in Annex 2). The rate for the young elderly ranges from 26 fatalities per million inhabitants in the United Kingdom to 120 fatalities per million inhabitants in Romania, whereas the EU-27 average was equal to 57. The fatality rate for this age group is also higher than average in Austria, Belgium, Bulgaria, Cyprus, the Czech Republic, Estonia, Greece, Croatia, Hungary, Italy, Latvia, Poland, Portugal and Slovenia (Table A2.4 and Figure A2.4 in Annex 2).

For the older elderly, the rate ranges from 44 fatalities per million inhabitants in Sweden to 143 fatalities per million inhabitants in Bulgaria, while the EU-27 average in 2013 was equal to 85. Older elderly fatality rates were also above average in Austria, Belgium, the Czech Republic, Finland, Greece, Croatia, Hungary, Ireland, Italy, Latvia, the Netherlands, Poland, Portugal, Romania and Slovakia (Table A2.4 and Figure A2.4 in Annex 2). Except for Cyprus, Ireland, Finland and the Netherlands, all the countries with higher than average young and older elderly fatality rates also have above average fatality rates for all age groups (Table A2.4 in Annex 2). This suggests that the elevated risk to die in a road traffic accident, in these countries, is not related to age but to the general poorer road safety situation of that country.

### 3.1.2 Characteristics and causes of accidents

#### Gender

Approximately, **two thirds of the young and older elderly fatalities are men** in the EU-27 between 2011 and 2013 (Table A2.5 & A2.6 in Annex 2). In most Member States **the fatality rate of young and older elderly men is (over) twice the rate of young and older elderly women** (Table A2.9 in Annex 2). The fatality rates for older elderly men are the highest in Austria, Bulgaria, Poland and Romania and are the lowest for Denmark and the United Kingdom. For young elderly men, the highest fatality rates can be found in Latvia and Romania while Ireland, the Netherlands and the United Kingdom have the lowest fatality rates. The higher fatality rates for men can be found across all age groups (Table A2.7 in Annex 2). On average, the fatality rate of middle-aged men is ± 4 times higher than the fatality rate of middle-aged females (Table A2.7 & Table A2.8 in Annex 2). The male fatality rate across all age groups is ± 3 times the female fatality rate of the entire EU-27 population in 2013 (Table A2.7 & Table A2.8 in Annex 2). It is likely that this is a result of **differences in behaviours and exposure patterns** of males compared to females. Despite the fact that more elderly males than females die in road traffic accidents, the fatality rates of young and older elderly men are only slightly elevated (respectively 1.12 and 1.70 times higher) compared to the fatality rate of the entire male population in 2013 (Table A2.7 in Annex 2).

However, **women account for a higher proportion of fatalities among the young (32%) and older elderly (39%) than within the entire European population (24%)** in the EU-27 between 2011 and 2013 (Table A2.6 in Annex 2). The highest proportions of young female elderly fatalities occur in Finland (44%), Ireland (43%), The Netherlands (41%, Bulgaria (40%) and France (39%) while the lowest are found in Cyprus (23%) and Italy (24%). For the fatalities among older female elderly, the highest proportions are found in Croatia (50%), Ireland (57%), United Kingdom (51%) and Slovenia (50%) while Finland (30%) and Hungary (29%) have the lowest proportions. The fatality rates of elderly females are also higher due to the higher share of female fatalities among the elderly. Compared to the entire female population in 2013, **the fatality rates of young and older elderly females were on average 1.60 and 2.25 times higher** (Table A2.8 in Annex 2). As a result, it appears that **elderly women are quite more vulnerable** than elderly men when their fatality rates are compared to the fatality rates of their younger counterparts. The young elderly fatality rates for females were the highest in Bulgaria, Poland and Romania and the lowest in Germany, Denmark, Italy, the Netherlands, Sweden and the United Kingdom. Cyprus, Poland and Romania have the highest fatality rates for older elderly women while the rates are the lowest for Spain, Sweden and the United Kingdom (Table A2.8 & Table A2.9 in Annex 2).

#### Type of road user

**35% of the elderly fatalities were pedestrians** in the EU-27 countries (Table 2.10 in Annex 2). The percentage of elderly fatalities who were pedestrians is the highest in Bulgaria (65%) and Romania (61%) and is the lowest in the Netherlands (14%). The proportion of elderly fatalities who were car drivers ranged between 8% in Romania and 40% in Ireland. This means that **across Europe**, **approximately two fifths of elderly fatalities were pedestrians** in 2011-2013 and one quarter were car drivers. These fatality proportions by type of road user differ according to the age group of the elderly (Table 2.10 in Annex 2). **29% of young elderly fatalities were pedestrians** in the EU-27 **compared to 41% of older elderly fatalities** (Table 2.11 & Table 2.12 in Annex 2).

However, the proportion of **fatally injured car drivers** is higher for **young elderly (30%**) than for **older elderly (25%)** (Table 2.11 & Table 2.12 in Annex 2). The main cause of this difference is the fact that with increasing age more drivers decide to stop driving. **Within the entire European population, the elderly (65+) make up 39% of all pedestrian and 40% of all pedal cyclist fatalities compared to 18 and 19% of all car driver and passenger fatalities** (Table 2.13 in Annex 2). For all Member States, the proportion of young and older elderly pedestrian and pedal cyclist fatalities is systematically higher than for car occupants (Table 2.14 & Table 2.15 in Annex 2). Conversely, middle-aged fatalities only make up 24% and 30% of all pedestrian and pedal cyclist fatalities and also represent 41% of all car occupant fatalities (Table 2.16 in Annex 2). This contrast illustrates the **disproportionate share of pedestrian and pedal cyclist fatalities within the elderly**.

The share of **elderly** within all **bus passenger fatalities (24%)** is similar to that of the middle-aged (28%) (Table 2.13 & Table 2.16 in Annex 2). The same applies for the moped rider fatalities: the **elderly make up 22% of all moped rider fatalities** while the middle-aged account for 18% (Table 2.13 & Table 2.16 in Annex 2). By contrast, the **elderly are underrepresented as motorcyclist fatalities**: **only 4%** of all motorcyclist fatalities were elderly compared to 24% of the middle-aged (Table 2.13 & Table 2.16 in Annex 2).

### Type of road

Compared to the middle-aged fatalities (9%), there are fewer young (6%) and older (3%) elderly fatalities on motorways. As a result, **most of the young (86%) and older elderly (88%) fatalities in the EU-27 occur on non-motorways** (Table A2.17 in Annex 2).

### Accidents in urban areas

There are remarkably **more young (45%) and older elderly fatalities (55%) in urban** areas compared to middle-aged fatalities (33%) (Table A2.18 in Annex 2). This is most likely due to the relatively higher share of young and older elderly fatalities who are pedestrians. The proportion of young elderly fatalities in urban areas ranges from 25% in Croatia to 72% in France. For the older elderly fatalities this proportion varies from 35% in Estonia to 81% in the Netherlands.

However, there are also considerable differences between Member States. Over 50% of the young elderly fatalities in Austria, Bulgaria, Croatia, Cyprus, Czech Republic, Germany, Denmark, Estonia, Spain, Finland, Sweden, Poland, Romania and Slovakia occur in rural areas. For the older elderly, more than half of the fatalities in Spain, Sweden, Denmark and Estonia take place in rural areas. This higher share of fatalities in rural areas is most likely related to the population distribution and vastness of certain countries. For instance, the majority of these countries are characterised by vast rural areas mostly inhabited by elderly people.

### Day of week and time of day

**Relatively few elderly are killed in road accidents at night** (Figure A2.6 & Figure A2.7 in Annex 2). The distribution of elderly fatalities has, at weekdays and weekends, peaks before noon (around 10 am) and in the afternoon (around 4 pm) while the middle-aged fatality distributions have clear peaks in the late afternoon and/or early evening.

### Seasonality

In most countries and in the EU-27, **the number of elderly fatalities reaches its peak at 30% in the fourth quarter (October-December)** (Table A2.22 in Annex 2). Conversely, the peak in Austria (30%), Cyprus (28%), Spain (29%) and Greece (32%) occurs in the third quarter (July-September) while the majority of the elderly fatalities (30%) in Ireland fall in the second quarter (April-June). In the Northern European countries most elderly fatalities (around 30%) occur in October and December. This is related to the lack of daylight in the winter period in these countries which reduces the visibility.

Compared to the middle-aged and overall distribution of fatalities in EU-27, it becomes very clear that **the number of elderly fatalities rises steadily from February to December and reaches its peak between October and December** (Figure A2.8 in Annex 2). As a result, there are very few elderly fatalities in the summer period while the number of middle-aged fatalities reaches its peak in the period from July until September.

### Weather circumstances

In general, **around 75% of the young and older elderly fatalities occur in dry and clear weather conditions** (Table A2.20 in Annex 2). This is also the case for the middle-aged fatalities. This higher share of young and older elderly fatalities is related to the elderly's exposure pattern as they tend to make more trips during the day and in good weather circumstances.

### Light conditions

**More than half of the young and older elderly fatalities take place during the day** (Table A2.21 in Annex 2). This is the case in all member states. The majority of the middle-aged fatalities (50%) also occur during the day but the share of middle-aged fatalities (27%) at night is higher compared to the younger (19%) and older elderly (14%) fatalities. The higher share of young and older elderly fatalities is related to their exposure pattern as they tend to make more trips during the day.

### Accidents at intersections

By comparison with the middle-aged fatalities (15%), **young (20%) and older (24%) elderly fatalities are overrepresented at intersections** (Table A2.19 in Annex 2). The proportion of young elderly fatalities at intersections ranges from 13% in France to 47% in the Netherlands. For the older elderly fatalities this proportion varies from 14% in Romania to 52% in the Netherlands. The Netherlands also have the highest share of middle-aged fatalities at intersections. Most likely, this is related to the fact that the Dutch in general make more trips by walking and cycling.

## 3.1.2.1 Mobility patterns

### Number of trips, distances travelled and trip circumstances

Research has demonstrated that the **number of trips, distances travelled and travel times decrease with age** (Eberhard, 2008; INFAS & DLR, 2010; Molnar &

Eby, 2008; OECD, 2001; TØI, 2011) due to the elimination of work-related trips in their travel patterns (Rosenbloom, 2004). These trips are mostly made in **well-familiar areas**, during the day, outside peak periods and in good weather circumstances (Eberhard, 2008). The **age of 75** appears to be a **turning point** since the **mobility of the elderly decreases** markedly around this age (Brög, Erl, & Glorius, 2000; CONSOL, 2013b; Hjorthol & Sagberg, 2000; Oxley, 2000). Most probably, this decrease is related to the fact that **health issues and impairments** are more prevalent with rising age. Gender also appears to have an impact on mobility or immobility. **Older women travel less than older men** and when they do travel they are more likely than older men to travel for shorter distances (CONSOL, 2013a, 2013c; OECD, 2001; Sirén, Heikkinen, & Hakamies-Blomqvist, 2001).

However, the trend that older people travel less than younger and middle-aged people is changing. **Currently, older road users travel more than their comparable age groups of 20-25 years ago; the everyday trip rates are higher and activities outside home are becoming more common**(Banister & Bowling, 2004; Dejoux, Bussière, Madre, & Armoogum, 2010; Hjorthol et al., 2010; Rosenbloom, 2001). Attitudinal effects (raised mobility needs, more active lifestyles), improved physical possibilities (fitness and health conditions) and cohort effects are the driving factors for the increased mobility of older road users (INFAS & DLR, 2010). A strong social network also has a significant influence on the number of trips conducted by older adults (Haustein, 2011; Scheiner, 2006). Given the fact that the proportion of elderly road users in the total European population is expected to reach 25% by 2050, it can be estimated that this increased mobility trend will continue.

### Trip purpose

Due to the change in activity structure (i.e. from active employment to retirement), older people tend to make **more trips for shopping, leisure and social activities or private arrangements** (Arentze, Timmermans, Jorritsma, Kalter, & Schoemakers, 2008; Hjorthol et al., 2010; INFAS & DLR, 2010; Kubitzki & Janitzek, 2009; Rosenbloom, 2004; van den Berg, Arentze, & Timmermans, 2011). This shift in trip purpose is even more prevalent for the older elderly (75+ years) (INFAS & DLR, 2010; TØI, 2011). The trip purpose of elderly also appears to be **related to their residence location**. Older people living in urban areas engage more in activities belonging to the category "education and culture" while the elderly residing in rural areas conduct more social activities (Ramatschi, 2004).

### Mobility preferences

On average, the **car is the most preferred transportation mode** by older people. In Europe approximately **half of all older people's trips are made by car** (OECD, 2001). The use of public transport appears to differ between countries (i.e. lower use in the Netherlands, higher in Scandinavia and the United Kingdom). Furthermore, walking is also an important transportation mode in Europe since **30-50% of the older people's trips are made on foot** (OECD, 2001). Cycling seems to be of minor significance as a transport mode for the elderly, except in Denmark and the Netherlands. Older road users have a higher share in walking and public transport use and drive a car less frequently than other adult age groups (INFAS & DLR, 2010; OECD, 2001; TØI, 2011).

The choice of a transport mode by older road users mainly depends on the availability of a car, gender, income, health, household structure and residence (CONSOL, 2013a, 2013c; Engeln & Schlag, 2001). **Women** are less dependent on the car and **rely more on walking and public transport** than **men** who **have a strong connection to the private car** (Li, Raeside, Chen, & McQuaid, 2012; Mollenkopf, 2004; Rosenbloom, 2006; Sirén et al., 2001). Furthermore, older road users with a higher income make more trips (Tacken, 1998), are more likely to drive (Kim & Ulfarsson, 2004), and less likely to use public transport (Su & Bell, 2009). Hakamies-Blomqvist and Wahlström (1998) also found that financial reasons play an important role in the decision to stop driving. Compared to two-person households, older people in single-person households dependent more on walking, public transport and special transportation services (Stjernborg & Waara, 2010). Finally, walking and public transport services are more dominant in urban areas while the private car is more often used in the countryside (CONSOL, 2013c).

#### 3.1.2.2 Functional limitations, diseases and medication

##### Age-related functional limitations

Safe mobility relies on key skills involving sensory, cognitive and psychomotor capabilities. **Declines in these functional skills** can occur at any age but **are more common in the older adult population**. However, it is mainly the biological and not the chronological age that determines how certain functional declines manifest themselves, as well as the pace at which this decline evolves (Davidse, 2007). Eventually, all elderly will slowly but certainly be confronted with changes in their functional capabilities and as a result of this it will become more difficult to maintain a safe mobility since these functional limitations can contribute to a higher crash risk. These **increases in crash risk can be mitigated or prevented by** other characteristics of older road users such as **traffic experience, compensation behaviour and insight into one's own limitations** (CONSOL, 2013a; DaCoTA, 2012a; Davidse, 2007). With increasing age, most elderly will experience some loss in sensory abilities, decreases in cognitive abilities and/or in psychomotor functions (Davidse, 2007; Eby et al., 2009; Holland et al., 2003; Janke, 1994; Oxley, Corben, Fildes, O'Hare, & Rothengatter, 2004; Whelan et al., 2006):

- **Sensory abilities**: visual acuity, contrast sensitivity, sensitivity to light, dark adaptation, visual field, space perception, motion perception, hearing.
- **Cognitive abilities**: fluid intelligence, speed of processing, working memory, problem solving, spatial cognition and executive functions like inhibition, flexibility and selective and divided attention.
- **Psychomotor functions**: joint flexibility, muscle strength, manual dexterity, and coordination.

Table 3 provides an indicative overview of the relationship between age-related impairments and driving difficulties. Although this table discusses driving problems, it can be assumed that these declines in sensory and cognitive abilities and psychomotor functions will also influence the behaviour of elderly pedestrians, cyclists, PTW-users and bus passengers.

**Table 3: Age-related impairments associated with driving problems**

| Age-related impairments | Driving problems |
|---|---|
| Increased reaction time. Difficulty dividing attention between tasks | Difficulty driving in unfamiliar or congested areas |
| Deteriorating vision, particularly at night | Difficulty seeing pedestrians and other objects at night, reading signs. Difficulty with wet weather driving |
| Difficulty judging speed and distance | Failure to perceive conflicting vehicles. Accidents at intersections |
| Difficulty perceiving and analysing situations | Failure to comply with Give Way signs, traffic signals and railway crossing signals. Slow to appreciate hazards |
| Difficulty turning head, reduced peripheral vision | Failure to notice obstacles while manoeuvring. Failure to observe traffic behind when merging and changing lanes |
| More prone to fatigue | Get tired on long journeys, run-off road single vehicle crashes |
| General effects of ageing | Worries over inability to cope with a breakdown, driving to unfamiliar places, at night, in heavy traffic |
| Some impairments vary in severity from day to day. Tiredness, symptoms of dementia | Concern over fitness to drive |

Source: (Langford & Koppel, 2006a)

Furthermore, it should be noted that **a decline in one function may interact with or intensify the effects of a decline in another function**, although declines in one functional area are not a prerequisite for declines in another (Department of Transport, 2001 cited in Eby et al., 2009). This means that many functional declines can occur together and will amplify the potential effects of these declines on safe mobility. It is also important to recognize, that the impacts of such declines on actual crash risk are not always fully known (Whelan et al., 2006). There is evidence to suggest that declines in sensory and cognitive functions due to normal ageing results in negative road safety consequences. However, Brouwer & Davidse (2002) mention that **the relation between functional limitations and crash risk only becomes evident in case of severe sensory, perceptual and cognitive limitations** such as eye disorders (e.g. cataract, macular degeneration, and glaucoma) and diseases like dementia, stroke, and diabetes (see section age-related illnesses).

### Age-related illnesses

Ageing does not necessarily lead to declines in the abilities that are important for maintaining a safe mobility. However, several medical conditions and associated impairments are more prevalent in the older adult population and are, therefore, associated with aging. These **medical conditions can potentially impact the crash risk of older road users** (Charlton et al., 2010; Eby et al., 2009; Holland et al., 2003; Marshall, 2008). In fact, it is not the condition itself that increases the crash risk, but rather **how the condition influences the functional abilities that underlie critical skills for safely participating in traffic** (Eby et al., 2009). The crash risk of medical conditions or illnesses is affected by various factors. The influence on the crash risk strongly depends on the condition and individuals with the same illness differ significantly in how they are affected (Charlton et al., 2010; Dobbs, 2005). Furthermore, the abilities to compensate for the functional limitations imposed by the illness are also individually dependent. Certain chronic illnesses such as Parkinson's disease are progressive; i.e. the disease may be harmless in the early stages but can endanger road user safety in later stages (Eby et al., 2009; Holland et al., 2003). Finally, **comorbidity** (i.e. having more than one illness) **is more common among the elderly** and is also related to a higher crash risk.

Several medical conditions and disorders have been identified to be related to a higher crash risk. These are: alcohol abuse, cardiovascular diseases, cerebrovascular accident/traumatic brain injury, depression, dementia, diabetes mellitus, epilepsy, hearing impairments, musculoskeletal and motor disability conditions, Parkinson's disease, psychiatric disorders, renal disease, schizophrenia, sleep apnoea and vision disorders. The specific crash risk associated with these age-related disorders can be found in table 4. Nevertheless, it is important to keep in mind that **these increased risks can also be caused by the medications that are being consumed to treat these conditions**.

**Table 4: Crash risk associated with selected medical conditions**

| Diagnosis/Impairment | Vaa (2003) Relative risk (and 95% CI) | Charlton et al. (2010) Relative risk | Dobbs (2005) ("Red Flags") |
|---|---|---|---|
| Alcohol abuse and dependence | 2.00 (1.89-2.12) | 2.1-5.0 | Yes |
| Cardiovascular diseases (all types) | 1.23 (1.09-1.38) | 1.1-5.0 | Yes |
| Cerebrovascular accident/traumatic brain injury (TBI) | 1.35 (1.08–1.67) | Inconclusive | Yes (stroke) N/A (TBI) |
| Depression | 1.67 (1.10-2.45) | Inconclusive | No |
| Dementia | 1.45 (1.14-1.84) | 2.1-5.0 | Yes |
| Diabetes mellitus | 1.56 (1.31–1.86) | 1.1–2.0 | Yes |
| Epilepsy | 1.84 (1.68–2.02) | 1.1–5.0+ | Yes |
| Hearing impairment | 1.19 (1.02–1.40) | N/A | No |
| Musculoskeletal and motor disability | 1.17 (1.00–1.36) | 1.1-2.0 | No |
| Parkinson's disease | N/A | Inconclusive | N/A |
| Psychiatric disorder | 1.72 (1.48–1.99) | 1.1-5.0 | Yes |
| Renal disease | 0.87 (0.54–1.34) | N/A | Yes |
| Schizophrenia | 2.01 (1.60–2.52) | 2.1-5.0 | Yes |
| Sleep apnoea | 3.71 (2.14–6.40) | 2.1-5.0+ | Yes |
| Vision disorder | 1.09 (1.04–1.15) | 1.1-2.0 | Yes |

N/A = not available, NS = not significant.

*1.1–2.0 = slightly increased, 2.1–5.0 = moderately increased, 5+ =considerably increased.

Source: (Marshall, 2008)

### Medication

Medicines are designed for treating various medical conditions. Regardless of the age of the patient, medicines frequently have adverse effects that have the potential to affect the vulnerability (e.g. anticoagulant medication) and crash risk. This is especially true for older adults since the use of medication tends to increase with age. Furthermore, **older adults may be overly affected by medication use**. They are more likely to use **multiple medications** (polypharmacy) and to exhibit an **altered sensitivity to medication** (Dobbs, 2005; Lococo & Staplin, 2006; Moore & O'Keeffe, 1999). This altered sensitivity usually expresses itself in an increased effect, including side-effects, adverse reactions and the duration of action of a medicine may be significantly prolonged. Additionally, polypharmacy and an inappropriate or overuse in medications, further increases the altered sensitivity of the elderly to medication ( Holland et al., 2003).

Vaa (2003) calculated that the **relative crash risk for "drugs and medical products" in general is equal to 1.58** (95% CI 1.45-1.73). This result implies that road users under influence of drugs and medicinal products have a 58% increased crash risk compared to road users who are not under the influence. This increased crash risk is mostly due to the fact that **several medication classes affect the ability to safely participate in traffic through different mechanisms** such as drowsiness, memory problems, movement difficulties or visual problems. Especially older-generation antidepressant medications and antihistamines and any medicine which significantly affects the central nervous system such as analgesics, anxiolytics, benzodiazepines, and some antihypertensive agents are already identified as medicinal compounds that induce a higher crash risk (Dobbs, 2005). A more specific analysis of the medicinal subgroups revealed that **the risks of being involved in a crash is the highest for users of modern antidepressants** (RR 1.76, 95% CI 1.38–2.24), combinations of psychoactive medicines (RR 1.55, 95% CI 1.20-2.02), benzodiazepines (RR 1.54, 95% CI 1.24–1.90), patients using at least one psychoactive medication (RR 1.28, 95% CI 1.12-1.46) and opioid analgesics (RR 1.21, 95% CI 1.08-1.36) (DRUID, 2012; Vaa, 2003). The use of antihistamines appears to be unrelated to a higher crash risk (RR 1.10, 95% CI 0.91– 1.32) (Vaa, 2003).

Besides influencing the crash risk, **some medicines and/or substance groups also influence the risk of getting seriously injured or killed**. Table 5 provides an overview of the relative risk level of getting seriously injured or killed for various substance groups. These results originate from the DRUID-project (2011) and provide general trends of the magnitude of the relative risk by substance group across several European countries and population characteristics (age and gender). The discussion of the results is limited to the general trends since the relative risks do not significantly differ according to gender and age. A more detailed analysis of the relative risks can be found in the deliverable of the DRUID-project (2011).

**Table 5: Relative risk level of getting seriously injured or killed for various substance groups.**

| Risk level | Risk | Substance group |
|---|---|---|
| Slightly increased risk | 1-3 | 0.1 g/L ≤ alcohol in blood < 0.5 g/L<br>Cannabis |
| Medium increased risk | 2-10 | 0.5 g/L ≤ alcohol in blood < 0.8 g/L<br>Benzoylecgonine<br>Cocaine<br>Illicit opiates<br>Benzodiazepines and Z-drugs<br>Medicinal opioids |
| Highly increased risk | 5-30 | 0.8 g/L ≤ alcohol in blood < 1.2 g/L<br>Amphetamines<br>Multiple drugs |
| Extremely increased risk | 20-200 | Alcohol in blood ≥ 1.2 g/L<br>Alcohol in combination with drugs |

Cannabis and amphetamines: due to very different single country estimates, the risk estimate must be treated with caution. Benzoylecgonine, cocaine and illicit opiates: due to few positive cases and controls, the risk estimates must be treated with caution

Source: (DRUID, 2011)

As indicated in table 5, the highest risk to get seriously injured or killed is related to a high blood alcohol concentration and alcohol combined with other psychoactive substances, followed by medium alcohol concentrations, multiple medication use and driving with amphetamines. Alcohol concentrations between 0.5 and 0.8 g/L, medicinal opioids, illicit opiates and benzodiazepines and Z-drugs are associated with a medium increased risk.

Together these findings indicate that **some medicinal compounds are specifically associated with higher road accident and injury risk**. Some of these medications might also have greater effects on older people because they can react differently to many medications. Furthermore, it is also pivotal to keep in mind that each individual is unique, regardless of the age. Therefore, **not all medications affect everyone in the same way and not everyone has the same resources for coping with the effects of medications** (Eby et al., 2009). As a consequence, the crucial point is not whether the specific medicine may have an effect on traffic performance, but rather, whether the individual is capable of functioning safely in their environment (Holland et al., 2003).

#### 3.1.2.3 Behavioural compensation

As indicated previously, age-related functional limitations and illnesses may adversely affect the skills to safely participate in traffic. The extent to which elderly road users experience these declines, what functions are affected and the resulting effects on safe traffic behaviour vary among individuals. Several studies indicate that elderly road users in general have good judgement and the ability to assess their traffic skills realistically. Consequently, **many elderly road users self-regulate** their participation in traffic. Self-regulation typically refers to the strategy that elderly road users may **adjust or reduce, their participation in traffic in order to compensate successfully to changes in their health and functional abilities** (Donorfio, D'Ambrosio, Coughlin, & Mohyde, 2009). This compensation potential relies on the degree to which a specific function is affected and on the fitness of the other functions that need to compensate for the deficit. For example, a restricted visual field can be compensated by turning your head but if neck rotation is also restricted, the compensation potential is insufficient to fully compensate (Davidse, 2007).

Various factors appear to motivate self-regulation. **Declines in functional abilities** and increasing cognitive and visual restrictions have been found to be related with self-regulation (Ball et al., 1998; Charlton et al., 2006; Holland & Rabbitt, 1992; Ross et al., 2009; Stutts, 1998). However, various studies also concluded that elderly road users with a declining health do not always respond to these changes by self-regulating their traffic behaviour (Baldock, Thompson, & Mathias, 2008; Okonkwo, Crowe, Wadley, & Ball, 2008; Stalvey & Owsley, 2003). The latter is related to the fact that the adoption of self-regulation is more strongly related to self-perceived traffic abilities than to objective traffic abilities (MacDonald, Myers, & Blanchard, 2008). In other words, **elderly road users need to be aware, acknowledge and have insight into their functional impairments in order to self-regulate. As such, not all elderly road users will decide to self-regulate**. For example, elderly road users with cognitive impairments, such as dementia, may not be able to appropriately self-regulate their behaviour because they lack insight into their functional declines (Molnar et al., 2014). In addition, self-perceptions of confidence or (dis)comfort in specific traffic situations function as an indirect self-monitoring of the ability to participate in traffic and affects self-regulation (Baldock, Mathias, McLean, & Berndt, 2006; Meng & Siren, 2012). Lifestyle is also an important barrier to self-regulate as elderly appear to persist in participating in risky situations in order not to compromise their lifestyle (Baldock et al., 2006).

Age-related decline is not the only factor to self-regulate. Household income, the presence of other drivers in the household and having been involved in a crash are also driving factors of self-regulation (Charlton et al., 2006; Charlton, Oxley, Fildes, Oxley, & Newstead, 2003; Ragland, Satariano, & MacLeod, 2004). Gender also seems to be related to self-regulative behaviour. **Older women self-regulate more than older men** (Charlton et al., 2006; D'Ambrosio, Donorfio, Coughlin, Mohyde, & Meyer, 2008; Kostyniuk & Molnar, 2008). According to Kostyniuk et al. (2008) this gender effect may be partially explained by the perceived level of confidence of an individual in different traffic situations, with older women reporting lower confidence than men.

**Critical road user skills** allow every type of road user to safely and efficiently participate in traffic. Michon (1979, 1985) identified that these critical skills or problem-solving abilities can be divided into three levels of skills and control that interact with each other in a hierarchical way: **strategic (planning), tactical (manoeuvring), and operational (control)**. Decisions at the strategic level relate to the general planning stage of a trip and are made before the trip even begins (Smiley, 2004). The tactical level has to do with the actual manoeuvres drivers make in traffic in response to conditions in the driving environment at any given time (Eby et al., 2009) while decisions at the operational level require quick decisions and actions in response to sudden obstacles or hazards on the road. Therefore operational decisions are of a more automated nature. **These three levels are very relevant for the compensation behaviour of all types of elderly road users**. Cognitive, visual and psychomotor abilities play an important role on all three levels. The risk of a crash or potential conflict increases when road users experience difficulties in decision making or actions at the operational and tactical levels. Since older road users most often experience declines and impairments in the functions that are necessary or affect their ability to make immediate decisions, self-regulation is generally not possible or effective at operational and tactical levels (Eby et al., 2009). As a result, **the greatest opportunity for adaptations or compensation strategies for the elderly can be found at the strategic level** where decisions can be planned in advance.

#### 3.1.2.4 Experience

**Older road users** have the **benefit of traffic experience** because they have encountered and participated in numerous traffic situations in their life. As a result, numerous traffic situations and unexpected events are embedded in their memory and became a key component of the skill and experience 'package' of the older road user (GOAL, 2013a). The traffic insight and experience that they have acquired during the years enables them to anticipate on (potentially problematic) situations that they will encounter and may also lead to lower crash involvement. In a study of Massie, Green & Campbell (1997) it is assumed that **more experienced drivers are more proficient in the driving task and thus more likely to avoid crashes which leads to lower crash rates**. Until so far, the relation between experience and lower crash involvement has only been investigated for drivers. However, this does not necessarily mean that only driving experience is associated with a lower crash rate. The strength of traffic experience in general lies in the fact that experienced road users have developed mental models of the transportation mode and the traffic system (i.e. road network, traffic rules, other road users) they use. These mental models support the road user in choosing the appropriate action for every traffic situation (Wickens & Hollands, 2000).

On the other hand, experience as such is no prerequisite for older road user safety**. Experience can only compensate for age-related functional limitations to a certain degree**. Holland (2001, p. 38 cited in Davidse, 2007) argues that "experience contributes significantly to the ability to compensate for deficits at the manoeuvring (i.e., tactical) level, but only up to a certain point at which information processing related deficits begin to outweigh the experience advantage." So it seems that **experience and self-regulation can control or compensate for slight functional**

**declines**. However, in their late 70s these impairments begin to outweigh the experience and self-regulation advantages for most older road users, and combined with their increased vulnerability their crash risk will start to increase (Holland, 2001, cited in Davidse, 2007).

### 3.1.2.5 Increased fragility

Compared to younger road users, the **elderly have a disproportionate injury risk**. This increased physical fragility is the result of the normal ageing process. Because of reductions in bone and neuromuscular strength and fracture tolerance, elderly road users are at a significantly greater risk to sustain serious injuries or be killed as a result of a crash (Evans, 2004; Kim & Ulfarsson, 2004; McKnight & McKnight, 1999; Oxley, Corben, Fildes, O'Hare, et al., 2004). **Essentially, this increased fragility means that, given the same crash and physical injuries, older road users are more prone to have serious injuries or die than younger road users**. This elevated injury risk is independent of the crash severity; i.e. moderate crashes also encompass a higher risk of being seriously injured or killed. All elderly road users are affected by this increased vulnerability. For older pedestrians, the mortality in road crashes is more than double compared to younger pedestrians (Martin, Hand, Trace, & O'neill, 2010). Bíl, Bílová & Müller (2010) also found that the elderly, compared to other age groups, have the highest mortality risk in bicycle to car crashes. Mitchell (2000) illustrated the increased fragility with age by setting a fatality index (the risk of an injury being fatal) at 1.0 for the age group 20-50 years. This fatality index for older car drivers, car passengers and pedestrians rose from a defined 1.0 for ages 20-50 to 1.75 at age 60; 2.6 at age 70; and 5-6 for people aged 80 or more. **Additionally, 60-95% of the increase in mortality rate per distance travelled for drivers aged 60 and over is the result of increases in fragility** (Li, Braver, & Chen, 2003). According to other studies (Eberhard, 1996; Eberhard & Trilling, 2001 cited in Shinar, 2007), frailty is the primary cause of older driver fatalities after the age of 70.

Furthermore, **the recovery time of older injured road users is also much longer** compared to younger road users (Oxley et al., 2004). To illustrate, hospital records of older road users in Australia and the USA indicate that they **have longer hospital stays**, more severe injuries, an increased likelihood of being admitted to the Intensive Care Unit (ICU), a longer length of stay within the ICU and are less likely of being discharged at the same day of admittance compared to other age groups (Bauzá, Lamorte, Burke, & Hirsch, 2008; Meuleners, Harding, Lee, & Legge, 2006). The same trend has also been observed in Europe by Broughton et al. (2012). They found that **43% of all elderly road accident causalities were admitted to the hospital compared to merely 32% of all road accident casualties**. The probability to be admitted to hospital also differs according to road user type. Around 50% of the elderly pedestrians, motorcyclists and moped riders were hospitalized, followed by ± 40% of the elderly cyclists. The largest difference can be observed for the number of injured car occupants, with ± 50% of the elderly hospitalized compared to ± 25% of the overall number of hospitalized car occupants. On average, the length of stay was eight days overall and twelve days for elderly road accident casualties. For vulnerable road users (i.e. pedestrians, cyclists moped riders and motorcyclists) and other transport modes, the average admittance period for the elderly was even higher and ranged from 12-15 days.

The injury patterns of the elderly also vary by road user type (Broughton et al., 2012). Overall, the **most frequent injured body part locations are the head, upper extremities and lower extremities**. Lower and upper limb and head injuries are more common for elderly pedestrians, cyclists, motorcyclists and moped riders while elderly car occupants have higher rates of head and trunk injuries. Furthermore,

**fractures make up more than 40%** of all traffic injuries endured by elderly attending to hospital.

#### 3.1.2.6 Experiences and perceived safety of elderly road users

Concerning the transport system, **older people** have been found to **value most the aspects of safety and security in mobility**, followed by independence, getting exercise and avoiding pollution while travelling (Flade, 2002 & Transek, 2005 cited in CONSOL, 2013a). Furthermore, heavy traffic and the aggressive, ruthless driving style of various car drivers and cyclists are identified as the main road traffic problems by the elderly (Mollenkopf & Flaschenträger, 2001). Similarly, in a qualitative study by Risser, Haindl and Ståhl (2010) three of the five highest ranked barriers to elderly mobility were related to the behaviour of other road users: inconsiderate car drivers, vehicles on the pavement and a negative attitude towards senior citizens. The experts also ranked "inconsiderate car drivers" and "vehicles on the pavement" as important barriers but they also identified two intrinsic factors that the elderly themselves do not consider as important crucial barriers: "decreasing senses" and "having to rely on other persons in connection with one's mobility". This is in line with Siren and Kjær (2011) and Ernst (1999 cited in CONSOL, 2013a), who found that the **elderly tend to perceive risk as something external, originating from other road users that sometimes can be managed by internal means (i.e. skills)**. However, they also desire that other road users change their behaviour to reduce accident risks.

Perceived safety in a particular transportation mode is a decisive factor for using it. Dependent of the transportation mode, older people perceive particular situations and conditions as unsafe:

- **Car drivers**: Older car drivers asses driving in specific weather conditions (fog, rain, snow), in peak hours with high traffic densities, on motorways, specific road characteristics (tunnels, roundabouts) and others' driving behaviour (tailgating, driving too close) as dangerous (Jansen et al., 2011 cited in CONSOL, 2013a; Sullivan, Smith, Horswill, & Lurie-Beck, 2011).
- **Cyclists**: Elderly cyclists feel uncomfortable in heavy traffic, on busy main roads, at night and try to avoid these situations as much as possible. The highest motivators to not use a bicycle are health, fear of falling off the bicycle or fear induced from busy traffic situations (Janoška, Bíl & Kubeček, 2011 cited in CONSOL, 2013a).
- **Pedestrians**: The mobility of elderly pedestrians is restricted by the fear of falling. They identified poorly maintained pavements as the most important risk factor in their outdoor environment (Ståhl, Carlsson, Hovbrandt, & Iwarsson, 2008)
- **Public transport**: Most elderly are afraid of becoming a victim of a crime. The fear of crime has such a strong influence on the elderly that it restricts their mobility and is the most important obstacle for using public transport (Knight, Dixon, Warrener & Webster, 2007 cited in CONSOL, 2013a; Schlag, 2008) . Other barriers for the use of public transport include access (Davey, 2007), convenience, discontent with the stability of the vehicles, the risk of falling or injuries (Broome, McKenna, Fleming, & Worrall, 2009), uncertainty concerning the usage of the technical equipment (i.e. ticket vending machines), finding a safe position in the bus and physical problems when entering trams or buses (SIZE, 2006).

#### 3.1.2.7 Diversity of elderly road users

Several studies that examined older people's mobility behaviour, preferences, limitations, road safety and road safety relevant human factors identify **the elderly as a highly heterogeneous group** with respect to road accident risk, individual characteristics, mobility needs, patterns and problems (Alsnih & Hensher, 2003; BASt, 2014; OECD, 2001). In order to cope with this diversity, older people are often segmented into specific subgroups. These segments are mostly distinguished based on various factors such as aging phases, levels of fitness, severity of physical limitations, use of transport modes, consumer behaviour and social activities (GOAL, 2013d). The most recent and comprehensive segmentation of elderly was composed in the GOAL-project (GOAL, 2013d). Based on survey results, a literature review and information embedded in the SHARE-database, five distinctive profiles or segments of older people were created. The segments take demographics, physical and mental health characteristics, social life, living environment, mobility-related aspects and transition points into account. At first sight, the five profiles differ significantly according to age and level of activity (health); namely one younger and more active profile ("Fit as a Fiddle"), a very old, highly impaired and immobile segment ("Care-Full"), a quite mobile and still independent senior despite his/her old age ("Oldie but a Goldie"), young, fit and active elderly ("Happily Connected") and young, severely impaired and immobile elderly ("Hole in the Heart"). A detailed overview of the characteristics of each profile is provided in table 6.

The comparative study of the aforementioned five segments reveals important differences that should not be neglected. As a consequence, there is a need for the development and implementation of individual preventive measures for the different target groups of elderly road users in order to effectively enhance and guarantee safe mobility for all elderly.

**The mobility behaviour and profiles of older people will almost certainly change in the future** due to current and future changes in built, social and cultural environments (Haustein & Siren, 2015). **The urban sprawl and the withdrawal of public transport in rural areas** (Ahern & Hine, 2012), will likely **decrease older people's public transport use and increase their car use**. Due to later retirement ages and increased longevity, the **elderly population of the future will be healthier and age-diverse**. For instance, young elderly will become more active, independent and healthier compared to earlier cohorts whereas the older elderly will experience a population growth due to increases in life expectancy (Haustein & Siren, 2015). However, as chronic diseases are more prevalent with increasing age (Holland et al., 2003), the probability exists that this rise among the older elderly will be accompanied by increases in the number of older people with chronic illnesses. Both social trends will have opposing effects on travel patterns and mode choice of future generations of older people.

Regarding the **changes in the cultural environment**, the elderly of the future are assumed to have **higher expectations for living active and independent** and are more demanding consumers of products and services (Kirchmair, 2005 cited in Haustein & Siren, 2015). Additionally, it is expected that they **will uphold more active mobility patterns and hold there driving licenses into advanced ages** (Hakamies-Blomqvist et al., 2005; Hjorthol et al., 2010). **Future cohorts of older women** are also assumed to be more frequently employed, hold a driving license and have car access (Siren & Haustein, 2013). This will not necessarily mean that older women will also drive more, but the prognosis that significantly more older women will continue to work into old age implies that they will be **car-dependent** (Siren & Haustein, 2015).

**Table 6: Profiles of older people (GOAL, 2013d)**

| | | Fit as a fiddle | An Oldie but a Goodie | Hole in the Heart | The Care-Full | Happily Connected |
|---|---|---|---|---|---|---|
| Demographics | Main age group | 50-59 | 80-90 | 50-75 | 85-100 | 60-75 |
| | Financial resources | +++ | + | --- | -- | ++ |
| | Still employed | +++ | -- | - | --- | + |
| | Household information | married or in partnership | single | O | single | married or in partnership |
| Health | General health | +++ | + | -- | --- | ++ |
| | Eyesight and hearing | +++ | -- | O | --- | ++ |
| | Limitation in activities | --- | + | ++ | +++ | - |
| | Suffer from pain | --- | - | ++ | +++ | -- |
| | Dementia/Alzheimer's | --- | + | -- | +++ | -- |
| | Drugs needed | --- | + | +++ | +++ | + |
| | Mobility aid needed | --- | +++ | O | +++ | - |
| Transport | Importance of driving | +++ | + | ++ | + | ++ particularly for men |
| | Importance of public transport | -- | ++ | -- | - | ++ particularly for women |
| | Importance of walking | - | +++ | -- | + | ++ |
| | Number and length of trips | +++ | -- | -- | --- | ++ |
| | Purpose of trips | work, leisure, socializing (no difference to average society) | socializing, shopping, religious services | many trips to hospitals, medical facilities | many trips to hospitals, medical facilities, religious services | entertainment, recreation, sport, socializing, clubs, family |
| Environment | Problems with infrastructure barriers | --- | ++ | ++ | +++ | - |
| | Afraid of assault/crime | --- | + | ++ | ++ | - |
| Life satisfaction | Satisfaction & mental health | +++ | ++ | --- | --- | +++ |
| | Social networks (friends, neighbours, family,…) | ++ | ++ | - (mainly family) | -- (only family) | +++ |
| | Activities (clubs, volunteering, religious organisations,…) | +++ | + | -- | --- | ++ |
| | Independency | +++ | + | - | --- | ++ |
| | Technology usage | ++ | -- | O | --- | + |
| Transitions | Life changing events | retirement, birth of grandchildren, severe illness | severe illness, death of a close person | severe illness, loss of social contacts, death of partner | illness, need for (nursing) care, loss of social contact | death of partner, severe illness |
| | Follow-up profiles | Happily Connected, Hole in the Heart | The Care-Full | The Care-Full, an Oldie but a Goodie | x | an Oldie but a Goodie, Hole in the Heart, the Care-Full |

+++ above average; - - - below average; o not clear; x not applicable

Overall, these trends seem to provide some evidence to **indicate a growth in the number of older car users**. According to Haustein & Siren (2015) **the younger elderly will more likely become highly mobile car-oriented people while the**

**older elderly will belong to the car-dependent segment**. They also predict that the elderly segment of public transport captives will shrink due to the current lack of adequate public transport facilities and the future increases in driving licenses and health among the elderly. **Besides, becoming highly car-oriented, the young elderly are also expected to be multi-modal seniors compared to earlier cohorts**. However, the extent of their multi-modal mobility will depend on investments in infrastructure, developments of supportive technologies and changes in social norms with regard to the use of different transport modes (Haustein & Siren, 2015).

### 3.1.3 Areas of Improvement and Suggested Countermeasures

#### 3.1.3.1 Areas of Improvement

During the stakeholders' consultation workshop (Durso et al., 2015), **possible areas of improvement** in the field of infrastructure, vehicle technologies and human behaviour were identified to reduce the risk of elderly road users in road traffic.

Possible areas of improvement in the **field of infrastructure design** include (Durso et al., 2015):

- The **road infrastructure** should be made **more elderly friendly**. This is not only beneficial for all types of elderly road users but also for all road users regardless of their age. An example of road user friendly designs are forgiving roads. This design concept is beneficial but can also include some dangerous aspects which need to be taken into consideration. For example, wider cycle lanes may lead to larger differences in cycle speeds between younger and elderly cyclists and can result in more crashes between cyclists.

- The **infrastructure for vulnerable road users** should to be **separated from motorized traffic**, and when this is not possible clear and consistent regulations (e.g. 30kmh speed limits when vehicles share a road with cyclists) should be applied.

- The **length of the green phase** could be adjusted to allow for the slower walking speeds of elderly pedestrians or areas could be implemented where elderly could stop when crossing a road.

- Special attention should be given to the elderly when **introducing new infrastructural design concepts** such as shared space. In the early introduction phase, these modern concepts could induce higher risks for elderly due to unfamiliarity issues but after a few months they get used to it and learn what is expected from them, how to communicate and interact with other road users.

With respect to **vehicle design and technologies** the following areas of improvement could be identified (Durso et al., 2015):

- **Braking assist technologies** are very relevant for elderly drivers.

- **Vehicle detection systems** are also beneficial for the safety of elderly road users.

- More attention should be given to improve the **physical protection** of elderly. Future applications should be targeted at protecting the whole body in case of a crash.

- Vehicle technologies could also assist in increasing the **efficiency of medical support** when a crash occurs.

The following areas of improvement, related to **human behaviour**, were identified (Durso et al., 2015):

- **Education, awareness raising activities and training** are very useful. Unfortunately however, experience shows that most people who attend them are already aware about their own limitations and functional impairments and thus are less in need of such initiatives. The real challenge is therefore to make those people aware who are most in need of such initiatives.

- The elderly's awareness to seek **life-after-car mobility alternatives** should be increased. However, society should also provide such transportation alternatives in the future instead of abandoning them. For example, a good public transport system that should be accessible by default and other options (i.e. dial a ride) should be available only when public transport is insufficient. This should be a universal approach that is not only focused on elderly.

- All the impairments of the elderly driver and his/her compensation potential should be taken into account when deciding to **restrict or cease driving**. Therefore, the **biological age and medical condition are more relevant** in the assessment of fitness-to-drive than the elderly's chronological age. In this respect a uniform arrangement across the European Member States is needed.

Finally, the group of **older road users** is also a **very heterogeneous group** with strong differences in mobility needs, mobility participation, health and financial status, and accident risks. Hence, in order to be effective, **tailored solutions for each subgroup are needed**.

#### 3.1.3.2 Suggested Countermeasures

Besides the formulation of possible areas of improvement, the stakeholders' also provided the following ideas concerning **beneficial countermeasures** for elderly road users (Durso et al., 2015).

1. Overall **road safety policy** for the elderly should focus to:
   - providing safe and easy transportation alternatives,
   - restrictive policies should not be priority,
   - interventions should not be discriminatory,
   - any policy should be in combination and integrated within other policies,
   - introduction of voluntary driver assessments linked with raising awareness.

2. The **medical and pharmaceutical sectors** should play a more active role:
   - there is need for raising awareness within the medical and pharmaceutical sector,
   - each sector is having a clear distinct role,
   - physicians should be trained to judge fitness to drive,
   - medical control should concern both physical and cognitive impairments,
   - further research is needed for identifying criteria of non-fitness to drive.

3. **Road infrastructure oriented policies** for elderly safety should focus on:
   - the development of road environments without surprises and forgiving,
   - both urban and rural road networks,
   - in urban networks, junctions should be treated in priority,
   - more protective signs for pedestrians,
   - higher traffic sign uniformity across Europe.

4. **Vehicle oriented policies** for elderly safety should focus on:
   - further development of crash avoidance systems,
   - intensify research addressing current technical limitations,
   - adapt the vehicle and its technologies to the particular needs of the elderly,
   - industry should switch the focus from the vehicle to the driver,
   - elderly safety should be introduced in EuroNCAP testing, especially the VRU.

5. **Awareness campaigns** for elderly safety should focus on:
   - sensitization of all road users (not only drivers)
   - the particular needs of the elderly (drivers, pedestrians)
   - more campaigns are needed for heavier vehicle drivers (cars, HGVs, buses etc.),
   - campaigns should be combined with enforcement to increase results,
   - campaigns should be coordinated at national, regional and local level.

6. The idea of **gradual license restrictions** needs further development:
   - the focus should be on health issues and not on age (for all drivers),
   - gradual license restrictions should be voluntary,
   - there is need for identifying specific medical criteria for any type of gradual license restrictions,
   - a need for combined medical and driving tests (in certified centers),
   - explore the prediction of non-fitness to drive (instead of fitness to drive).

7. **Other specific measures** for elderly safety could be explored:
   - introduction of cheaper public transport for the elderly,
   - investigation of new problems from electric vehicles and pedelecs (e-bikes),
   - new cars should be able to identify the driver characteristics and adapt,
   - all new solutions should be tested also by the elderly (not only by the young),
   - elderly safety implications of shared space schemes should be investigated.

8. The **EU policy** should focus on:
   - increasing awareness actions at EU, national, regional and local level,
   - exchange of knowledge and promotion of best practices on elderly safety,
   - develop stronger policies for traffic and safety of pedestrians and other VRUs,
   - promote urban road safety policies within sustainable urban mobility plans,
   - explore the safety potential of automated vehicles.

## 3.2 Car users

This section describes the current road safety situation of elderly car drivers and passengers. For this purpose, the European accident database and relevant literature are consulted. The crash data extracted from the CARE database can be found in Annex 3 and 4.

### 3.2.1 Accident statistics

#### Car drivers

According to the CARE database, almost **21% of all car driver fatalities** in the EU **were elderly** in 2013 while they account for ± 18% of the total EU-27 population (Eurostat, 2015a) (Table A3.1 & Figure A3.2 in Annex 3). There is however a large difference between Member States. For example, the highest share of elderly car driver fatalities in 2013 could be observed in Sweden (31%), Italy (28%), the United Kingdom (27%), Finland (25%) and Greece (25%) while the proportion of elderly car driver fatalities was the lowest in Romania (8%), Poland (10%), Latvia (10%) and Hungary (13%) (Figure A2.2 in Annex 2). A possible explanation for the differences in fatalities between the Eastern and other European countries is the lower degree of car ownership. For instance, the car ownership across all age groups ranges from 224, 301 and 305 cars per 1000 inhabitants in Romania, Hungary and Latvia to 621, 551, 525 and 464 cars per 1000 inhabitants in Italy, Finland, Germany and Sweden in 2011 (Eurostat, 2015c).

In general, the total number of elderly car driver fatalities has decreased between 2000 and 2013 by 28% while the total number of car driver fatalities decreased by 59% in the EU-27 (Figure A3.1 in Annex 3). Despite this decrease in the total number, the **proportion of elderly car driver fatalities increased by ± 9%** in the same period. In the last 13 years, the number and proportion of older elderly fatalities (75+ years) has also gradually increased to reach approximately the same level as the young elderly (65-74 years) car driver fatalities in 2013. On average, the proportion of both young and older elderly car driver fatalities was equal to ± 11% in 2013 (Table A3.2, Table A3.3 & Figure A3.2 in Annex 3). This trend indicates that more and more older elderly start to behave like their younger counterparts and continue to drive (cohort effect) (Hjorthol et al., 2010). This **cohort effect** combined with the **increased longevity in good health conditions** allows more elderly to use the car to meet their mobility needs. There are notable differences between Member States, Italy (14%) and Sweden (18%) have the highest proportion of young elderly fatalities while the proportion of older elderly fatalities is above average in Finland (15%), the United Kingdom (16%), Greece, Italy, the Netherlands, Sweden (all 14%), Austria, Germany, Spain (all 13%), and France (12%) (Table A3.2, Table A3.3 & Figure A3.2 in Annex 3).

The **fatality rate of elderly car drivers** (65+ years) is **1.07 times higher** when compared to the fatality rate of the entire EU-27 population in 2013. This fatality rate also increases with a higher age. As an example, the **young elderly car driver fatality rate is 0.97 times lower** and the rate **for older elderly car drivers equals 1.14 times** the fatality rate of the entire population (Table A3.4 & Figure A3.4 in Annex 3). Car drivers aged ≥ 75 years even have the third highest fatality rate of all age groups in 2013 (Figure A3.3 in Annex 3). For the EU-27 on average, the fatality rate of young and older elderly as car drivers is respectively 2.66 and 1.73 times higher than for elderly car passengers. The fatality rate of young-elderly and older elderly car drivers are respectively 1.03 and 1.25 times higher compared to the fatality rate of middle-aged car drivers (Table A3.4 in Annex 3). To summarize, **young and older elderly car drivers have an above average fatality risk in most EU Member States**. The EU-27 average of the young elderly fatality rate was equal to 16 fatalities per million inhabitants in 2013, with a range of 4 fatalities in the Netherlands to 34 fatalities in Croatia (Table A3.4 & Figure A3.4 in Annex 3). Young elderly car driver fatalities are also increased in Hungary, Austria, Sweden, Poland, France, Bulgaria, Finland, the Czech Republic, Italy and Greece, as well as in Slovenia and Luxemburg. The older elderly fatality rates ranged from 3 fatalities per million inhabitants in Slovakia to 39 fatalities per million inhabitants in Ireland, while the EU-27 average in 2013 was equal to 19 (Table A3.4 & Figure A3.4 in Annex 3). Austria, Belgium, Cyprus, Estonia, Finland, France, Greece, Croatia, Ireland, Italy and Latvia are also characterized by an intensified number of older elderly car driver fatalities.

### Car passengers

An analysis of the CARE database revealed that **elderly car passengers constituted 23% of all car passenger fatalities** in the EU-27 in 2013 (Table A4.1 & Figure A4.2 in Annex 4). The proportion of elderly car passenger fatalities was the highest in Greece (39%), Portugal (36%), Austria (35%) and Italy (31%) and the lowest in Romania (10%), Poland (15%) and the Czech Republic (17%). Although the **proportion of elderly car passenger fatalities has increased by 8%** in EU-27 from 2000-2013, the total number of elderly car occupant fatalities decreased by 44% (Figure A4.1 in Annex 4). On the other hand, the total number of car passenger fatalities in the EU-27 declined with 65%. In contrast to the elderly car driver fatalities, **the number and proportion of elderly car passengers is still higher for the older elderly (14%) than for the younger elderly (9%)** in the EU-27 in 2013 (Table A4.2, Table A4.3 & Figure A4.2 in Annex 4). As a result, it seems that the **age of 75 is a turning point for car mobility** at which some elderly because of health or other reasons decide to stop driving and take place in the car passenger seat or find their refuge in alternative modes. Greece (18%), Italy (13%), Sweden (13%) and Spain (12%) have the highest proportions of young elderly car passenger fatalities while the highest proportions of older elderly car occupant fatalities can be found in Portugal (29%), Austria (23%), Greece (21%) and the United Kingdom (20%) (Table A4.2, Table A4.3 & Figure A4.2 in Annex 4).

The fatality rate of car passengers gradually starts to increase at the age of 65 to twice this value at the age of 75+ (Figure A4.3 in Annex 4). As a consequence, **elderly car passenger occupants have the second highest risk to die in a traffic accident after passengers between the ages of 15-24**. Compared to the fatality rate of the middle-aged car passengers and the entire population, **the risk of being killed in an accident is respectively 2.30 and 1.60 times higher for the older elderly car passengers** (Table A4.4 in Annex 4). Compared to elderly bus passengers, the fatality rates of young and older elderly as car passengers are respectively 26 and 25 times higher in the EU-27 in 2013. Fatality rates of older elderly car passengers ranged from 3 fatalities per million inhabitants in Belgium to 21 fatalities per million inhabitants in Ireland and Portugal with an average rate of 11 fatalities per million inhabitants in the EU-27 in 2013 (Table A4.4 & Figure A4.4 in Annex 4). Austria, the Czech Republic, Denmark, Greece, Croatia, Hungary, Italy, Luxemburg, Latvia, Poland and Slovenia are also characterized by an increased number of older elderly car passenger fatalities. Fatality rates of young elderly car passengers ranged from 1 fatality per million inhabitants in the Netherlands to 16 fatalities per million inhabitants in Greece, while the EU-27 average was equal to 6 in 2013 (Table A4.4 & Figure A4.4 in Annex 4). Young elderly car passenger fatalities are also increased in Bulgaria, Estonia, Spain, Finland, Greece, Hungary, Italy, Luxemburg, Poland, Romania and Slovakia.

These higher fatality (and injury) rates of older car occupants are caused by their **physical frailty** which leads to more severe injuries at the time of the crash and reduced resilience in recovering from their injuries (CONSOL, 2013c; Li et al., 2003).

Their **over-involvement in more severe crash patterns** (i.e. angle crashes at intersections) and the indication that they tend to drive with older, used cars without the safety advantage of advanced passive safety measures also play a significant role (Choo & Mokhtarian, 2004; Koppel, Bohensky, Langford, & Taranto, 2011; Langford & Koppel, 2006a; McGwin & Brown, 1999; Oxley, Fildes, Corben, & Langford, 2006; Preusser, Williams, Ferguson, Ulmer, & Weinstein, 1998). However, the tendency to drive with older cars may change in the future. Results of the SARTRE 4 study indicated that older drivers are becoming more and more in favour of advanced passive and active safety devices compared to younger drivers because they perceive them more as a support than as an interference with their driving activity (SARTRE 4, 2012). In addition, elderly people can also afford to buy more expensive cars than their younger counterparts. Therefore, future generations of elderly drivers can or will also buy newer cars.

### 3.2.2 Characteristics and causes of accidents

#### Gender

For 2011-2013, **more than 80% of the young and older elderly car driver fatalities in the EU-27 were men** (Table A3.6 in Annex 3). The same distribution can be found for the middle-aged and the entire population of car drivers. Although, the majority of the older population is female (58% in EU-27 in 2013) (Eurostat, 2015a) and car ownership among **older women** has increased during the past decades (Hjorthol et al., 2010), they **are still less likely to hold a driving license** (Frändberg & Vilhelmson, 2011; Hjorthol et al., 2010; Li et al., 2012; Siren & Haustein, 2013). Nonetheless, older women are also identified as the fastest growing segment among car drivers in the future (Oxley et al., 2005). This future trend can already be observed in the female elderly car driver fatalities in some European countries. The highest proportions of young elderly female car driver fatalities occurred in Ireland and the Netherlands (both 44%) followed by Sweden, Denmark, France (all 32%) and the United Kingdom (30%) (Table A3.6 in Annex 3). For the fatalities among the older elderly female car drivers, the highest proportions are found in Ireland (41%) and the Netherlands (31%) (Table A3.6 in Annex 3). Romania, Croatia, Greece, the Czech Republic, Bulgaria, Poland, Spain, and Portugal were characterised by the lowest proportions of young and older elderly female car drivers, ranging from 0-10% (Table A3.6 in Annex 3).

On the other hand, **more than 70% of the young and older elderly car passenger fatalities in the EU-27 were women** (Table A4.6 in Annex 4). Several studies, also confirm that older women are more often passengers when travelling by car (Hanson & Hildebrand, 2011; Li et al., 2012; Rosenbloom, 2006; Siren & Hakamies-Blomqvist, 2006). The overrepresentation of older women as car passengers stems from the fact that **older women are more likely to give up driving when they are still fit to drive** (Bauer, Adler, Kuskowski, & Rottunda, 2003; Hjorthol, 2013; Siren, Hakamies-Blomqvist, & Lindeman, 2004; Siren & Haustein, 2014). For women, the main reasons are no experience in driving, feeling insecure, having a partner who drives while men have high confidence in their own driving skills and mostly give up driving because of health issues (Hakamies-Blomqvist & Wahlström, 1998; Hjorthol, 2013). The tendency for driving cessation maybe gender specific (Bernhoft & Carstensen, 2008) as the gender differences in confidence remain, even after controlling for driving experience and other background variables (D'Ambrosio et al., 2008). For the middle-aged category only half of the car passenger fatalities were female.

This gender effect also has an influence on the fatality rate of car occupants. **As elderly females are underrepresented as car driver fatalities, the fatality rate**

**of elderly male car drivers (65+) is 7 times higher in EU-27** (Table A3.7 & A3.8 in Annex 3). The fatality rate for young elderly male car drivers is 5 times higher and the rate for older elderly male car drivers even equals 9 times the fatality rate of their female counterparts (Table A3.9 in Annex 3). For the middle-aged group, the fatality rate of male car drivers is around 4 times higher compared to female car drivers (Table A3.7 & A3.8 in Annex 3). Further, the fatality rates of young and older elderly males as car drivers are 9.33 and 4.78 times higher than for elderly male car passengers. For the young and older elderly male car drivers the fatality rates are the highest in Portugal, Poland, Italy, Greece, Finland, Spain, Germany and the Czech Republic and the lowest in Slovakia, Malta, Ireland, Estonia, Romania, The Netherlands, Luxemburg, Hungary, Croatia, Denmark and Cyprus (Table A3.7 in Annex 3). Compared to the fatality rate of the middle-aged and all age groups, **elderly female car drivers even have a decreased risk to die in a road traffic accident**. Despite their lower fatality rate as car drivers, **older women** appear to **have a greater physical frailty** than older men. According to Meuleners et al. (2006), **increased frailty explains at least 50% of the excessive injury risk incurred by older female drivers**, while the relationship between injury risk and frailty was less obvious for older male drivers. So even though older females in general do not seem to drive very often, it appears that once they get behind the wheel and are involved in a crash they have a higher risk to be fatally or seriously injured. The higher than average fatality rates for both younger and older elderly female car drivers in Austria, the Czech republic, Germany, Spain, Finland, France, Greece, Italy, Poland, Portugal, Sweden, Ireland and the United Kingdom in 2013 illustrate this insight (Table A3.8 in Annex 3).

Conversely, **the fatality rate of elderly female car passengers (65+) is 2 times higher in EU-27 than for elderly male car passengers** (Table A4.7 & A4.8 in Annex 4). The difference between the fatality rates of male and female car passengers is less prominent for the older elderly. For example, the fatality rate for young elderly female car passengers is 3 times higher while the rate for older elderly female car passengers amounts to 1.33 times the fatality rate of their male counterparts (Table A4.9 in Annex 4). **Although the male fatality rate of car passengers approaches the female fatality rate in old age, older elderly female car passengers still have the highest fatality rate in the EU-27 with 12 fatalities per million inhabitants** (Table A4.7 & A4.8 in Annex 4). Kubitzki & Janitzek (2009) also found that older female car passengers are at much greater risk and have not equally benefited from the safety improvements in cars over the past decades. Additionally, the fatality rates of young and older elderly female car passengers are 1.50 and 2.40 times higher than for elderly female car drivers. Furthermore, the ratios of the young and older elderly female car passengers to all female car passenger fatalities also show that both elderly age categories have an above average fatality risk in most of the 27 EU Member states (Table A4.8 in Annex 4). Across all age groups, the fatality rates for male and female car passengers are the highest in Italy, Poland and Portugal. For the young and older elderly female car passengers the fatality rates are also increased in Finland, Spain, Germany and the Czech Republic while Slovakia, Malta, Estonia, The Netherlands, Croatia, Denmark and Cyprus have the lowest female fatality rates (Table A4.7 & A4.8 in Annex 4).

### Mileage

**People make fewer journeys as they age**, mainly because of **reductions in the number of work trips** (CONSOL, 2013a; DaCoTA, 2012a; Martensen, 2014; Whelan et al., 2006). The average length of all trips also decreases with increasing age (Whelan et al., 2006). In general, drivers with low annual kilometres have increased crash rates per kilometre driven compared to those who have larger annual kilometres. As a result, the **low mileage of older drivers may amplify older driver crash risk per driven kilometre** (Janke, 1991).

Conversely, the **age difference or effect disappears if driver groups with the same yearly driven kilometres are compared**. In that case, older and younger car drivers with low annual driven kilometres have more crashes per million driver kilometres than drivers in both age groups who travel more kilometres per year ( Hakamies-Blomqvist, Raitanen, & O'Neill, 2002; Langford, Methorst, & Hakamies-Blomqvist, 2006; Shinar, 2007). **The crash rate also appears to increase only for drivers who travel less than 3.000 km per year, and that rise is not observed until the age of 75** (Langford et al., 2006). Thus, older drivers as a group do not have a higher crash risk. If there is an older driver safety problem it can only be found in those who drive less than 3.000km annually and they represent **less than 10% of the older driver population** (Langford et al., 2006). Furthermore, the **elevated crash risk can also be biased by the location where the older driver crashes occur**. Many older drivers typically avoid driving on motorways, the safest roads, and tend to drive on **roads with intersections** which are in general less safe and more crash prone (Janke, 1991). Therefore, risk estimates for older drivers based on injuries or fatalities per kilometre driven will be overestimated when compared to those of younger drivers with higher annual kilometres on safer roads (OECD, 2001).

### Type of road

**Over 80% of the young and older elderly car driver fatalities in the EU-27 occur on non-motorways** (Table A3.10 in Annex 3). The same applies for the middle-aged car driver fatalities. However, there are considerable differences between Member States. Slovenia (46%) and the Netherlands (25%) had the highest share of young elderly car driver fatalities on motorways, followed by Spain (18%), Denmark (16%), and Croatia (15%). With respect to the older elderly, the highest share of car driver fatalities on motorways occurred in Portugal (20%), Spain (18%) and Slovenia (15%). The Netherlands (17%) and Spain (18%) also have the highest share of middle-aged car driver fatalities on motorways.

**The majority of the young and older elderly car passengers (± 80%) also die in crashes on non-motorways** (Table A4.10 in Annex 4). However, Spain (27%), Portugal (21%), the Netherlands (21%) and France (20%) had the highest share of young elderly car passenger fatalities on motorways between 2011 and 2013. The highest share of older elderly car passenger fatalities on motorways occurred in Bulgaria (25%), Denmark (19%) and Portugal (19%). The higher share of elderly car driver and passenger fatalities on motorways in several EU countries is related to the **greater density of the motorway network** in these countries. For example, The Netherlands and Slovenia have a dense motorway network of respectively ±6.0 and 3.0 km motorway per 100km² (Nicodème et al., 2012).

### Accidents in urban areas

There are more **young (23%) and older elderly car driver fatalities (23%) in urban areas** compared to middle-aged car driver fatalities (19%) (Table A3.11 in Annex 3). In Belgium, Italy, Croatia, Poland Portugal and Romania even 35% of the young and older car drivers die in crashes in urban areas. However, the **vast majority of the car driver fatalities for both elderly age groups (77%)** and the middle-aged (80%) still occurred in **rural areas** (Table A3.11 in Annex 3). This is most likely due to the **lack of car mobility alternatives** and the **greater distances** that elderly need to travel in rural areas to reach their destination. Additionally, the **higher impact and operating speeds in crashes at rural roads** also play an important role in the number of elderly car occupant fatalities.

Car driver fatalities for all ages ranged to 80% and over in rural areas in Austria, Germany, Denmark, Spain, Finland, France, Sweden, United Kingdom, Bulgaria, Ireland and Slovakia. Conversely, the **proportion of young (19%), older elderly (22%)** and middle-aged (19%) **car passenger fatalities in urban areas** is quite similar (Table A4.11 in Annex 4). And for all age groups the highest proportions (around or over 30%) of car passenger fatalities in urban areas are found for Poland, Portugal, Romania and Slovakia. Additionally, Greece, Italy and the Czech Republic are also characterised by higher proportions of young and older elderly car passenger fatalities in urban areas.

### Accidents at intersections

By comparison with the middle-aged car driver fatalities (11%), **young (16%) and older (24%) elderly car driver fatalities are overrepresented in crashes at intersections** (Table A3.12 in Annex 3). The proportion of older elderly car driver fatalities at intersections is remarkably higher than for young elderly and the highest shares could be observed for Denmark (52%), Czech Republic (40%), Poland (41%) and the United Kingdom (48%). **Also significantly more young (20%) and older elderly (21%) car passengers die in crashes at intersections compared to the middle-aged (14%) car passenger fatalities** (Table A4.12 in Annex 4). However, there are considerable differences between Member States. In Austria, Belgium, the Czech Republic, Denmark, Estonia and the United Kingdom over 30% of young and older elderly car passenger fatalities died in crashes at intersections compared to around 10% of the elderly car passenger fatalities in Romania.

Langford & Koppel (2006a) confirm that **older drivers are more likely to experience difficulties in crossing intersections**. The main issue is that the **complexity of the driving task** conflicts with **age-related impairments** such as declining vision, perception, cognitive functioning and physical abilities (Koppel et al., 2011; Oxley et al., 2006). For example, older drivers have difficulties in selecting safe gaps in conflicting traffic because they are less able to correctly estimate the speed of approaching vehicles (Oxley et al., 2006). They overestimate the speed of vehicles driving at slow speeds, and underestimate the speed of vehicles driving at higher speeds (Scialfa, Guzy, Leibowitz, Garvey, & Tyrrell, 1991). However, older drivers' overrepresentation in intersection crashes is also partly attributable to **exposure patterns** since their choice to avoid motorways results in greater exposure to intersections than is the case for middle-aged drivers (Langford & Koppel, 2006). Intersection crashes also seem to increase more frequently with age (Kubitzki & Janitzek, 2009). **Drivers aged 65-69 and 85+ are respectively 2.26 and 10.62 times more at risk of being involved in multiple vehicle crashes at intersections than middle-aged drivers between 40 and 49 years** (Preusser et al., 1998). Furthermore, older drivers are more likely to be involved in crashes at **intersections only controlled by stop or give-way signs** because they tend to drive and accelerate slower than other drivers (Langford & Koppel, 2006). This might lead to dangerous situations when interacting at these intersections because other drivers might incorrectly interpret the slower speeds as an intention to give way (Keskinen, Hatakka, & Katila, 2001).

The **main crash types** at these stop or give-way sign controlled intersections are **failing to yield** when they want to enter the intersection or **making an improper left turn** (McGwin & Brown, 1999; Preusser et al., 1998). In line with their greater propensity to be involved in intersection crashes; they are more than twice as likely than middle-aged drivers to be involved in conflicts in which they turned left into the path of an oncoming vehicle from the opposite direction, they are more than twice as likely to be involved in right-angle conflicts at intersections; and they are five times more likely to be involved in conflicts in which one vehicle turned right into the path of another vehicle that was proceeding straight through the intersection (Langford & Koppel, 2006).

### Self-regulation

**Older drivers self-regulate their driving** by reducing their overall amount of driving, reducing their speed, and avoiding driving in difficult situations such as: driving at night; at rush hour and in dense traffic; at complex intersections and at motorways; driving in bad weather; at unprotected left turns; for long distances; in unfamiliar areas; and parallel parking (Anstey & Smith, 2003; Baldock et al., 2006; Ball et al., 1998; Charlton et al., 2003; D'Ambrosio et al., 2008; Donorfio et al., 2009; Holland & Rabbitt, 1992; Molnar et al., 2014; Molnar & Eby, 2008; Raitanen, Törmäkangas, Mollenkopf, & Marcellini, 2003; Rimmö & Hakamies-Blomqvist, 2002). The aforementioned situations are all examples of **self-regulation at the strategic level** i.e. the planning stage of the trip. At the **tactical level** i.e. while driving, older drivers tend to self-regulate by leaving greater distances between their car and a lead vehicle; by avoiding in vehicle distractions such as talking on a cell phone, reading a road map, conversing with passengers and personal grooming (Molnar et al., 2013).

However, **a lack of insight into possible cognitive, sensory or physical limitations may constitute a risk factor for poor driving performance and crash risk** (Anstey, Wood, Lord, & Walker, 2005) while older drivers who compensate for their driving problems can reduce their crash involvement (De Raedt & Ponjaert-Kristoffersen, 2000). **Self-perceptions of confidence or (dis)comfort** in specific traffic situations functions as an indirect self-monitoring of the ability to participate in traffic and affects self-regulation (Baldock et al., 2006; Meng & Siren, 2012). According to Baldock et al. (2006) **older drivers self-regulate in a manner consistent with driving ability but only for a small number of specific situations in which they have low confidence and which they can easily avoid**. In their study, they found an association for three situations: driving in the rain, driving at night and driving at night in the rain. Overall, there seems to be some evidence to indicate that functionally impaired elderly road users self-regulate their participation in traffic.

Still, **for self-regulation to be an effective strategy to reduce crash involvement without unnecessary restricting mobility, greater self-regulation needs to be practiced by those with greater deficits in driving abilities** (Baldock et al., 2006). Unfortunately, this mechanism is not used by all impaired elderly road users. **Some older road users continue to participate in traffic 'in spite of everything'. They do not recognize and accept their limitations, still have high confidence in driving alone and thus do not perceive their risk accurately** (Baldock et al., 2006; Matthews, 1986). Therefore, creating a better awareness among the elderly of health and medical conditions and functional abilities that affect their driving, and the adoption of self-regulation strategies will be a key policy priority in the future. Especially, since it is speculated that **future cohorts of women** who have been driving most of their lives while have more driving experience and confidence in their own driving skills compared to current cohorts. Therefore, Kostyniuk and Molnar (2008) predict that future cohorts of older women may be less inclined to adopt self-regulation strategies since the perceived level of confidence in own driving skills and different traffic situations restrains the motivation to self-regulate.

### Crash type and manoeuvre before crash

Compared to middle-aged car driver fatalities, younger and older elderly car occupant fatalities in the EU-27 are underrepresented in single-vehicle and head-on crashes (Figure A3.6 in Annex 3 & Figure A4.6 in Annex 4). This underrepresentation is caused by the **risk-aversive behaviour** of older road users as these crashes can be typically regarded as "violation crashes" caused by risky behaviour such as speeding, inappropriate speeds, risky overtaking and alcohol consumption (DaCoTA, 2012a; Daigneault, Joly, & Frigon, 2002; Eby et al., 2009). However, **involvement in fatal rear-end and angle crashes increases with old age in the EU-27** (Figure A3.6 in Annex 3 & Figure A4.6 in Annex 4). This is related to the higher share of left-turning manoeuvres or normal driving circumstances that preceded the fatal crashes with older car occupants in the EU-27 between 2011 and 2013 (Figure A3.5 in Annex 3 & Figure A4.5 in Annex 4). These findings are supported by Langford & Koppel (2006a) and Koppel et al. (2011) who note that **older drivers are more likely to be involved in multiple-vehicle crashes when compared to younger drivers**. The older drivers' movements immediately prior to the crash were most likely driving straight ahead (i.e. normal driving) and turning left (Eby et al., 2009; Koppel et al., 2011; Langford & Koppel, 2006). This is mainly a consequence of their high involvement in intersection crashes (Langford & Koppel, 2006). In these multiple vehicle crashes, older car occupants are more likely to sustain **severe head and chest injuries** (i.e. multiple rib fractures, sternum fractures and internal organ injuries) than their younger counterparts (Koppel et al., 2011; Welsh, Morris, Hassan, & Charlton, 2006). The elderly's lower injury tolerance for chest injuries indicates the significance of an intelligent restraint system that is adaptable to the injury tolerance of car occupants (Welsh et al., 2006).

Older drivers also have a **higher risk of crashing with vulnerable road users** (Ewert, 2012; Martensen, 2014; Pottgiesser et al., 2012). This is most likely the result of their exposure pattern; that is they drive more often in urban areas were the probability to encounter vulnerable road users is increased. Moreover, **perceptual limitations** (i.e. decreases in visual acuity and contrast sensitivity) may also cause that vulnerable road users are not always visible for the older driver (Charlton et al., 2010; Pottgiesser et al., 2012).

Also typical for **older drivers** is that they are, compared to middle-aged drivers, **more likely to be at fault in crashes due to a higher error-rate in their traffic decisions** (CONSOL, 2013a; Cooper, 1990; Hakamies-Blomqvist, 1993; Kubitzki & Janitzek, 2009). Direction and lane control, decision-making, recognizing and responding to signs and visual checking and physical control are the most prevalent driving errors among older drivers (Vichitvanichphong, Talaei-Khoei, Kerr, & Ghapanchi, 2015). Cicchino & McCartt (2015) also identified **driver error as the contributory factor in 97% of older driver crashes**. The main issue is that when older drivers make an error, it is more difficult for them to regain control over the situation by making the right decisions (i.e. error recovery) (Vichitvanichphong et al., 2015). These errors are not made deliberately but are mostly **the consequence of age-related functional impairments**. Older drivers with sensory, physical and cognitive declines are more likely to be at-fault in crashes than drivers without these declines (Eby et al., 2009).

**Despite their higher at-fault rate in crashes, older drivers pose relatively small risks to crash-related morbidity and mortality** (Dellinger, Kresnow, White, & Sehgal, 2004). Older drivers even appear to be more at risk themselves because they are more susceptible to injuries (DaCoTA, 2012; Eberhard, 2008; Langford, Bohensky, Koppel, & Newstead, 2008). It is even more likely that it is the older driver and the occupant in the older drivers' vehicle, also frequently a senior, who dies in fatal crashes with older drivers (Braver & Trempel, 2004). Dellinger et al. (2004) also noted that deaths among other road users decreased with increasing driver age. For instance, drivers aged 16 to 19 were responsible for 63.1% of fatalities to others; ages 20 to 34, 68.1%; ages 35 to 59, 66.6%; ages 60 to 74, 52.2%; ages 75 to 84, 37.9%; and ages 85+, 18.9%. Hence, drivers in younger age groups pose a greater crash-related morbidity and mortality risk to others than older drivers.

### Risk-taking behaviour

**Elderly drivers are less prone to show risky behaviours**. Older drivers adopt a **more defensive driving style** by driving with lower average speeds (Chipman, MacGregor, Smiley, & Lee-Gosselin, 1992) and keeping larger following distances (Rajalin, Hassel, & Summala, 1997). Additionally, they are less likely to drink-drive ( Langford & Koppel, 2006), be engaged in drowsy driving (Levin, Dukic, Henriksson, Mårdh, & Sagberg, 2009) and more likely to wear a seat belt (Langford & Koppel, 2006; Martensen, 2014; Mizenko, Tefft, Arnold, & Grabowski, 2014). However, **young elderly drivers tend to underestimate their own limitations** and are less risk aversive than older elderly drivers (Pottgiesser et al., 2012).

The risk-aversive behavior of elderly drivers is confirmed by the findings of the SARTRE 4 study (SARTRE 4, 2012). With respect to **speeding**; older drivers held a more negative attitude with 1% of the older drivers (65+) indicating that they had the intention to speed compared to 10% of the younger drivers (18-24 years). Older drivers also hold a more positive attitude (82% compared to 69% of the younger drivers) towards increased penalties and are convinced that is less likely for them to be checked for speeding (65% compared to 50% of the younger drivers) (SARTRE 4, 2012). There are however, notable differences between countries since drivers across all age groups in Poland, the Czech Republic and Estonia have a stronger positive attitude towards speeding. Regarding **drink-driving**; the SARTE 4 study revealed that the odds of being drunk over the legal limit and driving decreases by 23% for drivers ≥ 65 compared to drivers aged 17 to 24 (SARTRE 4, 2012). Country variations also indicate that drink driving in general is more prevalent in Belgium, Cyprus, France, Italy and Spain (SARTRE 4, 2012). Another study also confirmed that more older (79%) than younger (54%) drivers use **seat belts** all the time (Shinar, Schechtman, & Compton, 2001). However, the findings of SARTRE 4 (2012) and Shinar (2001) are based on self-reports. Therefore, it should be kept in mind that the above mentioned results may be influenced by response bias.

Compared to middle-aged drivers, older drivers are also **less likely to be engaged in distracting activities while driving**, such as reading and sending text messages, calling on the mobile phone or adjusting in-vehicle equipment (Fofanova & Vollrath, 2011; McEvoy, Stevenson, & Woodward, 2006; Mizenko et al., 2014). However, this does not mean that **older drivers** do not engage in distracted driving. Between 1995-1999, 52.2% of the older American drivers (65+) were not attentive **at the time of the** crash with **7.9% of them being distracted** (Stutts, Reinfurt, Staplin, & Rodgman, 2001). Most strikingly, the **share of distracted older drivers (70+) at the time of the crash even increased to 14% between 2000-2003** (Stutts et al., 2005). These studies even found no significant differences between young and older drivers (Stutts et al., 2001; 2005).

A recent study examining older driver engagement in distracting behaviours, identified that older drivers were more frequently involved in the following secondary activities when the vehicle was in motion: scratching/grooming (42.5%), talking/singing (30.2%) and manipulating the vehicle control panel (12.2%) (Charlton, Catchlove, Scully, Koppel, & Newstead, 2013). Engagements in secondary tasks such as reading, reaching for an object and using a mobile phone only occurred while the vehicle was stationary (Charlton et al., 2013). Interestingly, older drivers were very selective in engaging in these secondary activities. **They adjusted their involvement according to the roadway/driving situations**, supporting the notion that drivers self-regulate by engaging in secondary tasks less frequently when the driving task is more challenging compared with less challenging manoeuvres (Charlton et al., 2013). Nonetheless, **elderly drivers still make significantly more at-fault safety errors when being distracted** than middle-aged drivers, indicating that their driving performance is stronger affected by the engagement in secondary tasks (Thompson et al., 2012). Additionally, elderly distracted drivers also drive slower than middle-aged distracted drivers in order to mitigate the negative effects of distracted driving on driving safety (Horberry, Anderson, Regan, Triggs, & Brown, 2006).

### 3.2.3 Areas of Improvement and Suggested Countermeasures

For reducing the accident risk of **elderly drivers** some areas of improvement are:

- Improving roadway design, especially at intersections in urban areas,
- Installing/improving traffic signalization and improving guidance in urban networks,
- Increasing conspicuity of pedestrians and cyclists,
- Improving education and training of older drivers to assess their driving capabilities and limitations,
- Raising awareness for physical and cognitive deficiencies.

The non-motorway road network and especially **urban road networks and intersections** increase the accident risk for older car users. To mitigate this risk, recommendations include:

- Provision of non-skewed intersections
- Longer acceleration/deceleration lanes on motorways
- Construction of roundabouts
- An unobstructed view on the intersection in urban and rural areas

Regarding **traffic control at intersections**, some effective countermeasures are:

- Installation of traffic signals with improved /optimized phases and timings
- Protected signal phases for left turns and pedestrians
- Better lighting and conspicuity at intersections and crossings
- Advanced warning signs in urban and rural areas (dynamic speed limits, variable sign messages etc.)
- Improved luminance of marking and signs

Countermeasures **to raise awareness** for older drivers should target the following:

- The effect of functional limitations (cognitive, sensory, physical) on abilities
- Their increased vulnerability and the importance of using protection devices
- The influence of age-related illnesses and prescribed medication on driving abilities
- Assistance in the possible decision to no longer drive a car
- How and where to seek and access mobility alternatives for the car

**Educational countermeasures** should include formal courses or communications provided directly to older drivers or to families, friends, and organizations that deal regularly with older drivers, training and rehabilitation programs for:

- Developing strategies for defensive driving and self-regulation
- Inform and train older road users about new traffic rules and situations and road layouts in urban and rural areas
- Provide refresher courses on traffic rules in urban and rural areas
- Assess their ability to drive

### 3.3 Powered two-wheelers

This section describes the current road safety situation of elderly users of powered two-wheelers. For this purpose, the European accident database and relevant literature are consulted. The crash data extracted from the CARE database can be found in Annex 5.

#### 3.3.1 Accident statistics

**Elderly moped and motorcycle users**, together referred to as Powered Two-Wheelers (PTW), **accounted for 7% of all PTW fatalities** in the EU-27 in 2013 while they make up ± 18% of the total EU-27 population (Eurostat, 2015a) (Table A5.1 & Figure A5.2 in Annex 5). There are considerable differences between European countries. For example, the highest share of elderly PTW fatalities in 2013 could be observed in Portugal (17%), the Netherlands (16%) and Slovenia (14%) while the proportion was the lowest in Belgium, Finland, Croatia, Poland and the United Kingdom (all 3%). In the past 13 years, the total number of elderly PTW fatalities has decreased by 38% while the proportion slightly increased with 0.25% (Figure A5.1 in Annex 5). In contrast, the total number of PTW fatalities fell by 40% in the EU-27. The number and proportion of elderly PTW fatalities is slightly higher for young elderly (4%) than for older elderly (3%) in the EU-27 in 2013 (Table A5.2, Table A5.3 & Figure A5.2 in Annex 5). Portugal (13%), Sweden and the Netherlands (both 9%) have the highest proportions of young elderly PTW fatalities while the highest proportions of older elderly PTWs can be found in the Netherlands (7%) and the Czech Republic (8%).

Across all age groups, **the fatality rate of PTW users sharply rises to peak at the age of 20-24 and then gradually falls to reach the second lowest value at the age of 65 and older** (Figure A5.3 in Annex 5). In the EU-27, compared to the fatality rate of the middle aged PTW users and the entire population, **the risk of being killed in an accident as a PTW user is 2 times lower for the young and 3 times lower for the older elderly age groups** (Table A5.4 & Figure A5.4 in Annex 5). Fatality rates for young elderly PTW users range from 2 fatalities in Finland, Poland, Hungary and the United Kingdom to 18 fatalities per million in habitants in Greece whereas the EU-27 average equals to 4 in 2013 (Table A5.4 & Figure A5.4 in Annex 5). The EU-27 average for older elderly fatality rates was equal to 3 fatalities per million inhabitants in 2013, with a range of 1 fatality in Belgium, Hungary, Sweden and Romania to 9 fatalities in Greece (Table A5.4 & Figure A5.4 in Annex 5). Moreover, PTW user fatality rates of all ages (and thus not only the young and older elderly) were also increased Slovenia, Portugal, Greece, Italy and Austria. This indicates that PTWs are more popular in Southern European countries.

#### 3.3.2 Characteristics and causes of accidents

##### Gender

**The share of female fatalities in the young and older elderly PTW users is very low (6%)** in the EU-27 between 2011 and 2013 (Table A5.6 in Annex 5). This low share (6%) of female fatalities under the PTW users is also present among the middle-aged category. The proportion of female fatalities in the young and older elderly PTW users is the highest in France (17 and 19%) and the Netherlands (11 and 25%). For the middle-aged PTW users, the highest proportion of female fatalities could be found in Belgium (12%), Denmark, France and the Netherlands (all 9%). Across all age groups, the fatality rate of female PTW users is very low in EU-27 (Table A5.8 in Annex 5).

**On average, the fatality rate of male PTW users is the highest in the middle-aged group (17), followed by the young elderly (9) and the older elderly (8)** (Table A5.7 in Annex 5). **Compared to their female counterparts, the fatality rates of middle-aged, young and older elderly male PTW users are respectively 12, 20 and 26 times higher** (Table A5.9 in Annex 5). The highest fatality rates for the middle-aged, young and older elderly male PTW users are found in Portugal, Poland, Italy, Greece, Spain, Germany and the Czech Republic. This indicates that PTWs are a popular transportation mode in Southern European countries and are more often used by males.

#### Type of road

Around **85% of all fatalities** in the EU-27 among the young, older and middle-aged PTW users fell in traffic accidents on non-motorways (Table A5.10 in Annex 5).

#### Accidents in urban areas

**43% and 38% of the young and older elderly PTW fatalities died in traffic accidents in urban areas** (Table A5.11 in Annex 5). For the middle-aged group, this share amounted to 35%. Romania (74%), the Netherlands (68%), Portugal (67%), Italy (57%) and Greece (56%) had the highest share of young elderly PTW user fatalities in urban areas while the United Kingdom (92%), France (78%), Spain (76%), Austria (78%) and the Czech Republic (70%) had more young elderly fatalities in rural areas. For the older elderly PTW user fatalities, the highest proportions in urban areas could be found for Romania (89%), the Netherlands (75%), Portugal (66%) and Poland (60%) while Spain (89%), France (75%), Germany (68%) and Italy (61%) had the highest fatality share in rural areas.

#### Accidents at intersections

**27% and 31% of the young and older elderly fatalities died in traffic accidents at intersections** compared to 22% of the middle-aged fatalities (Table A5.12 in Annex 5). The Netherlands (53%), Italy (39%), Portugal (33%), and Austria (39%) had the highest share of young elderly PTW user fatalities at intersections. For the older elderly PTW user fatalities, the highest proportions at intersections could be found for the Netherlands (58%), Spain (52%), Poland (43%) and Portugal (42%).

#### Manoeuvre before crash

Before the fatal crash, young and older elderly PTW users mostly intended to turn left or were driving in normal circumstances (Figure A5.5 in Annex 5).

#### Crash type

Compared to middle-aged PTW users (15%), **young (16%) and older elderly (20%)** fatalities are **overrepresented in head-on crashes**. The share of fatalities in angle and rear-end crashes is similar for the middle-aged and elderly PWT users (Figure A5.6 in Annex 5).

### 3.3.3 Areas of Improvement and Suggested Countermeasures

**Powered two-wheelers** are an extremely vulnerable class of road users. Age-related factors that increase accident risk include the road type and the crash type. Possible areas of improvement include:

- Rural/urban network design and specific intersection characteristics,
- Urban traffic channelization,
- Well-maintained roadway conditions.

Regarding **roadway design**, PTW accident risk is positively influenced by interventions in the framework of "**self-explaining and forgiving roads**". Measures may include:

- Signposting of speed limits at dangerous spots in curves,
- Installation of rumble strips,
- Clarification / highlighting of longitudinal roadway arrangements,
- Enhanced lane separation by floor markings and better signage on curves.

The **forgiving roads concept** includes interventions such as:

- Elimination of dangerous obstacles in bends,
- The provision of full paved shoulders,
- PTW dedicated technical standards for road restraint systems, wire rope barriers, under-ride barriers for guardrails, the installation of guide posts made of flexible material etc.

Moreover, **intersection-level countermeasures** should also address:

- Entry angles at intersections and roundabouts,
- Provision of advanced stop lines.

**Traffic channelization** may be achieved with the construction of separate lanes for PTW traffic.

Finally, **measures to improve roadway conditions** include:

- Increased skid resistance,
- Removal of roadway debris from the roadway and roadside,
- Maintenance of roadway surfaces in work zones.

## 3.4 Pedestrians

This section describes the current road safety situation of elderly pedestrians. For this purpose, the European accident database and relevant literature are consulted. The crash data extracted from the CARE database can be found in Annex 6.

### 3.4.1 Accident statistics

In 2013, **2.350 elderly pedestrians were killed** in traffic accidents**, which is 44% of all pedestrian fatalities** while they account for ± 18% of the total EU-27 population (Eurostat, 2015a) (Table A6.1 & Figure A6.2 in Annex 6). There are notable differences between EU countries, ranging from values around 20-35% in Poland and the United Kingdom to over 50% in Greece, France, Germany, Portugal, Finland, Spain, Austria and Italy. In the period 2000-2013, the total number of elderly pedestrian fatalities fell by 36% whereas **the proportion of elderly pedestrian fatalities increased with 7%** (Figure A6.1 in Annex 6). On the other hand, the total number of pedestrian fatalities in the EU-27 declined with 46%. Furthermore, the **number and proportion of pedestrian fatalities is higher for the older elderly (75+ years) than for the young elderly (65-74 years)**: approximately 29% of all pedestrian fatalities in 2013 in the EU were older elderly while the younger elderly accounted for 15% (Table A6.2, Table A6.3 & Figure A6.2 in Annex 6). There are also considerable differences between the Member States, but in all Member States the proportion of older elderly fatalities is significantly higher than for younger elderly. Italy (44%), Austria (43%), Finland (41%) and the Netherlands (41%) have the highest proportions of older elderly fatalities (Table A6.3 & Figure A6.2 in Annex 6).

In general, the **pedestrian fatality rate strongly increases with age**; from a slight increase in the age group 65-69 to twice this value for ages 75-79 and even three times this value for ages 80-84 (Figure A6.3 in Annex 6). As a result, **the elderly have the highest pedestrian fatality rates of all age groups**. The primary cause of this higher fatality rate is **the increased fragility** of the elderly. Compared to younger adult pedestrians, the increased physical vulnerability of older pedestrians leads to an over-involvement in serious injury and fatal crashes and underrepresentation in minor severity crashes (Oxley et al., 2004). Another significant contributory factor is that **more drivers give up driving as age increases**. A very likely consequence of this decision is a modal shift among the older elderly from driving to unprotected and less safe transportation modes such as walking. Additionally, **older pedestrians appear to be one of the road user groups who are at greatest risk while simultaneously representing the lowest risk to others** (Kubitzki & Janitzek, 2009).

The **fatality rate of elderly pedestrians (65+ years) is 2.4 times higher** when compared to the fatality rate of the entire EU-27 population in 2013 (Table A6.4 & Figure A6.4 in Annex 6). This fatality rate also increases with a higher age. As an example, **the young elderly pedestrians' fatality rate is 1.6 times higher** and **the rate for older elderly pedestrians even equals 3 times** the fatality rate of the entire population (Table A6.4 & Figure A6.4 in Annex 6). Compared to elderly car occupants, the fatality rates of young and older elderly pedestrians are 1.06 and 1.84 times higher in the EU-27 in 2013.

On country level, the rate for young elderly ranges from 2 pedestrian fatalities per million inhabitants in the Netherlands to 68 and 67 pedestrian fatalities per million inhabitants in Latvia and Romania, while the EU-27 average is equal to 17 (Table A6.4 & Figure A6.4 in Annex 6). Young elderly pedestrian fatality rates are also increased in Bulgaria, Cyprus, the Czech Republic, Estonia, Spain, Greece, Croatia, Hungary, Ireland, Luxemburg, Malta, Poland, Portugal and Slovakia. For older elderly, the rate ranges from 11 pedestrian fatalities per million inhabitants in Sweden to 108 and 100 pedestrian fatalities per million inhabitants in Bulgaria and Romania, whereas the EU-27 average equals 35 (Table A6.4 & Figure A6.4 in Annex 6). The pedestrian fatality rate for this age group is also higher than average in Austria, Cyprus, the Czech Republic, Estonia, Greece, Croatia, Hungary, Italy, Latvia, Malta, Poland, Portugal and Slovakia.

### 3.4.2 Characteristics and causes of accidents

#### Gender

On average and across all age groups (i.e. not only for elderly) male pedestrians fatalities are higher than female pedestrian fatalities. However, the **share of female pedestrian fatalities in the EU-27 starts to increase with a higher age** and more or less approximates the share of male pedestrian fatalities. For example, 27% of the middle-aged pedestrian fatalities were female from 2011-2013 in the EU-27 compared to 43% and 49% of the pedestrian fatalities among the young and older elderly (Table A6.5 & A6.6 in Annex 6). This indicates that the share of female pedestrian fatalities is much higher in old age. With regard to the young elderly, the share of female pedestrian fatalities exceeds the proportion of male pedestrian fatalities in Belgium, Bulgaria, the Czech Republic, Finland, France, the Netherlands, Portugal and Slovenia. For the older elderly, the share of female pedestrian fatalities is higher compared to the share of male pedestrian fatalities in Austria, Belgium, Croatia, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, the Netherlands, Poland and Slovakia.

It appears that **elderly females have a higher vulnerability as pedestrians**; women over the age of 70 even have been found to be the most vulnerable with respect to severe accidents (Li et al., 2012). This is also reflected in the fatality rates. The **fatality rate of young elderly female pedestrians is 2 times higher** when compared to the fatality rate of the entire EU-27 population in 2013 (Table A6.8 in

Annex 6). For **older elderly female pedestrians this rate is even 4 times higher** (Table A6.8 in Annex 6). For **male pedestrian fatalities**, **this rate is respectively 1.5 and 3 times higher for the young and older elderly** (Table A6.7 in Annex 6). The fatality rates for young and older elderly females as pedestrians are respectively 1.50 and 6.40 times higher than for elderly female car occupants. The situation is entirely different for elderly males. In that case, the fatality rates of young and older elderly pedestrians are 1.32 and 1.04 times lower than for elderly car occupants. The higher pedestrian fatality rate of older females, might result from the fact that they show less connection to the private car and rely more on other transportation modes such as walking or public transport (CONSOL, 2013a, 2013c; Whelan et al., 2006).

### Type of road

**Over 88% of the elderly pedestrian fatalities occur on non-motorways** (Table A6.10 in Annex 6). This is of course related to the lack of pedestrian facilities in the vicinity of motorways.

### Accidents in urban areas

The **majority of pedestrian fatalities** among the **young (77%) and older elderly (86%) occur in urban areas** (Table A6.11 in Annex 6). This is related to the fact that most pedestrian trips typically occur in urban environments.

However, around one third of the young elderly pedestrian fatalities in Belgium, Bulgaria, Finland, Denmark, Estonia, Hungary, Austria, Spain, Sweden, the Netherlands, the Czech Republic, Latvia and Slovenia take place in rural areas. **The death to injury ratio for pedestrians is estimated to be three times higher in rural than in urban areas because of the higher operating and impact speeds** (Lamm, Choueiri, Mailänder, Choueiri, & Choueiri, 1993). As people age, they are also much more likely to die at lower impact and operating speeds due to their fragility. **Older pedestrians in particular are more likely to suffer severe injuries at lower impact speeds** (Davis, 2001). The probability to die increases from 0.05 at 50 km/h, 0.10 at 60 km/h to 0.4 at 80 km/h for children and young adults. For older pedestrians the probability to die is higher at all speed limits: 0.60 at 50 km/h, 0.90 at 60 km/h and 1 at 70 km/h (Davis, 2001).

### Accidents at intersections

**Around 20% of the young and older elderly pedestrian fatalities occur on intersections** compared to 15% of the middle-aged fatalities (Table A6.12 in Annex 6). The United Kingdom (49%), The Netherlands (47%) and Denmark (33%) had the highest share of young elderly pedestrian fatalities at intersections while Portugal (10%), Slovakia (11%) and France (12%) had the lowest share. For the older elderly pedestrian fatalities, the highest proportions at intersections could be found for the United Kingdom (61%), Denmark (55%), the Netherlands (45%), and Austria (39%), whereas Romania and Slovenia (both 13%) had the lowest share. The Netherlands and the United Kingdom also had the highest proportion of middle-aged pedestrian fatalities at intersections.

The involvement of older pedestrians in intersection crashes stems from their **reduced ability to handle complex traffic situations**. For instance, they have problems when crossing wide streets or intersections because of their slower walking speeds and difficulties with simultaneously scanning the different directions of the traffic environment (Carthy, Packham, Salter, & Silcock, 1995). Additionally, they also experience difficulties with assessing traffic in the furthest carriageway (Oxley, Fildes, Ihsen, Charlton, & Day, 1997). **Crossing at signalized crosswalks** is also quite challenging because the walk phases are often too short for the elderly to safely complete the crossing manoeuvre and the signal phases are often confusing (Oxley et al., 2004). The elderly as pedestrians are overinvolved in crashes at every type of intersection except for intersections with traffic signals and roundabouts (Martensen, 2014; Martin et al., 2010). **Unsafe driver behaviour** may contribute to the overrepresentation of older pedestrian crashes at intersections. For example, older pedestrians trust that drivers will respect their right of way (Oxley et al., 2004), causing them to fail to check for oncoming traffic or following other pedestrians without checking for hazards (Mathey, 1983).

Finally, older pedestrians also experience great difficulties in interacting safely at intersections because the **design features of these locations are not explicitly adjusted to age-related functional declines** (Oxley et al., 2004).

### Self-regulation

**Older pedestrians compensate for age-related functional declines** by selecting very large gaps, avoiding complex traffic situations, only crossing at formal pedestrian crossings and planning their walking routes in function of the presence of the pedestrian crossing facilities (Bernhoft & Carstensen, 2008; Oxley et al., 2004). They also adopt a **more defensive behaviour at pedestrian crossings** by allowing significantly more motor vehicles and bicycles to pass before they start their crossing manoeuver (Kubitzki & Janitzek, 2009). Probably, they act in this way because it makes them feel safer and more secure. This will be especially the case **for older women** as recent evidence by Bernhoft & Carstensen (2008) suggest that they often question their own skills, whereas older men feel more confident. The **elderly also put more value on pedestrian facilities** because they are convinced that it is dangerous to cross the road in the absence of these facilities (Bernhoft & Carstensen, 2008).

### Crash type and manoeuvre before crash

The majority of the **young and older elderly pedestrian fatalities (±90%) occur in crashes in which the elderly pedestrian is hit by another vehicle** (Figure A6.5 & A6.6 in Annex 6). This results from the fact that elderly pedestrian fatalities, in the EU-27 between 2011 and 2013, are overrepresented in accidents in which they initiated a crossing manoeuvre. This is confirmed by Fildes et al. (1994), Koepsell et al., (2002) and OECD (1998) who found that a **large proportion of older pedestrian crashes** still **occur at signalized or marked pedestrian facilities**. Even after controlling for confounding factors such as pedestrian and vehicle volumes and site characteristics, **crosswalk markings lead to a 2.1 times increased crash risk for older pedestrians** (Koepsell et al., 2002). A possible explanation is that marked crosswalks give older pedestrians a false sense of security in believing that drivers notice them and will yield.

Older pedestrians also appear to be hit more often than younger people while drivers were turning left, reversing or taking an evasive action and when they are boarding or exiting public transport (Koepsell et al., 2002; Martin et al., 2010; Oxley et al., 2004; Oxley et al., 1997). **The most common pedestrian crash is an elderly pedestrian that is struck side-on by the front of a vehicle** (Oxley et al., 2004). Their most frequent collision partners in these crashes are drivers of heavy goods vehicles [RR = 1.90 (1.45–2.60)], followed by car drivers [RR = 1.01 (0.98–1.05)] and drivers of public service vehicles [RR = 0.46 (0.32–0.67)] (Martin et al., 2010).

Additionally, compared to the middle-aged (6%), **young (10%) and older (12%) pedestrian fatalities** in the EU-27 **are also overrepresented in single-pedestrian accidents** as a result of falling (Figure A6.6 in Annex 6). These single-pedestrian accidents affect significantly more older road users than any other accident type (Feypell, Methorst, & Hughes, 2012) because the elderly experience more **difficulties** than younger adults **in maintaining postural stability and balance** (Oxley et al., 2004). Therefore, older pedestrians have a **higher risk of falling**, stripping or stumbling while walking, especially on uneven surfaces (Oxley et al., 2004). Approximately, one third of pedestrian fatalities and three quarters of injuries across all age groups are caused by falls in public places (International Transport Forum, 2012). A Swedish study, also revealed that **single-pedestrian accidents start to increase from the age of 42 with a peak for people over the age of 75** (Larsson, 2009). **Women** in particular seem to be overrepresented in these accidents (Larsson, 2009; Stevens & Sogolow, 2005). These pedestrian-only causalities are mostly caused by slipping, stumbling or tripping in the absence of ice or snow (Larsson, 2009). **Upper limb (33%), head (21%) and face or neck (18%) injuries are very common for pedestrian only events while lower limb injuries are more common for older pedestrians struck by vehicles** (Oxley et al., 2004). Older pedestrians not struck by vehicles also have lower rates of fractures (intracranial and other injuries) compared to those who are involved in pedestrian-vehicle events (Oxley et al., 2004).

### Risk taking behaviour

In general, **older pedestrians are more cautious** compared to younger age groups. For instance, elderly pedestrians almost never cross at a red light, return in a non-signalized crossing and always choose to walk to a pedestrian crossing if they can see one (Bernhoft & Carstensen, 2008). However, sometimes they also cross the street at their present position, irrespective of the nearby presence of a crossing facility because they have a good overview of the traffic situation, the traffic volumes are low at that time, to avoid a detour or for a specific reason (e.g. getting to a bus stop or shop) (Bernhoft & Carstensen, 2008). The latter two motives are typical for elderly with poor health conditions. Furthermore, alcohol does not seem to be a causal factor in older pedestrian crashes (Martin et al., 2010; Oxley, Corben, Fildes, O'Hare, et al., 2004).

Despite, the elderly's attempt to compensate for age-related changes, it becomes **more difficult to safely cross the road as age increases**. Unknowingly, their road crossing behaviour even puts themselves at risk. Compared to younger pedestrians, older pedestrians spent more time to leave the kerb, need longer walking times and apply shorter safety margins between them and approaching vehicles reaching the crossing point (Oxley et al., 2004). These behaviours are the result of **age-related declines**. For example, older road users have difficulties in estimating the speed of oncoming vehicles due to declines in motion and depth perception abilities (Dommes, Cavallo, Vienne, & Aillerie, 2012). They try to take their **slower walking speeds** into account but still overestimate their own speed and underestimate the speed of oncoming vehicles. **Dense and complex traffic situations** can also compel the elderly to take more risks when crossing because the elderly need more time to initiate actions and to get an overview of the situation (Liu & Tung, 2014; Zivotofsky, Eldror, Mandel, & Rosenbloom, 2012). **Because older pedestrians are afraid of falling, they mostly look to the ground when crossing and as such pay less attention to the surrounding traffic** (Ewert, 2012). They are also frightened to be involved in a crash caused by their personal limitations. As a result they trust in the traffic regulations and reside in their beliefs that everyone obeys these rules which might give them a false feeling of security and increased crash risk (Stahl, 1991 cited in Oxley et al., 2004). Older pedestrians also have the **tendency to wear dark clothes**, especially in winter, which can reduce their visibility (Oxley et al., 2004).

### 3.4.3 Areas of Improvement and Suggested Countermeasures

**Older pedestrian safety** may be significantly enhanced through interventions targeting the following:

- Reducing interactions between pedestrians and other road user types,
- Reducing the average speed of motorized traffic at locations with high pedestrian flows,
- Improving the conspicuity of pedestrians for drivers,
- Improving the perception of elderly pedestrians about other road users.

Interactions between pedestrians and other road users may be reduced through the **physical separation of flows in urban areas** using for example raised planter boxes and outdoor seating and the use of wider sidewalks.

At **intersection level**, roadway design and signalization play a critical role to pedestrian safety. Some critical interventions are:

- Adjusting the traffic signals to allow for the slower walking speed of elderly pedestrians in urban areas,
- Use of exclusive pedestrian signal phases,
- Use of protected phases during signalization,
- Pedestrian islands or sidewalk extensions in urban areas.

Moreover, **roundabouts** have a positive impact to safety especially when constructing large splitter islands, banning parking near roundabouts, using adequate street lighting, speed reduction installations, reduced width of circular carriageway, as well as increased deflection and improved signing.

**Free-vehicle zones in urban areas or traffic calming measures** reduce speeds and contribute to the safety, comfort, and attractiveness of neighbourhoods which again determines environmental-related and safety-related walking conditions for elderly. **Out-of-vehicle ITS applications** have the potential to enhance speed limit compliance. These applications include dynamic messaging, in the form of active speed warning signs and variable message signs.

Regarding **conspicuity**, measures should target:

- Lighting at intersections and pedestrian crossings
- Installation of conspicuous 'give way to pedestrian' signals
- Reflective pavement markings

Regarding **behavioural factors**, for example risk taking behaviours such as the inability to scan and react properly to urban areas and so on, successful countermeasures may include:

- Educational campaigns to promote the use of specialized clothing
- Educational campaigns to increase the awareness of age-related cognitive and sensory declines
- Inform and train pedestrians about the proper search behaviour on the road or related to novel traffic rules, situations and road layouts in urban and rural areas

## 3.5 Cyclists

This section describes the current road safety situation of elderly cyclists. For this purpose, the European accident database and relevant literature are consulted. The crash data extracted from the CARE database can be found in Annex 7.

### 3.5.1 Accident statistics

In 2013, **elderly cyclists** accounted for **39% of all cyclist fatalities** while they make up ± 18% of the total EU-27 population (Eurostat, 2015a) (Table A7.1 & Figure A7.2 in Annex 7). The share of elderly cyclist fatalities ranges from 10-30% in Spain, Latvia, Portugal and the United Kingdom to over 45% in Austria, Belgium, Cyprus, Germany, Denmark, Croatia, Italy and the Netherlands. From 2000-2013, the total number of elderly cyclist fatalities fell by 25%, while the total number of cyclist fatalities decreased by 39% in the EU-27 (Figure 7.1 in Annex 7). Furthermore, the **proportion of elderly cyclist fatalities increased by 7.5%** in the same period (Figure 7.1 in Annex 7). The number and proportion of cyclist fatalities is slightly higher for the older elderly (22%) than for the younger elderly (17%). Except for the United Kingdom, Romania, Portugal, Poland and Latvia, the proportion of older elderly cyclist fatalities is significantly higher than for younger elderly (Table A7.2 & Figure A7.2 in Annex 7). Austria (38%), the Netherlands (34%), Germany (31%), Sweden and Belgium (both 29%) have the highest proportions of older elderly fatalities (Table A7.3 & Figure A7.2 in Annex 7).

The cyclist fatality rate gradually increases with age; from a slight increase in the age group 60-64 to 1.4 times this value for ages 65-69 and even twice this value for ages 75-79 (Figure A7.3 in Annex 7). The primary cause of this higher fatality rate is the **increased fragility** of the elderly and the fact that cycling is a favourite leisure activity of the elderly. The **fatality rate of elderly cyclists** (65+ years) is **2.15 times higher** when compared to the fatality rate of the entire EU-27 population in 2013 (Table A7.4 in Annex 7). This fatality rate also increases with a higher age. As an example, the **young elderly cyclist fatality rate** is **1.80 times higher** and the rate for **older elderly cyclists** even equals **2.53 times** the fatality rate of the entire population (Table A7.4 in Annex 7). Several studies investigating the effects of age on cyclist fatality and serious injury risk found that **older cyclists** have an **increased fatality risk** compared to young cyclists, irrespectively of international variability in cycling rates (CONSOL, 2013a; Oxley et al., 2004). The trend between 2001-2010 indicates that the bicycle in the EU is getting safer for all ages, but to a greater extent for younger people (Candappa et al., 2012).

On country level, the young elderly fatality rate ranges from 1 cyclist fatality per million inhabitants in Greece to 20 cyclist fatalities per million inhabitants in Poland, while the EU-27 average is equal to 7 (Table A7.4 & Figure A7.4 in Annex 7). Young elderly cyclist fatality rates are also above average in Austria, Belgium, Cyprus, the Czech Republic, Germany, Denmark, Estonia, Croatia, Hungary, Italy, Latvia, the Netherlands, Romania, Slovenia and Slovakia.

For the older elderly, the rate ranges from 1 cyclist fatality per million inhabitants in the United Kingdom to 31 cyclist fatalities per million inhabitants in the Netherlands, whereas the EU-27 average equals 10 (Table A7.4 & Figure A7.4 in Annex 7). The cyclist fatality rate for this age group is also higher than average in Austria, Belgium, Bulgaria, the Czech Republic, Germany, Denmark, Finland, Croatia, Hungary, Poland, Romania, Slovenia and Slovakia. Besides an increased fatality risk, the **injuries of older cyclists** also appear to be of a **more severe** nature than for younger cyclists. To illustrate, a Dutch study revealed that **hospital admissions** due to cycling crashes **increased with age**, from 25% for 50-54 year olds to 45% for the older elderly (75+ years) (Kingma, Duursma, & ten Duis, 1997). **Lower extremity injuries in the form of fractures are also more typical amongst older cyclists** (51%) than for younger people (15%) who suffer more upper extremity injuries (Oxley et al., 2004).

### 3.5.2 Characteristics and causes of accidents

#### Gender

Approximately **80% of the cyclist fatalities** among the **young and older elderly** were **male** in the EU-27 between 2011 and 2013. As a consequence, the **average fatality rate for young and older elderly males** in the EU-27 in 2013 **is 5 times the female cyclist fatality rate** within the same age categories (Table A7.9 in Annex 7). These higher fatality rates of elderly men, are caused by fact that cycling is a specific leisure-related activity related to the retirement age of men (Kubitzki & Janitzek, 2009). The same distribution can be found for the middle-aged cyclist fatalities.

In contrast, for young elderly, the share of female fatalities is the highest in Finland (69%), Austria (39%), the Netherlands (36%), Hungary (34%), Poland and Sweden (both 31%). With regard to older elderly, the proportion of female fatalities is the highest in Denmark (48%), Sweden (38%), the Netherlands (36%), Finland (33%) and Germany (32%) (Table A7.6 in Annex 7).

Nevertheless, the fatality rates of elderly male and female cyclists are quite similar. For the **young elderly male and female fatalities this rate is approximately 2 times higher** compared to the fatality rate of the entire EU-27 population whereas **the rate is 2.3 and 3 times higher for the older elderly females and males** respectively (Table A7.7 & A7.8 in Annex 7). On average in the EU-27, the fatality rates of young and older elderly males as car occupants are respectively 2.07 and 2.40 times higher than for elderly male cyclists. For females, the fatality rates of young and older elderly car occupants are 3 and 1.25 times higher than for elderly cyclists.

#### Type of road

Over **90%** of the **elderly cyclist fatalities occur on non-motorways** (Table A7.10 in Annex 7). This is of course related to the lack of cycling facilities in the vicinity of motorways.

#### Accidents in urban areas

The **majority of cyclist fatalities** among the **young (59%) and older elderly (65%)** are an **urban phenomenon** (Table A7.11 in Annex 7). In Davidse et al. (2014) it is stated that two thirds of the older cyclist crashes occur on an urban road with 50% of these crashes occurring on a 30 km/h road and the other half taking place on the bicycle facility near a 50 km/h road. A Dutch study (Goldenbeld, 1992) also found that approximately 20% of all crashes with older cyclists were collisions with other cyclists and moped riders in urban areas. Even though, **rural cyclist crashes** are rare events among the elderly, it appears that a large share (≥ 50%) of the young and older elderly cyclist fatalities in Belgium, the Czech Republic, France, Portugal, Spain and The United Kingdom occur in rural environments (Table A7.11 in Annex 7).

#### Accidents at intersections

Approximately **30% of the young and older elderly cyclist** fatalities in the EU-27 **occur at intersections** (Table A7.12 in Annex 7). The Netherlands (59%), Austria (46%), Hungary (45%), Denmark (44%) and Italy (41%) had the highest share of young elderly cyclist fatalities at intersections while France (18%) had the lowest share. For the older elderly cyclist fatalities, the highest proportions at intersections could be found for the Netherlands (62%), Denmark (62%) the United Kingdom (56%), Belgium (53%), and Hungary (50%) whereas France (20%) had the lowest share. The Netherlands and Denmark also had the highest proportion of middle-aged cyclist fatalities at intersections. It is also remarkable, that **intersections are more hazardous for elderly and middle-aged cyclists than for other transport modes while over 50% of the cycle accidents occur elsewhere** (Candappa et al., 2012). **Fatal cycle crashes** at intersections mostly occurred when the **older cyclist approached a priority road** from a side road and **tried to cross** a multi-lane road with busy traffic (Goldenbeld, 1992).

**Declines in physical and cognitive abilities influence the older cyclist's skills to safely negotiate intersections**. This includes for example, slower cycling speeds, difficulties in controlling a bicycle (i.e. keeping track and balance), controlling conflicts with other road users and with decision making in complex traffic environments. These **age-related functional declines combined with inappropriate intersection design features** such as inadequate sight distances; lack of refuge islands, the absence of signals to control turning movements, etc. **play a significant role in the higher crash rates of older cyclists** (Oxley et al., 2004). A particular difficult situation for older cyclists at intersections is a turning vehicle failing to give way (Oxley et al., 2004). The **instability difficulties** of older cyclists even become very problematic when they are mixed with motorized traffic (Oxley et al., 2004). Finally, the elderly are also very skill-full in finding the easiest and most direct routes and prefer to keep their cycling momentum even when negotiating intersections (Oxley et al., 2004).

### Self-regulation

**Older cyclists** may also tend to **self-regulate** by avoiding complex traffic, planning cycling routes and selecting very large gaps in traffic while crossing (Oxley et al., 2004). Furthermore, older cyclists consider themselves to be very good in avoiding risks, even more so than younger cyclists. However, they also feel somewhat insecure on electric bikes. Subsequently, **older cyclists tend to cycle slower** than their younger counterparts, both on e-bikes as on regular bikes. Both younger and older cyclists adjust their speed when a task becomes difficult and they do this more strongly on the e-bike than on a regular bike (SWOV, 2014).

### Crash type and manoeuvre before crash

**The majority of the young and older elderly fatalities (36%)** in the EU-27 **occurred in angle crashes** (Figure A7.6 in Annex 7). This stems from the fact that elderly cyclist fatalities, in the EU-27 between 2011 and 2013, are overrepresented in accidents in which they intended to turn left (Figure A7.5 in Annex 7). This is supported by Goldenbeld (1992) and Bernhoft, Hansen, Johansen, & Larsen, (1993, cited in Bernhoft & Carstensen, 2008) who found that **older cyclists are overinvolved in crashes in which they attempted to cross the road or turned left at intersections**. Additionally, they were also involved in crashes on straight roads when they turned left and were hit from behind by a car (Goldenbeld, 1992). These crashes occurred in the following circumstances: the cyclist did not cycle on the separate cycle path near the road and neglected to indicate the intended left turn. Kubitzi and Janitzek (2009) also found that **older cyclists are more often at fault in crashes due to right-of-way and turning errors**. Furthermore, **older cyclists often do not watch out for traffic from behind** and have **problems with manoeuvring** their bicycle (Bernhoft et al., 1993, cited in Bernhoft & Carstensen, 2008). Several other factors also contribute to the occurrence of older cyclist crashes. For example, the behaviour or presence of another road user who forced the older cyclist to act which (in)directly led to a crash or fall (Davidse et al., 2014). Distraction and in particular **'narrow focus'** also plays an important role. In this case, the older cyclist is so focused on the cycling task that he misses other elements in the traffic environment which contributed to the crash (Davidse et al., 2014). Additionally, **narrow cycle lanes** give the older cyclist not enough space to swerve, overtake or safely pass an object (Davidse et al., 2014; Oxley et al., 2004).

**Elderly cyclists** are also **overrepresented in bicycle to car crashes** and compared to other age groups they also face the highest fatality rates in these crashes (Bíl et al., 2010; Goldenbeld, 1992; Oxley et al., 2004). A lot of severe injury crashes with cyclists also involve collisions with vehicles at intersections (Klop & Khattak, 1999; Räsänen & Summala, 1998).

**Non-vehicle collisions or single-cyclist crashes are also typical for the elderly**. These crashes are predominantly the result of falling over while (dis)mounting, being surprised or startled by other road users and collisions with an off-road object ( Davidse et al., 2014; Martensen, 2014; Ormel, Klein Wolt, & den Hertog, 2009; Oxley et al., 2004). **The risk of falling or slipping is also significantly higher for elderly cyclists and their injury risk is even twice as high as for adult cyclists** (Oxley et al., 2004). This higher risk of falling or slipping might explain that ± 20% of the elderly cyclist fatalities occurred in normal cycling situations in the EU-27 between 2011 and 2013 (Figure A7.5 in Annex 7).

### E-bikes

E-bikes or pedelecs are a popular transportation mode among the elderly. These bikes provide elderly, even with impaired health, the opportunity to increase their mobility. Recent evidence from the Netherlands suggests that more elderly cyclists buy an e-bike and make more and longer trips than on a classic bike (Fietsberaad, 2013). This increased exposure may result in a growing number of causalities. **The injury risk of cyclists aged 75+ on e-bikes equalled twice the injury risk on classic bikes whereas the injury risk of cyclists until the age of 75 did not differ by bicycle type** (Fietsberaad, 2013).

Three factors may contribute to the assumed higher causality risk of elderly cyclists. Firstly, **e-bikes are approximately 10 kg heavier** than classic bicycles which might make (dis)mounting more problematic for elderly because of age-related stiffness (Vlakveld et al., 2015). As a consequence, **e-bike crashes are more often single-bicycle crashes due to falls** of e-bikers while (dis)mounting, riding in curves or overtaking (Schepers, Fishman, den Hertog, Wolt, & Schwab, 2014). Secondly, elderly **e-bike riders may have a frailer health condition** than elderly riders of classic bikes so that comorbidity between diminishing physical strength and cognitive functions cannot be eliminated (Vlakveld et al., 2015). This view is supported by McGough et al. (2011), who revealed that elderly aged 70 years or over with mild cognitive impairments also suffer from physical declines. Thirdly, **elderly ride faster on e-bikes**. In complex traffic situations they rode ± 1.7 km/h faster and in normal traffic situations they even rode 3.6 km faster on the e-bike than on the classic bicycle (Vlakveld et al., 2015). A consequence of these **higher speeds** is that the **injuries will be more severe** in case of a fall or collision. The **accident risk may also be increased** since **higher bicycle speeds** require **extra demands on information processing capacities and reaction times** to unexpected events or in complex situations (Aarts & van Schagen, 2006). Since elderly cyclists in general have a higher mental workload, their crash and injury risk on an e-bike may be higher than it already is on a classic bike due to the combination of higher bicycle speeds and mental workload. This will especially be the case in **complex traffic situations** such as turning left at intersections.

However, the **higher bicycle speeds of e-bikes** may also have **positive road safety effects**. For example, **cycling speeds will become more homogenous** if most elderly ride an e-bike and younger age groups keep cycling on classic bikes (Vlakveld et al., 2015). Subsequently, this can give rise to fewer collisions between bicycles. Finally, **exposure to unsafe situations will also decrease** as it for instance will take less time to cross an intersection (Vlakveld et al., 2015).

#### Risk taking behaviour

**Older cyclists more adhere to the traffic rules** than younger cyclists. Bernhoft and Carstensen (2008) found that elderly cyclists less often run red lights, ride on the pavement and ride in the opposite/wrong direction on the cycle path because it is not allowed and perceive these situations as too dangerous. Compared to younger cyclists, the **elderly** also **appreciate cycle paths and signalized intersections significantly more** as they are convinced that it is unsafe to cycle near or cross a road where these facilities are missing (Bernhoft & Carstensen, 2008). This feeling of unsafety leads to a very thorough planning of the elderly's cycle route to guarantee the presence of these facilities (Bernhoft & Carstensen, 2008). Alcohol is also an infrequent contributory factor in older cyclist crashes (Oxley et al., 2004).

However, the **cyclists' visibility appears to be a causal factor**. It has been reported that older people tend to wear darker clothes, particularly in winter, which can reduce their visibility even more (Oxley et al., 2004). **The risk aversive behaviour of the elderly most likely results from awareness of their limitations and doubting their abilities**. For example, elderly cyclists have slower cycling speeds and balancing problems due to functional declines (Davidse, 2002).

### 3.5.3 Areas of Improvement and Suggested Countermeasures

Areas that may need interventions to improve **older cyclists' safety** bare similarities with those of pedestrians. Possible areas of improvements include:

- Separation of traffic streams,
- Advanced design and traffic control at intersections to accommodate safe cycling,
- Perception/observation of cyclists by car drivers.

The **separation of traffic streams** may be achieved by cycle tracks which may lead to a significant reduction in accidents involving elderly cyclists.

Near **intersections**, the provision of safe stopping locations where the older cyclists have a good view on the intersection in urban and rural areas is recommended.

Improving the **conspicuousness of obstacles** for older cyclists may be achieved by:

- Removing obstacles (e.g. bollards, kerbs, bicycle track narrowing etc.) from cycle tracks and lanes,
- Placing red-white bollards, painting kerbs white, by enhancing clearness of the road's shoulder,
- Applying high contrast road markings on the side of the cycle path/road.

**Educational and training programmes** for enhancing the use of protective clothing, the awareness of cognitive declines due to age and for constantly checking and improving the cycling skills may also be considered.

## 3.6 Public transport users

This section describes the current road safety situation of elderly bus passengers. For this purpose, the European accident database and relevant literature are consulted. The crash data extracted from the CARE database can be found in Annex 8. Since the number of fatalities is very low for this road user type, the road safety situation will only be described at EU-level.

### 3.6.1 Accident statistics

**Elderly bus passenger fatalities** amounted to **26% of all bus passenger fatalities** in 2013 while they make up ± 18% of the total EU-27 population (Eurostat, 2015a) (Table A8.1 & Figure A8.1 in Annex 8). In general, the total number of elderly bus passenger fatalities has risen by 76% while the total number of bus passenger fatalities fell by 27% between 2000 and 2013 (Figure A8.1 in Annex 8). Subsequently, the increase in the absolute number of elderly fatalities has been accompanied by an **increase of 14% in the proportion of elderly bus passenger fatalities**. The number and proportion of elderly bus passenger fatalities was higher for the older elderly (15%) than for the young elderly (9%) in the EU-27 in 2013 (Table A8.2, A8.3 & Figure A8.1 in Annex 8). This trend has already been present since 2009. Most likely, some elderly decide to stop driving, walking or cycling around the age of 75 because of health or other reasons and try to fulfil their mobility needs by using public transport.

The **fatality rate of elderly bus passengers** (65+ years) is **1.27 times higher** when compared to the fatality rate of the entire EU-27 population in 2013 (Table A8.4 & Figure A8.2 in Annex 8). This fatality rate also increases with a higher age. As an example, the bus passenger fatality rate of young elderly is 0.90 times lower and the rate of older elderly equals 1.27 times the fatality rate of the entire population. The fatality rate of older elderly bus passengers becomes even more pronounced when compared to the fatality rate of middle-aged bus passengers since the older elderly fatality rate is 1.87 times higher.

### 3.6.2 Characteristics and causes of accidents

#### Gender

**Over 50%** of the young and older elderly bus passenger fatalities were **women** in the EU-27 between 2011 and 2013 (Table A8.5 & A8.6 in Annex 8). The same trend could be observed for middle-aged bus passengers. In general, public transport appears to be most commonly used by women and the older elderly (CONSOL, 2013c; INFAS & DLR, 2010; OECD, 2001; TØI, 2011; Whelan et al., 2006). Compared to older men, older women also become more dependent on public transport in transition from a two to a one person household (Stjernborg & Waara, 2010). This may be related to the fact that women in general depend more on others for their personal mobility (Siren & Hakamies-Blomqvist, 2006), the role of women throughout their course of life due to domestic responsibilities, the absence of a driving license or the fact that the household has only one car which is used by the partner (GOAL, 2013b).

Compared to the fatality rate of the middle-aged in 2013, **the fatality rate of bus passengers was the highest for older elderly males (2.78) and females (1.30)** (Table A8.7 & A8.8 in Annex 8). For older elderly males this fatality rate was 2 times higher than the fatality rate for females within the same age category (Table A8.9 in Annex 8). On the other hand, the fatality rate for younger elderly females was 1.5 times higher than the fatality rate of young elderly males (Table A8.9 in Annex 8).

#### Mileage

It appears that the number of elderly using public transport is increasing. For example, a recent travel statistics report of the United Kingdom indicates that public transport is becoming a frequently used transportation mode of the elderly (DfT, 2012). The number of elderly using public transport at least once a month or more even experienced a modest increase in the last decade (DfT, 2011). The growing number of elderly in the future in combination with the current increase in public transport usage, entails that adequate public transport alternatives need to be provided proactively in order to manage the increased number of elderly users in the (near) future.

### Type of road

As for the middle-aged category, the vast majority of young (76%) and older elderly bus passenger fatalities (94%) in the EU-27 fell in traffic accidents on non-motorways (Table A8.10 in Annex 8).

### Accidents in urban areas

Compared to the middle-aged (24%) bus passenger fatalities, 43% and 79% of the young and older elderly fatalities died in traffic accidents in urban areas (Table A8.11 in Annex 8). This stems from the well-developed public transport services in cities while these facilities are mostly unavailable in the countryside and the car is more important for mobility (SIZE, 2006).

### Accidents at intersections

24% and 33% of the young and older elderly bus passenger fatalities occurred at intersections compared to only 8% of the middle-aged fatalities (Table A8.12 in Annex 8).

### Self-regulation

Elderly bus passengers also develop and adopt **compensation strategies** for a safe mobility. Examples of self-regulation among elderly public transport users are: avoiding the bus at peak hours, combining trip purposes into one trip (e.g. combining a trip to the doctor in the city centre with shopping) and being early at the bus stop in order to avoid to hurry (Fiedler, 2007).

### Crash type and manoeuvre before crash

Young (30%) and older elderly (24%) fatalities are overrepresented in rear-end and single-vehicle crashes compared to middle-aged bus passenger fatalities (11%). A large proportion of older elderly fatalities also died in angle-crashes (Figure A8.4 in Annex 8). These crashes were mostly preceded by normal driving and stopping manoeuvres (Figure A8.3 in Annex 8).

### Non-collision bus injuries

The elderly suffer a higher proportion of injuries related to public transport. In the United Kingdom, bus and coach passengers aged 60+ are overrepresented in the injury figures (8.4%) while the injury rates for all ages are very low (2.7%) (Barnes et al., 2014). Older road users are also more susceptible for non-collision injuries on buses (Kirk, Grant, & Bird, 2003; Palacio, Tamburro, O'Neill, & Simms, 2009; Zegeer, Huang, Hummer, Stutts, & Rodgman, 1993). For example, a US study found that the **elderly comprised 36% of non-collision bus injuries** compared to 17% of collision injuries (Zegeer et al., 1993). These injuries typically occur during boarding and alighting (with more casualties when boarding than when alighting), harsh speed changes, while turning and are associated with slip or trip related falls (CONSOL, 2013e; Kirk et al., 2003; Palacio et al., 2009). Inappropriate acceleration and deceleration patterns, inappropriate design of the internal structure of buses with regard to injury prevention and injury severity as well as the design and protocols of entering and exiting the bus are the underlying causes of non-collision bus injuries (Palacio et al., 2009). These incidents also often lead to head and lower extremity injuries (Palacio et al., 2009).

Furthermore, **elderly women** appear to be especially at risk of being injured in a non-collision bus incident. This is most likely related to their travel frequency and to their greater physical vulnerability (Kirk et al., 2003). Standing passengers are also more likely to be seriously injured in a non-collision incident than sitting passengers (Kirk et al., 2003; Palacio et al., 2009).

### 3.6.3 Areas of Improvements and Suggested Countermeasures

Improvements dedicated **to public transport users** should focus on three areas:
- The accessibility to buses and trams,
- The approaches to ticketing,
- The interactions between the different modes.

Suggested countermeasures to **improve accessibility** include
- Low-floor buses and trams to facilitate kerbside access to these vehicles, handrails,
- Access ramps for wheelchairs,
- Walking frames and tactile paving,
- Audio messages should be used to support PT use,
- Directly and easily accessible bus stops from footpaths and/or to pedestrian networks.

Other radical interventions include:
- "**Service routes**", a concept aiming to minimize the distance to bus stops and remove stressful situations during boarding and alighting and to avoid crowding,
- "**Flex-route**" services, a combination of fixed-route service and demand-responsive, kerb-to-kerb service that are based on advanced booking approaches.

The use of **clear and legible signs**, along with audibly available information, should also be included at transit stops.

**Ticketing procedures** should be expanded to include smart "contactless" technologies or prepaid tickets mailed to a customer's residence.

The increased accident risk during the process of drop-off and boarding of public transport users should be mitigated through **educational campaigns** to raise awareness of both elderly and transit staff. **Training programs** should be drafted and put into practice to raise awareness of bus drivers to pay attention in order to avoid that the older road user falls/stumbles inside the bus.

## 3.7 Typology of risk factors

### 3.7.1 High-level analysis of risk domains

Risk factors can make a considerable contribution to crashes or injuries. However, it is not always straightforward to reduce or eliminate the negative effects of certain risk factors or domains. Elvik (2008) uses the term **'amenability to treatment'** to refer to the prospects of implementing measures that will reduce the size of the risk, or, at best eliminate the risk. In this project the amenability to treatment and/or importance of various risk domains for elderly road users are identified by combining information on the **magnitude of these risk domains** with information about the **level of public support for interventions** to address these risk domains.

Figure 7 shows such a combination for **thirteen risk domains for elderly road users** in Europe. The thirteen risk domains are urban roads, rural roads, transportation mode (car driver/car passenger/PTW-user/pedestrian/cyclist/public transport user), illnesses/functional limitations, medication, risk taking/distraction, self-regulation and fragility. The public support for each of the risk domains is shown on the horizontal axis. The higher the public support, the easier it is to implement acceptable interventions to reduce the risk domain. The vertical axis of the graph in figure 7 depicts the fatality risk attributable to each risk domain. This dimension indicates the importance of the risk domain in terms of the safety gains which can be achieved if the risk is reduced or eliminated.

Overall, the results of figure 7 suggest that a wide public support for interventions in a certain risk domain is no prerequisite for the importance or magnitude of this risk domain and vice versa. However, for most risk domains the relationship between importance/magnitude and public support appears to be quite consistent. Hence, the risk domains of elderly road users can be ranked based on their overall importance and public support (Table 7). The calculations for identifying the magnitude and public support of each risk domain can be consulted in Annex 9.

**Table 7: Ranking of various risk domains of elderly road users in Europe**

| Priority | Risk domains | PAR | Public support |
|---|---|---|---|
| 1 | Fragility | 62% | 100% |
| 2 | Illnesses/functional limitations | 42% | 55% |
| 3 | Urban roads | 39% | 54% |
| 4 | Pedestrian | 36% | 68% |
| 5 | Medication | 34% | 54% |
| 6 | Cyclist | 14% | 63% |
| 7 | Risk taking/distraction | 10% | 0% |
| 8 | Self-regulation | 8% | 47% |
| 9 | Car passenger | 3% | 42% |
| 10 | Car driver | 2% | 53% |
| 11 | Public transport user | 2% | 34% |
| 12 | Rural roads | 1% | 46% |
| 13 | PTW | -1% | 48% |

According to the ranking in table 7, **fragility, illnesses/functional limitations, urban roads, walking, medication and cycling are the most important risk domains for elderly.** This means that the highest safety gains for elderly road users can be achieved by implementing interventions to reduce or eliminate these risks. For example, with respect to the risk domain 'fragility', the number of fatal crashes could be reduced by 62% if the excessive risk of this risk domain is eliminated for older road users. Furthermore, interventions designed to reduce these risks also enjoy wide support indicating that it is the easier to implement acceptable interventions to interfere in these risk domains. To illustrate, 100% of the interviewees supports an intervention in the risk domain 'fragility' in order to increase the safety of elderly road users.

Safety gains can still be achieved by intervening in the risk domain 'self-regulation' and these interventions enjoy moderate support. To contrast, interventions in the risk domain 'risk-taking/distraction' also result in safety benefits but the public opinion does not support the implementation of interventions in this area. In this respect it becomes very difficult to implement acceptable interventions in order to reduce the effects of risk-taking/distraction.

Although interventions in the risk domains 'car drivers', 'rural roads', 'car passengers', 'Public transport users' and 'PTW-users' enjoy moderate public support, the safety benefits of intervening in these areas are very small.

The synthesis shows that the following **risk domains** require **prior attention** because they have the strongest impact on the reduction of serious traffic casualties among the elderly, and because they receive a strong support by the public in terms of countermeasures:

1. Fragility
2. Illnesses and functional limitations
3. Urban roads
4. Elderly pedestrians
5. Medication

The following sections provide a detailed description of the specific risk factors within each of the above mentioned risk domains for each group of elderly road users.

### 3.7.2 In-depth analysis of risk factors

The high-level analysis of risk domains only provides a general impression of the risks which threaten the road safety of elderly. Therefore, the following sections aim to provide a detailed overview of the most important risk factors for each group of elderly road users.

#### 3.7.2.1 Car occupants

The key risk factors of elderly car occupants (i.e. drivers + passengers) can be listed as follows:

- Elderly tend to drive with **older, used cars** equipped with less advanced passive safety measures compared to newer cars.
- **Rural environments** increase the crash risk due to the lack of car mobility alternatives and higher impact and operating speeds at rural roads.
- In **urban areas** the **complexity of the driving task** conflicts with **age-related impairments** such as declining vision, perception, cognitive functioning and physical abilities. This results in a high share of intersection crashes and collisions with vulnerable road users.
- Older drivers are overinvolved in intersection crashes, especially at intersections **controlled by stop or give-way signs**, because they fail to yield when entering the intersection or make an improper turn when turning left.
- **Functionally impaired elderly drivers** who lack insight into their cognitive, sensory or physical limitations do **not self-regulate** and pose risks to themselves and others because of their poor driving performance.
- Due to age-related impairments, **driver error** is the leading contributory factor in older driver crashes because they experience difficulties in applying error recovery strategies.
- Older drivers appear to be selectively engaged in **distracting behaviours** according to the roadway/driving situations. While being distracted they make significantly more at-fault safety errors than middle-aged drivers, indicating that their driving performance is stronger affected by the engagement in secondary tasks.

#### 3.7.2.2 Powered two-wheelers

The following risk factors are relevant for elderly PTW-users:

- **Urban areas** and **intersections** in particular increase the accident risk of elderly PTW-users. The most dangerous situation is turning left at intersections.
- The **limited protection** of moped riders, their **relatively low riding speeds** compared to other motorized modes combined with their **age-related fragility** are the driving factors for severe and/or fatal injuries.

#### 3.7.2.3 Pedestrians

The following risk factors play a notable role in the road safety of elderly pedestrians:

- The accident risk for elderly pedestrians is very high in **urban environments**. This is related to the fact that most pedestrian trips typically occur in urban environments.
- Elderly pedestrians are overinvolved in crashes at **intersections** because they experience greater difficulties in interacting safely since the design features of these locations are not adapted to their **age-related functional declines**. However, signalized intersections and roundabouts have a beneficial effect on their safety.
- A large share of crashes occurs on **pedestrian crossings**. The design features of the crossing facility have a substantial effect on the safety of elderly pedestrians. **Marked crossings** appear to induce higher risks than crossings without markings. **Crossings with traffic signals** also lead to higher crash risks since the walk phases are often too short for the elderly and the signal phases are often confusing.
- Due to **age-related physical declines, single-pedestrian crashes** as a result of **falling or stumbling** while walking are very common for elderly pedestrians, especially on uneven surfaces.
- Even at low impact and operating speeds, their **limited protection**, **slow walking speeds** and **age-related fragility** increase their risk of severe or fatal injuries when they are involved in collisions with motorized vehicles.
- **The road crossing behaviour** of the elderly also puts them at risk because they need more time to cross and apply shorter safety margins between them and approaching vehicles.
- Because of their personal limitations, elderly pedestrians fear to be involved in a crash. Therefore, they trust the **traffic regulations** and are convinced that everyone complies with these rules which results in an increased crash risk when another road user violates these regulations.
- Their tendency to wear **dark clothes** reduces their conspicuity, especially in winter.

#### 3.7.2.4 Cyclists

Several important risk factors for elderly cyclists are identified:

- The accident risk for elderly cyclists is evenly distributed over **urban and rural areas**.
- **Intersections** are dangerous locations for elderly cyclists although the majority of cycle crashes occur elsewhere. The most dangerous situation occurs when an older cyclist approaches an intersection and attempts to cross the road or turn left. Mixing cyclists with motorized traffic also increases the accident risk of elderly cyclists. The combination of **age-related functional limitations** and **inappropriate intersection design features** contributes significantly to their elevated risk.
- Elderly cyclists also experience difficulties with turning left, giving right of way and maneuvering their bicycle due to **age-related functional declines**.

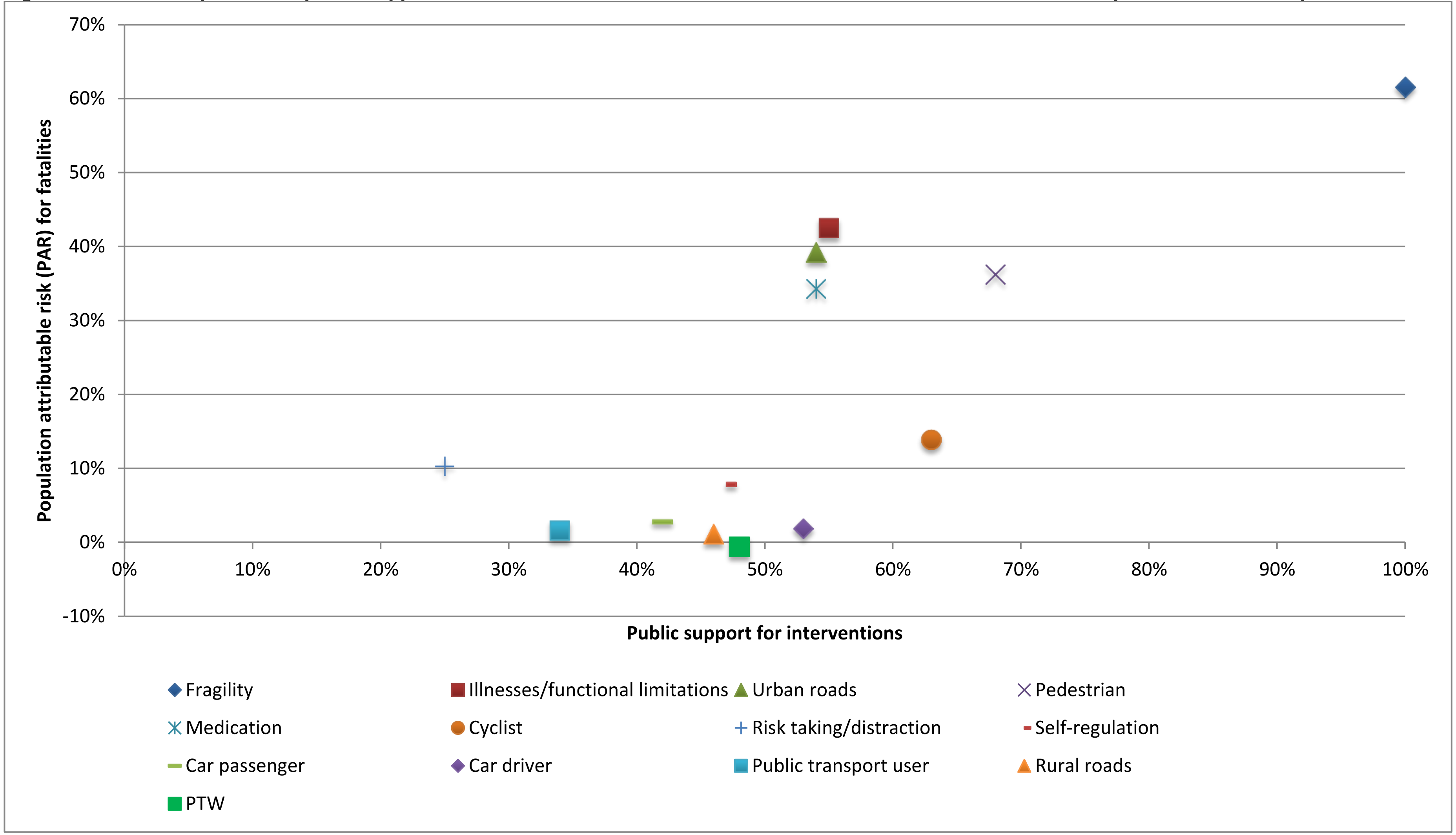
- **Narrow cycle lanes** also pose additional risks to elderly cyclists because they do not provide enough space to swerve, overtake or safely pass an object.
- **Age-related stability problems** of older cyclists lead to a higher share of **single-cyclist crashes** due to slips or falls.
- **Distraction** and especially '**narrow focus**' also contributes to crashes with older cyclists.
- The higher speeds and the increased weight of **e-bikes** result in more severe injuries in case of a fall or collision, especially in combination with the elderly's increased **fragility**.
- The conspicuity of elderly cyclists is reduced by their affinity to wear **dark clothes**.

#### 3.7.2.5 Public transport users

The following risk factors are important for elderly PT-users:

- **Urban areas** and **intersections** enhance the accident risk of elderly PT-users.
- **Non-collision bus injuries** are a particular hazard for the elderly. These injuries typically occur during boarding and alighting, harsh speed changes, turning manoeuvres and are associated with slip or trip related falls.
- The severity of these non-collision bus injuries is influenced by the **greater physical vulnerability** of the elderly and the **inappropriate design of the internal structure of buses** with regard to injury prevention.

**Figure 7: Relationship between public support for interventions and risk attributable to various risk domains of elderly road users in Europe**



# 4. Practices for improving the safety of elderly road users

The risk factor analysis in chapter 3 revealed that the **road safety of older road users** is significantly defined by their **age-related physical fragility** and **functional impairments**. Both risk factors contribute to the relatively high share of traffic fatalities among the elderly in two different ways. Functional impairments can increase crash risk while a higher physical fragility increases injury severity (DaCoTA, 2012a). These contributory factors combined with the expected demographic changes and the increasing mobility needs of the elderly requires a package of best practices or measures targeted at improving the road safety situation for different older road user groups. **In order to ensure the safety of older road users this package of measures should be composed in such a way that it includes the following aspects**:

- Infrastructural interventions
- Education & Training
- Licensing & Enforcement
- Vehicle & ITS technologies

Finally, this package of measures should be based on a **"design for all" approach**. This approach takes the specific needs, opportunities and limitations of different road users into account. As a result, these measures will not only enhance the road safety and mobility of the elderly; younger road users will also benefit from an age-friendly design.

## 4.1 Infrastructural interventions

One way to ameliorate older road users' safety is to **improve the roadway and driving environment** to accommodate the characteristics and needs of older drivers. Oxley, Langford, & Charlton (2010) underline that **current roadway design principles make few allowances for older drivers' performance**. Guidelines targeted to the safety of elderly road users have been drafted for the United States (Staplin, Lococo, Byington, & Harkey, 2001) and Australasia (Fildes, 1997). Several safety countermeasures have been proposed and evaluated with respect to their effect on older road users. These mainly include:

- Highway design parameters
- Design and operational aspects of rural and urban road networks
- Traffic control at intersections
- Road markings
- Lighting
- Route guidance and Signs

### 4.1.1 Highway design

#### 4.1.1.1 Longer acceleration and deceleration lanes on motorways

The decision making process, while entering and exiting highways, is significantly influenced by the age-related functional declines, such as systematic decline in visual acuity (Staplin et al., 2001). **Merging into traffic is more demanding for elderly** than for young drivers (de Waard, Dijksterhuis, & Brookhuis, 2009). Older drivers require approximately **twice the time** to process the vehicles at merging roadway conditions (Hills, 1975).

Staplin et al. (2001) provide the specifications for acceleration lane lengths; a parallel versus a taper design for entrance ramp geometry is recommended. **Longer acceleration lanes provide the older driver with extra time** to merge and at the same time reduce the time pressure. Unfortunately, no research is available concerning the minimal length of acceleration lanes necessary to accommodate older drivers (DaCoTA, 2012a). As far as **deceleration lanes** are concerned, it is important to **provide a good view on the approaching curve**. The acquired information gives the driver the opportunity to make the correct decision regarding braking and steering. The visibility of the curve can be improved by post-mounted delineators and chevrons (Staplin et al., 2001) (Staplin et al., 2001). To meet the needs of older drivers, the point of controlling the curvature on an exit ramp, as well as the advisory curve speed, must be highly conspicuous to create an appropriate expectancy of the required vehicle control actions (Staplin et al., 2001).

**Effectiveness**: According to a survey of older drivers, the length of freeway entry lanes is a highway feature that is more important to them now compared to 10 years ago (Benekohal, Resende, Shim, Michaels, & Weeks, 1992). de Waard et al. (2009), in a driving simulator experiment, showed that the existence of **driver support systems** and **extended acceleration lanes have positive effects for older drivers**.

#### 4.1.1.2 Lower design speeds on interurban connecting roads and motorways

The design speed is used to determine the various geometric features of the roadway. It is a fundamental aspect of highway design and is linked to concepts such as the minimum sight distance, the horizontal curve design criteria and so on (Montella, 2009; Wood & Donnell, 2014). **The relationship between speed and safety is influenced by factors such as the type of road, driver age and vehicle safety devices** (Wilmot & Khanal, 1999). Kanellaidis (1996) proposes a framework, which allows for the consideration of "non-design" road users, such as older drivers, and also incorporates checks for the overall safety of design as a feedback loop in the design process. It is recommended that in areas where there is a high concentration of **senior drivers**, it is **desirable to use the lower end of the speed range** in a particular roadway class (Staplin et al., 2001).

**Effectiveness**: Elvik et al. (2009) review the effects of design speed interventions on road safety. In general, low design speeds - when these are applied in long road sections – are found to lead to an increased number of accidents, due to the induced speed variations (Krammes, 1997). **In curves, reduced design speeds lead to fewer accidents and also reduces the accident severity** (Shankar, Mannering, & Barfield, 1995). No results are reported regarding the effectiveness of lower design speeds on older driver's safety.

### 4.1.2 Rural and Urban road networks

#### 4.1.2.1 Well-maintained road infrastructure in urban areas

To ensure that the maximum effect of infrastructure measures on road safety is achieved, infrastructure elements should be maintained at specified periods. **Well-maintained roadway markings** (e.g., painted edge-lines, lane control marking) can **enhance safety by providing visual cues to drivers** to help them to stay in their lane and to identify which lane they need to use. Improvements in roadway conditions can make the roadway infrastructure more forgiving to older drivers and pedestrians (NHTSA, 2008).

According to the GOAL project, **a well-maintained infrastructure for pedestrians includes** (GOAL, 2013c):

- Smooth and even paving (i.e. with few cracks, gaps, bumps or uneven texture, flat kerb edges, wide pavements and level or low gradients with no camber),
- Walkways free of obstacles (e.g. bins) and other hazards,
- Stable, firm and slip-resistant surfaces particularly against ice, snow or rain.

Other recommendations refer to clearing the road surface from sand, gravel and ice during winter, the provision of heated surfaces etc. (Oxley, Corben, Fildes, & Charlton, 2004).

**Well-maintained infrastructure is the key aspect of road safety**. PTWs are very sensitive to the road and traffic environment, including infrastructure design (e.g. alignment, curves, etc.), maintenance (holes, gravel, etc.), lighting and interactions with other road users (Vlahogianni, Yannis, & Golias, 2012). Haworth (2012) discusses a series of challenges related to PTW safety including infrastructure measures. PTW related countermeasures include skid resistance (i.e. magnitude and consistency), road surface testing, improvement of the transversal slope in curves, improvement of pavement friction on new asphalt, reduction of roadway debris from the roadway and roadside, maintenance of roadway surfaces in work zones (2BESAFE, 2012; ETSC, 2008).

**Effectiveness/ Cost-benefit Analysis:** A Swedish study among **pedestrians and cyclists involved in accidents** showed that the **condition of the road surface** was considered to be **a primary contributing factor** while important pedestrian and cyclists' routes should receive priority maintenance (Osberg, Stiles, & Asare, 1998). Osberg et al. (1998) also reported that **anti-skid surfaces reduced slipping dramatically**: only one in five pedestrian injuries occurred when surfaces were dry. Björnstig et al. (1997) also suggested to spread either sand or salt in areas with high incidences of slipping or to ensure that the snow is cleared.

The **design and maintenance of road infrastructure should be conducted holistically** to serve a variety of different means of transport and road users. In literature several measures have been implemented for increasing road safety, yet with conflicting outcomes. A typical example are various traffic calming measures; such as the use of raised lane markings, lane dividers, barriers and guardrails; which may be beneficial for passenger cars and pedestrians, but may have negative safety effects for PTWs (DaCoTA, 2012b).

Elvik et al. (2009) underline that the **benefit–cost ratio of general improvements of national highways ranges from 0.5 to 1**. Scully et al. (2008) reported significant reductions in PTW casualty crashes when treating for black spots. This intervention may lead to a benefit-cost ratio of about 15. Rizzi et al. (2011) state the effectiveness of smooth surfaces to fatal crashes.

#### 4.1.2.2 Right-angled junctions in rural areas

Conspicuity at intersections is significantly affected by the angle at which crossing streets meet. An angle less than 90 degrees significantly reduces visibility at the intersection and of other road users, especially for older drivers with reduced head and neck mobility. Therefore, a **right-angled junction is important for older road users** in particular (Staplin et al., 2001). In general, intersections where two approaches intersect at an angle of less than 60 degrees are considered as skewed.

For **older road users**, the **optimal angle** is one of **more than 75 degrees** (Staplin et al., 2001).

**Effectiveness/ Cost Benefit Analysis:** Elvik et al. (2009) summarized research on the effects of skewed approaches at junctions. Skewed junctions are the most problematic for older drivers (Fildes et al., 2000). Classen et al. (2007) evaluated the effectiveness of intersection design for senior adults and showed that **at improved non-skewed intersections older driver errors were significantly reduced compared to unimproved intersections**. Hauer (1988) reported that intersection channelization projects had an average benefit-cost ratio of 2.3.

#### 4.1.2.3 Unobstructed view on intersections in urban and rural areas

An obstructed or restricted view of the intersection is an additional difficulty for older road users (drivers, riders and pedestrians). **A restricted sight distance** or stopping sight distance **has more adverse consequences for older adult drivers** than for younger drivers, as they demand larger perception/reaction times than younger road users. Oxley et al. (2006) mention the **need to design based on longer sight distances** at intersections to accommodate older drivers by providing them more time to select a safe gap in which to turn across, enter or cross traffic. They proposed:

- Vegetation and roadside furniture (such as utility poles, signs),
- Adoption of design guidelines that specify higher values of perception–reaction time,
- Provision of offset turning lanes, gentle grades and horizontal alignment, advance warning signs at intersections with poor sight distance, and
- Speed reduction measures on intersection approaches.

On-road studies have found **age-related differences in the critical gap** for turning drivers ranging from 8.1s for young/middle-aged drivers to 10s for older drivers (Staplin et al., 2001).

**Effectiveness/ Cost-Benefit Analysis:** Sight distance improvements at intersections are the most **cost-effective interventions** with a benefit-cost ratio of 5.33 (Staplin et al., 2001). In a FHWA (1996) report, it is stated that improvements in intersection sight distance have a benefit-cost ratio of 6.1 in reducing fatal and injury crashes.

#### 4.1.2.4 Self- explaining and forgiving rural roads

**"The self-explaining road" concept** encapsulates **all possible aspects of road safety and infrastructure design to provide a simple and unambiguous, clear and understandable, readable and recognizable traffic situation** (Herrstedt, 2001). Examples of self-explaining and forgiving roads include visual flicker and visual narrowing of road lanes created by use of forgiving obstacles, reduced lengths and spacing of centre lines, rumbling road surfaces along edge and centre lines etc.

**Forgiving and self-explaining roads are rather complementary concepts**; self-explaining roads seek to prevent driving errors, while forgiving roads minimize their consequences (La Torre, 2012). **Forgiving roadsides aim to reduce the consequences of an accident caused by driving errors, vehicle malfunctions, or poor roadway conditions, as well as the severity of the crash**. In other words, the roadside should forgive the driver his/her error by reducing the severity of run-off-road accidents. Some features of forgiving roadsides are barrier terminals, rumble shoulder strips and forgiving support structures for road equipment.

Related to forgiving roads, barrier terminals—both energy-absorbing and non-energy-absorbing—are now standard practice on road networks. Literature indicates that improper installation or lack of maintenance was found to be the primary reason for unsatisfactory results in some applications (La Torre, 2012).

For PTWs, measures supporting the self-explaining nature of roads include signposting of speed limits at dangerous spots in curves, installation of rumble strips, clarification / highlighting of longitudinal roadway arrangements, enhanced lane separation by floor markings, elimination of sight barriers in curves and improving sight distances, predictable curvatures, transitional vs. circular bends (2BESAFE, 2012). For the forgiving nature of roads, some suggested countermeasures are (2BESAFE, 2012): the elimination of dangerous obstacles in bends, provision of full paved shoulders, technical standards for road restraint systems, wire rope barriers, under-ride barriers for guardrails and guide posts made of flexible material.

**Effectiveness:** Self-explaining and forgiving roads have a positive effect on accident rates and accident probability. Herrstedt (2006) reviews several relevant countermeasures and their effect on safety and concluded that physical dividers along centre lines on rural roads resulted in significantly reduced driving speeds, while the frequency of overtaking (legal and illegal) also decreased. Wiethoff et al. (2012) identified a series of **measures to treat road user errors and convert infrastructure to a more self-explaining and forgiving environment**, such as Navigational aid Variable message sign (VMS), VDS, Audio lane warning delineation, Electronic traffic signs, Rumble strips, VMS with fog warning. A preliminary multiple criteria analysis showed that different stakeholders will prefer different types of safety measures. Yet, no special treatment has been proposed for older drivers.

**Rumble strips** significantly reduce single-vehicle run-off-road accidents (Torbic, 2009). The risk associated with the use of 'passively safe' or 'forgiving' lighting columns resulted in a risk almost eight times lower than that associated with conventional unprotected columns (Williams, Kennedy, Carroll, & Beesley, 2008).

**Restraint mechanisms** on the road have been found to be extremely effective with regards to road safety (Bambach, Mitchell, & Grzebieta, 2013): wire-rope barriers lead to a reduction of 40% in PTW fatalities and high roadside barriers (i.e. guardrails) may lead to a significant reduction in serious and fatal PTW accidents.

#### 4.1.2.5 Better visibility of road markings in rural areas

Road markings should focus on **providing older drivers with better visual cues** (e.g., pavement markings along the roadway, raised channelization at intersections, and delineators at horizontal curves) **to recognize roadway elements** in order to maintain their lane and to safely negotiate through an intersection or a horizontal curve. Research findings describing driver performance differences related to pavement markings and delineation focus on age-related deficits in spatial vision (Staplin et al., 2001).

A variety of **treatments to enhance conspicuity is required** in current practice, e.g. delineation contrast, pavement markings and so on (MUTCD, 2010). These extend not only to drivers, but also to pedestrians and cyclists. Making older drivers more aware of roadway elements (e.g., pavement edges, intersections, and horizontal curves) through the use of enhanced pavement markings and delineation should improve overall safety. In theory, **these interventions improve older drivers' reaction times in case of conflicts**. Pavement markings and other delineation devices can wear quickly and lose their retro-reflectivity with time. As such, proper maintenance strategies are required (Staplin et al., 2001).

**Effectiveness:** Babbitt Kline et al. (1990) tested young and older drivers with respect to the visibility of text and icon signs under day and dusk lighting conditions and found that there were **no age differences in the comprehension of icon signs**. However, there was considerable variability from one icon sign to another in the degree to which they were comprehended; icon signs appear to offer drivers of all ages almost twice as much response time. Literature also reports **crash reductions of 21% with existing longitudinal pavement markings** and **crash reductions of approximately 8% with painted edge-lines on rural two-lane highways** (Miller, 1993). Griffith (1999) based on evidence of a before-after study suggests that the use of continuous shoulder rumble strips installed on freeways leads to a 18.3% reduction of all single-vehicle run-off-road crashes on all freeways and of 21% on rural freeways alone. Moreover, single-vehicle run-off-road injury crashes on all freeways are reduced by 13%. Elvik et al. (2009) review the effects of road markings to road users' safety with respect to different settings, for example edge and centre lines, raised pavement markers, flush medians, raised pavement markers, chevron markings, or a combination of the above.

#### 4.1.2.6 Roundabouts

Several studies have shown that **roundabouts reduce the number and severity of crashes, especially in rural areas** where speeds are higher than those in urban areas (Eby et al., 2009; Elvik et al., 2009; Jacquemart, 1998; Oxley et al., 2006; Persaud, Retting, Garder, & Lord, 2000). The **positive effects of roundabouts extend to pedestrian safety** (Candappa, Stephan, Fotheringham, Lenné, & Corben, 2014). Staplin et al. (2001) describe several characteristics of roundabout design that may enhance older road users' safety, such as retrospective markings on all roundabout elements (e.g. curbs, islands, etc.) to enhance conspicuity and overhead lighting. Literature indicates that **older drivers find it difficult to negotiate roundabouts**, especially those with multiple lanes due to the lack of relevant information and unfamiliarity of the design rules, signs, markings etc. (Benekohal et al., 1992). van Schalkwyk et al. (2007) underline that the level of information provided prior to reaching the roundabout and once the driver enters the roundabout has been marked as critical by older drivers. **Proper road markings significantly affect older drivers' ability to negotiate roundabouts** (Jacquemart, 1998). Moreover, special attention should be given to **speed limits in roundabouts**; senior drivers are more comfortable to make the right driving decisions at lower speed roundabouts (Staplin et al., 2001).

**Effectiveness/Cost Benefit Analysis:** Past evaluation studies have provided evidence that infrastructure interventions at intersections (for example roundabout construction, median island) consistently reduce accident probability (Dijkstra & Bos, 1997). Persaud et al. (2000) found significant reductions in crash severity at intersections that had been converted from other forms of traffic control (signals, 'stop' and 'give-way' signs) to roundabouts in the US. Right-angled connections are more effective in reducing driving speed. Compared to tangential connections right-angled connections also provide a better view of the traffic on the roundabout for the drivers that are about to turn into the roundabout (Brouwer, Herland, & van der Horst, 2000). The specific type of intersection is also advantageous for regulating conflicting and inhomogeneous flows, e.g. pedestrians, cyclists (Brouwer et al., 2000). **Converting an ordinary junction to a roundabout leads to decreases in injury crashes by 32% for a three-leg junction and 41% for a four-leg junction,**

**while the corresponding figures are 11% and 17% when converting a signalized junction to a roundabout** (Elvik et al., 2009).

**Roundabouts have been shown to reduce the number of vehicle-vehicle collisions; particularly rear-end, right-angle and left-turn crashes**. However, the evidence regarding their effectiveness as a safety measure for pedestrians and cyclists is less intense (Katz & Smith, 1994; Oxley, Corben, Fildes, & Charlton, 2004). Jensen (1999) summarized the effects of interventions to pedestrian safety and reported that **a well-designed roundabout may reduce pedestrian crashes by 46% to 89%.** Pedestrian and cyclist's safety in roundabouts may be improved by constructing large splitter islands, banning parking near roundabouts, adequate street lighting, speed reduction installations, reduced width of circular carriageways, increased deflection and improved signing (Jordan & Jones, 1996).

Constructing roundabouts in order to replace intersections is costly but efficient. An Australian study notes the benefits of roundabouts over other forms of intersection control, stating a benefit-cost ratio typically between 5 and 8 (Corben, Ambrose, & Foong, 1990; Newstead & Corben, 2001). **The benefit-cost ratio** when converting a typical three or four leg junction to a roundabout is around 1 (Elvik et al., 2009).

#### 4.1.2.7 Physical separation between pedestrian and traffic lanes in rural areas

The separation of pedestrian flows from other traffic has been systematically treated in literature. Separation may be done using barriers, guardrails and fencing to control the locations where pedestrians need to cross the roadways (Oxley, Corben, Fildes, O'Hare, et al., 2004). Moreover, the **provision of vehicle-free zones** is an extremely effective way of improving safety and mobility for pedestrians. **Even partial separation in the form of vehicle-restricted zones can be beneficial**. Vehicle-restricted areas are used worldwide and usually involve the use of traffic-calming measures and environmental beautification to discourage and slow vehicular traffic and promote walking and other forms of non-motorized transport. For aesthetic reasons, other types of barriers, e.g. raised planter boxes and outdoor seating, may be used. **Grade-separation of crossings** is another excellent way to eliminate conflicts between vulnerable road users and vehicles. However, these treatments have **not** been **very successful for older pedestrians** in particular because of the difficulties with walking up and down stairs or long ramps, and security issues (ETSC, 1999).

**Other approaches to enhance older pedestrian safety include well maintained footpaths, separation of cyclists and pedestrians**, e.g. through proper lane markings, and the simplification of the road environment (ITE, 1998; Oxley, Corben, Fildes, O'Hare, et al., 2004). Pedestrian safety is generally found to improve by physically separating pedestrians from vehicle traffic, when using underpasses and overpasses, regardless of the discomfort that most pedestrians, especially the elderly feel due to the difficulty in climbing steps etc. (Retting, Ferguson, & McCartt, 2003). **Pedestrian flow separation should also be considered in the case of cyclist-pedestrian interactions**.

<u>Effectiveness/ Cost Benefit Analysis:</u> **Barriers and fences designed for pedestrian flow channelization** in order to safely cross have been found to **reduce mid-road crossings and substantially decrease collision rates for pedestrians of all ages** (Stewart, 1988). A report in the framework of SAMERU (2013) underlines the strong views expressed by older pedestrians related to the circulation of bicycles in

sidewalks. In addition, **relocating bus stops** from the near side to the far side of junctions can increase the visibility and conspicuity of pedestrians. Barrier systems have the potential to reduce fatal crashes and severe injury crashes by approximately 90% with a benefit-cost ratio of around 8 in high speed rural roads (Oxley, Corben, Fildes, O'Hare, et al., 2004). In a recent project report, the **infrastructure design which jointly considers pedestrian and cycling flows in a 'shared space" is not always advantageous**, especially **for older road users** who may feel unsafe and may therefore avoid such locations (GOAL, 2013c).

#### 4.1.2.8 Decreasing the crossing distance by the construction of a pedestrian island or sidewalk extension in urban areas

At intersections, the provision of medians – either kerbed or raised – may be used to reduce pedestrian accident risk, whereas on traffic routes, semi-mountable kerbing should be used (Staplin et al., 2001). **Curb extensions** could also be used to reduce crossing distance (Retting et al., 2003). Studies have showed a **positive effect of median islands on older pedestrian safety and cyclists** (Hagenzieker, 1996). A report of OECD (2001) emphasizes the need to **produce pedestrian routes of the minimum possible length in order to assist elderly pedestrians**. Dropped kerbs at crossings assist those with physical impairments while solid surfaces help those with visual impairments (ETSC, 1999).

**<u>Effectiveness:</u>** For older pedestrians, empirical evidence related to refuges is uncertain. Studies have suggested that central refuges, refuge islands, side-road junctions and major junctions decrease conflicts in two-way streets (Coffin & Morrall, 1995; Henderson, 2003; Oxley, Corben, Fildes, O'Hare, et al., 2004; Oxley et al., 1997). However, another study reported that the provision of a side road refuge with kerb may lead to a change in all pedestrian crashes of +50% to –27% (Jensen, 1999). Other studies have shown that the provision of a central reserve – marked or with kerb reduces pedestrian crashes with 57% to 82% (Jensen, 1999). Bella and Silvestri (2015) found that curb extensions are perceived as a more effective measure for pedestrian safety.

Bergman et al. (2002) suggested that **raised median refuges are most effective and appropriate when older pedestrians may not find acceptable gaps to cross roads** or when roads consist of multiple lanes. These measures are also very cost-effective as installation costs may range between US$2,000 and US$20,000, compared to US$60,000 and US$250,000 for traffic signals. On two lane roads in Melbourne, older pedestrians were found to efficiently select safe traffic gaps and react more quickly to the traffic compared to the crossing behaviour exhibited in streets without such refuges (Oxley et al., 1997).

#### 4.1.2.9 Reducing the speed of other traffic or excluding motor vehicles entirely from areas with many pedestrians

The effectiveness of **speed reduction measures** for pedestrian safety has been systematically addressed for both young and older road users (Haworth, Ungers, Vulcan, & Corben, 2001; Oxley et al., 1997; Staplin et al., 2001). Even low reductions in vehicle speeds result in substantial reductions in pedestrian crashes with severe injuries. Oxley et al. (2004) review the existing speed limits in urban areas in OECD countries and Australia. Speed reductions **provide elderly pedestrians the necessary time to complete the perceptual, information processing and response tasks** demanded by an often complex traffic environment (Hagenzieker, 1996).

Walking facilities for older people are systematically reviewed, in various levels (network, street, and individual) in the GOAL project (GOAL, 2013c). Lower speed limits and traffic calming measures can be used to reduce traffic speeds and contribute to the safety, comfort, and attractiveness of neighbourhoods which again results in environmental-related and safety-related walking and cycling conditions for the elderly (Pucher & Dijkstra, 2000; Pucher & Buehler, 2008; Pucher & Dijkstra, 2003).

For PTWs, several countermeasures, such as speed limits for PTWs, speed limits at hazardous sites and passing restrictions are suggested in literature (2BESAFE, 2012).

**Effectiveness:** Literature indicates that countermeasures achieving a speed reduction of 0.5 – 18km/h may lead to a **decrease in all pedestrian crashes ranging from 17% to 92%** (Jensen, 1999). **Speed reductions** dedicated but not limited to older drivers **have been successfully achieved with traffic calming measures**, such as pavement narrowing, refuge islands, alterations to the road surface, speed humps, roundabouts and gateway treatments (ETSC, 1999). In ‘best-practice’ designs, these measures are used to form an overall design concept in which pedestrians and cyclists have priority and high speed through-traffic is discouraged; such schemes have been successfully applied in many European countries (Oxley, Corben, Fildes, & Charlton, 2004; Oxley, Corben, Fildes, O’Hare, et al., 2004).

**In high-activity pedestrian and cyclist areas there is strong evidence to suggest that even small reductions in vehicle speeds result in substantial reductions in serious injury crashes** (Anderson, McLean, Farmer, Lee, & Brooks, 1997; Oxley, Corben, Fildes, O’Hare, et al., 2004). Anderson et al. (1997), using data from Adelaide (South Australia), estimated a 32 percent reduction in pedestrian deaths with 10 percent of collisions being completely avoided with an overall 5 km/h reduction in travelling speed. In urban areas, where most elderly pedestrian crashes occur, they estimated that there would be a 30 percent reduction in fatalities: 14 percent of these crashes would have been completely avoided and 16 percent of them would have resulted in injuries less severe than death. **The effects of reduced speed limits are greater in urban areas** (Hoareau, Newstead, & Cameron, 2002). Oxley et al. (2004) showed that reduced speed zones, along with other physical measures, such as painted medians between tram tracks, coloured crosswalks at intersections and pram crossings lead to estimated reductions of two to three percent in fatal pedestrian crashes and of 15 percent in serious injury pedestrian crashes; these benefits may be extended to older pedestrians. Oxley et al. (2004) reviewed relevant literature and state that the evidence shows that the frequency and severity of crashes increases when speed limits are raised.

#### 4.1.2.11 Wider sidewalks in urban areas

Providing street-narrowing measures (chicanes, slow points, "skinny street," etc.) for the benefit of pedestrians is an effective countermeasure (Campbell, Zegeer, Huang, & Cynecki, 2004). Gitelman et al. (2012) summarizes international experience on the effects of different pedestrian safety-related infrastructure measures in relation to:

- Accident reduction,
- Conflict reduction,
- Speed reduction.

**Effectiveness**: Gitelman et al. (2012) state that **providing wider sidewalks along with measures to improve visibility** (such as removing obstructions, improving lighting, adding light-reflecting high mounted traffic signs and installing a pedestrian warning system with lights) may **significantly reduce pedestrian-vehicle conflicts**, but also accidents.

#### 4.1.2.12 Installation of lighting at pedestrian crossings in urban and rural areas

Installation of lighting on crossroads has been found to significantly affect pedestrian safety. Findings date back to the early 70's (Campbell et al., 2004). In brief, a review of the effects of lighting at pedestrian crossings showed that the **detectability of pedestrians by the drivers improved when illumination was present** (Campbell et al., 2004). Lighting enhanced the awareness of pedestrians related to hazardous situations at crosswalks, for both younger and older drivers.

**Effectiveness:** Nambisan et al. (2009) assessed the effectiveness of an **automated pedestrian detection device and lighting for midblock crossings**. Results show an increase in pedestrians' observational behaviour, improvements in motorists' yielding behaviour and **positive safety benefits for motorists' and pedestrians'** behaviours at the test location. Pedestrian signal indications appear to reduce pedestrian crashes at some intersections but have little or no effect at others and even increase such crashes at other intersections (Campbell et al., 2004). Retting et al. (2003) reviewed the effects of several traffic engineering measures in pedestrian safety and concluded that the **intense lighting at crossings** was associated with **significant reductions in night time pedestrian crashes**.

#### 4.1.2.13 More and wider bicycle tracks in urban areas

Using more and wider bicycle tracks in urban roads will decrease accident risk, increase mobility and will provide a feeling of security when travelling in public traffic areas. Elvik et al. (2009) describe several requirements regarding track lane width in relation to the amount of bicycle traffic and the type of flow (one way, two way). Oxley et al. (2004) reviewed relevant literature and underlined that recommended countermeasures include the **separation of bicycle and motorised traffic**, including PTWs. This is also stated in 2BESAFE (2012).

**Effectiveness:** The combined use of footpaths and cycle paths may lead to a decrease of 37% in all pedestrian crashes (Jensen, 1999). Jensen's (2008) before-after study related to cycle tracks suggests that **the introduction of cycle tracks reduced some collisions** relative to the comparison-based predictions (rear-end crashes and associated injuries as well as crashes with left-turning bicycles/mopeds and with parked motor vehicles), **while raising others** (crashes with right-turning vehicles, between bicyclists/mopeds and other bicyclists/mopeds, and between bicyclists/mopeds and pedestrians).

Elvik et al. (2009) summarized previous before and after studies on the **effect of cycle tracks to road safety** and underlined their **small influence on the total number of accidents**. No effect is documented for older cyclists. Chen et al. (2013) emphasized the induced demand and how this may influence the frequency of crashes. In New York, a before-after study showed that bicycle crashes were increased after the installation of a bike lane. This increase was probably due to the increase in bike demand and the increase in the interactions between bikes and cars at the locations where the dedicated lanes stopped. **Extending the cycle path network can have a safety benefit but only if this does not increase conflicts and crashes at entry and exit points and at intersections** (Oxley, Corben, Fildes, & Charlton, 2004).

#### 4.1.2.14 Safe stopping locations where the older cyclists have a good view of the intersection in urban and rural areas

Evidence has shown that **drivers feel more comfortable** when knowing in which way stopped cyclists are positioned at an intersection (Herrstedt, Agustsson, Nielsen, & Lei, 1994). **Advanced Stop Lines** (ASLs) provide a waiting area for cyclists between two stop lines - one for drivers and an ASL for cyclists, so that the waiting cyclists are positioned ahead of the motor vehicles and can be seen easily (Allsop, 1999).

Apart from the concept of advanced stop lines, several studies have proposed a series of intersection dedicated measures for bicyclist safety, including raised cycle paths in crossings, coloured cycle paths, cycle lanes inside the circulatory area of a roundabout, etc.

**Effectiveness:** Where implemented, **ASLs have led to a 35% reduction in accidents involving bicyclists during left-turn manoeuvres** (Herrstedt, 1997; Herrstedt et al., 1994). **Separate phasing for cyclists** may also lead to a reduction in crashes involving vehicles turning across their line of movement (Allsop, 1999). Thomas and De Robertis (2013) review the effects of **intersection level treatments for cyclists' safety** and suggested that the most effective are:

- Bringing the cycle track closer to the parallel vehicle traffic at the intersection approach to increase the visibility of cyclists to motorists.
- Placing an advanced stop line for motorized traffic at least 20 m before the intersection.
- Raising cycle crossings to the level of the cycle track to lower vehicle turning speeds.
- Providing dedicated cyclist signals to separate the cyclist through-movement from turning vehicles.

#### 4.1.2.15 Improving the conspicuousness of obstacles for older cyclists in urban areas

**Obstacles** (e.g. bollards, kerbs, bicycle track narrowing etc.) **are critical for the safety of older drivers** (Fabriek, de Waard, & Schepers, 2012). Although no causal relationships have been established, research provides evidence that the **low conspicuity of obstacles may significantly affect single-bicycle crashes** (Schepers & den Brinker, 2011). Fabriek et al. (2012) revealed - through a questionnaire survey - that bollards, kerbs, and cycle path markings/shoulders are the most critical visual elements in the road infrastructure. They concluded that the **visibility can be enhanced** by placing red-white bollards, painting the kerbs white, by enhancing clearness of the road's shoulder or by applying high contrast road markings on the side of the cycle path/road.

**Effectiveness:** Reynolds, Harris, Teschke, Cripton, & Winters (2009) conducted a review on the **effects of infrastructure to bicycle safety** and concluded that **sidewalks and multi-use trails pose the highest risk** and major roads are more hazardous than minor roads. The presence of bicycle facilities (e.g. on-road bike routes, on-road marked bike lanes, and off-road bike paths) was associated with the lowest risk.

#### 4.1.2.16 Facilities at public transport stops and transit vehicles

Many pedestrian and cyclist crashes in rural areas occur at or close to bus or tram stops. In these areas, there is a significantly high level of interactions between the different modes of transport. A number of best practices covering various aspects of public transport (especially accessibility issues) are implemented at various local, national and EU levels in different countries around Europe. These best practices are followed by directives and guidelines to standardise implementation, but an increased degree of diversification still exists between countries (GOAL, 2013b). Several countermeasures have been proposed to deal with the pedestrians' and cyclists' safety near transit stops such as the improved design of transit stops, special road markings and installations to achieve separation of flows (Oxley, Corben, Fildes, & Charlton, 2004).

Fiedler (2007) provides several recommendations related to facilities and bus stops, such as physical strain installations at stops, design solutions to increase orientation and user-friendliness (e.g. clear signposting), and ensure appearance and functionality of transit vehicles. OECD (2001) reports **several measures to increase older passengers' safety**:

- Low-floor buses and trams to facilitate kerbside access to these vehicles,
- Handrails and access ramps for wheelchairs and walking frames,
- Tactile paving and audio messages should be used to support public transport use,
- Directly and easily accessible bus stops from footpaths and/or to networks of pedestrian,
- Ticketing using smart "contactless" cards or prepaid tickets mailed to a customer's residence.

Other concepts introduced to improve road safety of elderly transit users include:

- "**Service routes**", a concept aiming to minimize the distance to bus stops and remove stressful situations during boarding and alighting and to avoid crowding (Forsberg & Ståhl, 1991), and
- "**Flex-route**" services, a combination of fixed-route service and demand-responsive kerb-to-kerb service that are based on advanced booking approaches (Fiedler, 2007).

Finally, **information related measures** include clear and legible signs, audibly available information, real-time visual and audio information should also be included at transit stops (OECD, 2001).

**Effectiveness**: In public transport stops, where a painted pattern area on the cycle path around the bus stop is supplemented with a 6m warning area whose length becomes shorter as cyclists approach the conflict area, the number of serious conflicts dropped significantly (Dijkstra et al., 1998).

In Melbourne, the special design called **"super stops" at tram stops**, which provides a number of positive features to aide passenger comfort and convenience, safe boarding, and waiting (e.g. platforms that are wheelchair accessible, a safe fenced area separated from other vehicles, reduction of vehicle carriageway that acts to reduce vehicle speeds, real time information and trip planners, and other facilities (telephone, toilet, kiosk and ticketing)) **increases safety, due to the separation of pedestrians from trams, but has significantly high costs**.

**Road markings**, for example the painted edge of a tram reserve with raised pavement markers, rumble strips on the approach to the tram stop as well as narrow carriageways can **increase driver awareness** of potential conflicts **and reduces vehicle speeds** (Oxley, Corben, Fildes, & Charlton, 2004).

### 4.1.3 Traffic control at intersections

#### 4.1.3.1 Use of protected-only operations at signalized intersections in urban areas

Left-turn accidents and accidents at intersections with permitted left-turns are overrepresented among older drivers. **Older drivers and cyclists are more often involved in left-turning crashes and situations associated with time pressure** in which traffic from several directions needs to be scanned (Schepers, Hagenzieker, Methorst, van Wee, & Wegman, 2014). Older drivers also experience **difficulties with establishing the acceptable and safe time gap** in order to manoeuvre through traffic streams when there is no protective phase. To deal with this problem, various studies have drafted several measures for increasing the safety of older users at intersections (Knoblauch et al., 1995; Staplin et al., 2001); these include the following:

- Provide as many protected left-turn opportunities as possible
- Lengthen the protected left-turn signal
- Lengthen the left-turn lanes so that turning traffic does not block through traffic

The use of protected phases during signalization ensures that there are no uncontrolled conflicting flows either between vehicles or between vehicles and pedestrians, cyclists or PTWs.

<u>**Effectiveness:**</u> Various studies have showed that **converted permitted to protected left-turn phases improve left-turn safety** because of the decrease in potential conflicts between left-turning and opposing through vehicles (Staplin et al., 2001). Lyon et al. (2005) analysed the impact of flashing advance-green and left-turn green-arrow signals on injury and 95 fatal left-turn crashes and left-turn side-impact crashes and found that the number of left-turn crashes decreased by 16% while the number of left-turn side impacts decreased by 19%. The isolation of left-turning traffic usually reduces rear-end, angle, and sideswipe crashes and improves the flow of through traffic (Oxley et al., 2006). Classen et al. (2007) tested the effectiveness of the FHWA guidelines for intersection design for senior adults and showed that **improved intersections without left-turn movements significantly improve older drivers' safety**. A far more interesting result was that the **FHWA guidelines for intersection design had similar effects on younger drivers**. This indicates that these intersection design guidelines leave room for plausible policy-making opportunities to cover a wide spectrum of road users.

Srinivasan et al. (2008) reported that **converting permissive or permissive-protected phasing to protected left-turn phasing could lead to a virtual elimination of left-turn crashes but other crashes, which are likely to be less severe, could increase**. Srinivasan et al. (2012) in a recent study of 59 intersections in Toronto found a significant 14% decrease in the number of crashes between left-turn vehicles and through vehicles from the opposing direction, whereas a non-significant increase of 7.5% in the number of rear-end crashes was found.

De Pauw et al. (2013) found that **left-turn signal control** decreases the number of injury and severe injury crashes by 37% and 59%, **has positive effects on left-turn crashes** and no effect on rear-end crashes. The positive effect extends to **all road users** (car occupants, cyclists, moped riders and motorcyclists). However, Chen et al. (2013) in a study in New York City concluded that the change of permissive left-turn signal phasing to protected/permissive or protected-only signal phasing does not always result in a significant reduction in intersection crashes.

Regarding pedestrian safety, the **use of exclusive pedestrian signal** control may lead to an **improvement of up to 68%** in pedestrian crashes.

#### 4.1.3.2 Optimize green-times in signalized intersections in urban areas

Optimizing signalization is significant to assure that all flows may operate in an acceptable and safe manner. Upgrading may involve reorganizing phases, optimizing green-times etc. Concerning **older road users**, **better signalization times are said to increase conspicuity at intersections**. Staplin et al. (2001) underline that the provision of a leading green (for example around 3s) in which pedestrians are able to commence crossing before vehicles enter the intersection can increase visibility, especially to turning drivers.

**Effectiveness:** Many studies have evaluated the effect of different **upgrades to traffic signals** on accidents involving **older road users** (Shechtman et al., 2007). Retting et al. (2002) provided evidence for a **10% reduction in crashes** after the optimization of traffic signals. Elvik et al. (2009) review the effect of signal timing upgrading to road safety. In general, **signal timing optimization may reduce injury accidents at junctions by 12% and pedestrian accidents at junctions by 37%**. Coordination is also critical to improve road safety (Elvik et al., 2009).

#### 4.1.3.3 Placing traffic lights at intersection and at more crossing locations in urban areas

According to literature, most accidents involving vehicles or Powered Two Wheelers and/or pedestrians in urban roads occur at junctions and are a direct outcome of limited, false or non-existent traffic control (Polders, Daniels, Hermans, Brijs, & Wets, 2015; Tay & Rifaat, 2007; Torbic et al., 2011; Vlahogianni et al., 2012). By traffic control we imply signalization, signs and road markings. Installing traffic lights is one of the prevailing measures for alleviating the effects of uncontrolled traffic in urban road networks and reducing road accidents involving vehicles, two wheelers and pedestrians. **Signal–controlled pedestrian crossings can improve safety** especially on higher speed roads or with high traffic levels (Coffin & Morrall, 1995; Stollof, McGee, & Eccles, 2007). Qiao, Gampala, & Yu, (2010) emphasized the need to install advanced traffic control devices at pedestrian crossings for pedestrians and cyclists to improve safety. These technologies include:

- Infrared Detector and In-pavement Lighting with Illuminated Push Button,
- Microwave Detector and Animated Eye Display with Illuminated Push Button, and
- Infrared/Microwave Detector and Count - Down Signal with Illuminated Push Button.

**Effectiveness:** McGee et al. (2003) examined the safety impact of installing traffic signals at 122 locations that were previously controlled by stop signs. The results indicated that fatal and injurious crashes at both 3-leg and 4-leg intersections decreased after the installation of traffic signals. However, the effect was insignificant due to a small crash count and large standard errors. Crashes involving pedestrians, however, were not studied separately. Wang, Chen, Pei, & Wang (2011) showed that safety improvement factors such as the presence of a signal light set, a traffic monitoring device and ITS measure have a positive association with intersection crashes. This suggests that different traffic control and management aspects may be helpful in identifying specific countermeasures. **The installation of traffic signals at**

**an intersection may lead to a decrease in pedestrian crashes of up to 70%** (Jensen, 1999).

**Puffin crossings** in Scotland **were found to be advantageous for older pedestrians** leading to reduced conflicts between pedestrians and vehicles during the flashing amber period (Reading, Dickinson, & Barker, 1995). For older pedestrians, these crossings also lead to a clear understanding of priority reduced stress and confusion at the pedestrian crossing location (Reading et al., 1995). Oxley et al. (2004) reported the positive attitude that older pedestrians have with regard to this specific countermeasure, as well as to other electronic installations that extend green and clearance times for pedestrians at intersections.

Huang et al. (2000) concluded that **safety cones and overhead crosswalk signs appear to be promising tools for enhancing pedestrian safety at mid-block crosswalks** on low-speed two-lane roads. Hakkert et al. (2002) showed that the installation of warning systems results in:

- A decrease in both free speeds and speeds near the crosswalks in the order of 2 to 5 km/h (only at sites where initial speeds were higher than 30 km/h);
- A positive change in giving way to pedestrians (increases to a level of between 35% and 70%);
- A reduction in the rate of conflicts in the crosswalk area to less than one percent; and
- A significant increase (10%) in the amount of pedestrians crossing at the crosswalk, rather than outside the area.

No clear relation to older pedestrians was reported.

#### 4.1.3.4 Adjusting the traffic signals to allow for the slower walking speed of elderly pedestrians in urban areas

Special attention must be given to elderly pedestrians. In general, the calculation of the **minimum required time for pedestrians to cross** an approach of an intersection is done based on an average pedestrian speed of **1.2 m/sec**. According to a survey, **this time window is too short for most elderly pedestrians** and should be revised to address the safety issues of those who walk slower due to age-related deficits or other impairments (Amosun, Burgess, Groeneveldt, & Hodgson, 2007). **Longer and less confusing walk and clearance phases are required for older pedestrians** (Catchpole, 1998).

__Effectiveness:__ Cleven and Blomberg (1998) reported that **posting signs, that explained the meaning of the different crossing signals, at crossing facilities lead to lower crash rates with respect to elderly pedestrians**. This method of information dissemination was also very memorable since 66 percent of the survey respondents indicated that they had seen these signs. Chen et al. (2013) in a before-after study showed that an **increase in the green time dedicated to pedestrians** leads to a **decrease in multi-vehicle, pedestrian, bicycle and injurious and fatal crashes** by 47.26%, 28.94%, 41.08% and 41.77%.

### 4.1.4 Lighting

#### 4.1.4.1 Better road lighting in rural and urban areas

Although older drivers drive less at night, **lighting provides a particular benefit to older drivers due to deteriorated visual acuity**, which comes with age. The link between reduced visibility and highway safety is conceptually straightforward. Low luminance contributes to a reduction in visual capabilities such as acuity, distance judgment, speed of seeing, colour discrimination, and glare tolerance, which are already diminished capabilities of older drivers (Staplin et al., 2001).

**At intersections, illumination is critical**. Studies have shown that illumination is the cornerstone to increase the detectability of pedestrians in roadways and intersections (Staplin et al., 2001).

**Older drivers will generally need higher levels of luminance than younger ones**. In general, drivers encounter difficulties in night-time guidance, particularly during periods of rain and fog, because the roadway delineation system does not function as well during adverse weather circumstances. The most affected group of road users may be older drivers who need the improved visibility of roadway delineation features (Dravitzki, Munster, & Laing, 2002).

**Effectiveness/Cost Benefit Analysis:** Improved lighting at pedestrian crossings has been found to decrease pedestrian crashes by 30 to 62% (Jensen, 1999). In the US, intersection illumination was associated with the highest benefit-cost ratio (26.8) in reducing fatal and injury crashes (FHWA, 1996; Oxley, Corben, Fildes, O'Hare, et al., 2004).

#### 4.1.4.2 Fixed lighting at interchanges of motorways

Adequate lighting is required for **older drivers** in order to react in time to unexpected situations, changes in lane configuration and lane width. With respect to motorways, **fixed lighting should be implemented at exits and entries** (Staplin et al., 2001). Fixed lighting installations are recommended where (Staplin et al., 2001):

- the potential for wrong-way movements is indicated through crash experience or engineering judgement;
- twilight or night-time pedestrian volumes are high; and
- shifting lane alignment, turn-only lane assignment, or a pavement-width transition forces a path-following adjustment at or near the intersection.

**Effectiveness:** A survey among older drivers showed that **70% of the older drivers** in the ages of 50 to 97 **indicated that more lighting is needed on motorways**, especially on interchanges, construction zones and toll plazas (Knoblauch, Nitzburg, & Seifert, 1997).

### 4.1.5 Route guidance and Signs

#### 4.1.5.1 Use of advanced warning signs in urban and rural areas

Timely and accurate traffic or safety information provided to road users is of great importance in urban road networks, where the complexity and inhomogeneity of traffic flows are significant. A typical aspect of urban driving is unnecessary driving (users do not always follow the optimum route to reach their destination) and the lack of information on the conditions of the road network or other incidents. These may significantly induce accident risk. Staplin et al. (2001) describe a series of measures related to **route guidance and signs to improve older drivers' road safety**. These include advanced warning signs in places where driving speeds should be reduced (curves, grades, bumps, grade crossings, intersections etc.) and guidance signs to inform road users about critical route choices, destinations and roadside services. To this end, **intelligent solutions** such as dynamic route guidance systems and Variable Message Signs (VMS) **may significantly improve older drivers' safety**. Their objective is to reduce dangerous behaviour by warning road users of conditions that occur seldom, by warning for dangerous situations as they occur and by giving road users feedback on their behaviour (Elvik et al., 2009).

Oxley et al. (2004) introduce the term perceptual countermeasures (PCMs) to describe those measures that influence visual information displayed to the driver to underline the unsafe and appropriate behaviour of speeding. Variable heights and spacing of posts on curves and peripheral edge line painting on approaches to intersections in urban areas lead to speed reductions and improvements in braking and lateral placement, particularly at approaches to intersections (Oxley, Corben, Fildes, O'Hare, et al., 2004).

**Out-of-vehicle ITS applications** have the potential to **enhance speed limit compliance**. These applications include dynamic messaging, in the form of active speed warning signs and variable message signs. Two supplementary solutions can be identified in literature; **dynamic speed limits (DSL) and variable speed limits** (OECD, 2006). The first change with the traffic conditions with the aim to normalize traffic and improve road safety, while the second are activated based on general criteria that are set in a national level (e.g. time of the day, season and certain weather conditions). DSL are usually introduced to harmonize traffic and reduce speed variability (Abdel-Aty, Cunningham, Gayah, & Hsia, 2008; Islam, Hadiuzzaman, Fang, Qiu, & El-Basyouny, 2013) and thus to reduce vehicle emissions and road noise (Papageorgiou, Kosmatopoulos, & Papamichail, 2008).

**Effectiveness/ Cost Benefit Analysis**: The effectiveness of this strategy in reducing crashes has not been satisfactorily quantified. The effect of dynamic route guidance with information sent to receiver units in vehicles has been evaluated in simulation studies (Maher, Hughes, Smith, & Ghali, 1993). De Pauw et al. (2014) show that **a 5% decrease in crash rates was achieved after the speed limit restriction** while the gain is greater for serious and fatal accidents.

Studies of variable speed limits that are combined with variable warning signs for slippery roads in Finland were found to reduce accidents in winter, yet the effect was not statistically significant (Rama & Shirokoff, 2004). There is a general consensus that **advanced warning signs can help reduce confusion and perception/reaction time at existing or potentially hazardous conditions** on or adjacent to the roadways. Further research is needed to develop safety effective measures for this strategy.

Lee and Abdel-Aty (2008) studied the effectiveness of warning messages and DSLs on speed variation in a simulator experiment. Van Nes et al. (2010) analysed the effects on the traffic homogeneity, the credibility of the posted speed limits and the acceptance of the different DSL systems. Hoogendoorn et al. (2012) used simulation to investigate the influence of the content, implementation, location and frequency of signs on the drivers' cognitive reactions and compliance. Kwon et al. (2007) studied the effect of DSLs at a work zone in Minnesota. Papageorgiou et al. (2008) investigated the effect of DSLs on aggregate traffic flow behaviour through traffic data from a European motorway, where a speed threshold-based DSL control algorithm was used.

With regard to traffic safety, Lee et al. (2006) studied the safety benefits of DSLs and used simulated traffic conditions on a freeway in Toronto and marked a reduction of the overall crash potential by 5%-17%. Islam et al. (2013) indicated that DSLs improve safety by 50%. De Pauw (2015) conducted a before-after study and concluded that **DSL systems have a positive effect on the number of injury crashes** (-18%), mainly due to a decrease in the number of rear-end crashes, but no effect was found on the number of severe crashes.

On the joint operation of speed and red light cameras, Elvik et al. (2009) found a reduction in the number of red light running violations between 20% and 80%. Vanlaar et al. (2014) found that there were significantly fewer red light running violations after the installation of the cameras compared to the before situation without cameras. De Pauw et al. (2014) in a before-after study state that the **joint consideration of speed and red light cameras can slightly increase injury crashes**, but decreases fatal crashes, severe side crashes and crashes involving cyclists. Li et al. (2014) reported that variable speed limit strategies effectively reduce collision risk in various road settings.

In general, a cost-benefit analysis showed that out-of-vehicle ITS applications can reduce average vehicle speeds between four and eight km/h, whereas the benefit-cost ratio associated with the use of these displays on different road and environment types ranges from 7.7 to around 45, depending on the environment (Corben, Lenné, Regan, & Triggs, 2001).

#### 4.1.5.2 Place traffic signs more upstream to give the driver more time to plan in urban and rural areas

The inability to reasonably estimate speed may be a more pronounced problem for older drivers. **Older drivers accept a critical gap that is approximately 1s longer than younger drivers, and they reject more acceptable gaps overall** (Campbell, Lichty, Brown, Richard, & Graving, 2012). The basic aspects of visibility and traffic signs are described using the decision sight distance (DSD), which is a longer sight distance than is usually necessary for situations in which (AASHTO, 2004; McGee, Hughes, & Daily, 1995):

1. drivers must make complex or instantaneous decisions,
2. information is difficult to perceive, or
3. unexpected or unusual manoeuvres are required.

Factors such as reaction time, decision making, and problem solving increase the distance required by **older road users** to detect and read signs, as well as to react (Lerner, Huey, McGee, & Sullivan, 1995). Empirical data have indicated that DSD is sufficiently long enough to accommodate the 85th percentile values in most challenging driving situations, even for older drivers (Campbell et al., 2012). However, to account for the older drivers' distinct characteristics, Mace (1988) introduced the **Minimum Required Visibility Distance (MRVD) model**. The MRVD for older drivers can be considerably longer than that for younger drivers because of diminished cognitive abilities and changes in motivation and risk-taking behaviours.

**Effectiveness:** Lyles et al. (1986) reported that **improvements to signs led to a 15% decrease in the number of injury crashes**. No results with respect to older road users are reported. Elvik et al. (2009) have reviewed previous research on sight distances and road accidents and emphasize the existence of conflicting results; increases in sight distance below 1km lead to increased accident rates, whereas above 1km no statistical significant relationship is found between accidents and sight distance. On road segments without intersections, the effect of increases in sight distance on road accidents is positive (Fambro, Fitzpatrick, & Koppa, 1997).

For PTWs, the implementation of a series of interventions that included better signage on curves, enhanced delineation, improvements to road surfaces, and protective materials on roadside barriers in the Australian State of Victoria resulted in a 24% reduction in PTW casualty (fatal and injury) crashes at those locations (Government of Victoria, 2009).

#### 4.1.5.3 Better conspicuity and luminance of traffic signs and markings

Research has shown that drivers require a minimum amount of luminance contrast for both conspicuity and legibility (Mace, 1988). **Older drivers take more time to scan and process a sign compared to a typical driver.** Both analytical and empirical studies show increasing luminance thresholds for sign legibility and conspicuity with age (Elvik et al., 2009). Mace et al. (1997) suggested that conspicuity of signs is related to uncertainty, the use of symbols and the purpose of the message. Since these factors are affected by age, it is important that they are considered in determining the specific requirements of older drivers. Mace (1988) **reviews sign conspicuity issues related to older drivers** and underlines that **conspicuity may** therefore **be aided by multiple or advance signing as well as changes in size, luminance, and placement of signs**. Regarding delineation, Dravitzki et al. (2002) suggest that road markings should provide all drivers younger than 75 with at least two seconds driving time for forward visibility and markings should be designed for conditions prevailing in the first hour of winter darkness.

Conspicuity of signals and signs is a problem not only for drivers but also for pedestrians at intersections. Some **guidelines proposed for older drivers include** the installation of conspicuous ‘give way to pedestrian’ signals, reflective pavement markings to stimulate drivers to look for vulnerable road users (Carlson, Hawkins, Schertz, Mace, & Opiela, 2003). Carlson et al. (2003) provide information on the minimum retro reflectivity levels of traffic signs for older drivers. In **roundabouts**, the guidelines to accommodate **older road users** indicate that the sides and tops of curbs on splitter islands and the central island should be treated with **retroreflective markings for conspicuity purposes** (Staplin et al., 2001).

**Effectiveness:** Srinivasan et al. (2008) based on a before and after study found that replacing 8-in. signal heads with 12-in. heads seemed effective in reducing right-angle crashes, but it could increase less-severe crashes. Schnell et al. (2009) provided evidence that increasing the **sign luminance significantly reduces the time to acquire information, while increasing the sign size also reduces the information acquisition time**. The above implies that larger and brighter signs are more efficient in transferring their message to the driver by reducing information acquisition time, or alternatively, by increasing the transfer accuracy, and, thus are likely to improve roadway safety. **Painting city cycling paths** was found to positively affect the behaviour of both cyclists and drivers since their behaviour was mostly positively modified after the installation of the road markings (Hunter, Harkey, Stewart, & Birk, 2000). Oxley et al. (2004) found significant **vehicle speed reductions** associated with the introduction of treatments including **coloured crosswalks**. Jensen (1999) reviewed literature on pedestrian safety and concluded that reflective strips are found to significantly reduce pedestrian crashes up to 89% at night.

Ribbens (1986) argued that provision should be made for pedestrians and cyclists at stops, such as wide paved or gravel areas so that buses can pull off the road to allow an unobstructed full view of pedestrians and cyclists for oncoming drivers.

## 4.2 Education & training

### 4.2.1 Effectiveness of Educational and Training Programs

The availability of comprehensive educational and training programs is essential for maintaining mobility among older adults. This is also acknowledged by older drivers. According to a study of Robertson and Vanlaar (2008), **the majority of older drivers realize that after a certain age they should be required to complete trainings** or to participate in educational programs to assess their driving abilities and renew their driving privileges. Furthermore, they agreed that they had to lose their driving license in case they fail to succeed in the tests.

There are several educational programs available for the older driver ranging with respect to purpose, format and content. **Educational schemes aim to increase older drivers' awareness and knowledge** about declines related to aging that may explicitly or implicitly affect the driving task.

Recognizing and understanding characteristics and behaviours of older drivers who attend remedial driver education is essential to the design and delivery of successful driver safety programs (Nasvadi & Vavrik, 2007).

Oxley et al. (2013) categorize the **educational and training interventions** to four different categories related to:

- The provision of knowledge about the general association between ageing, changes in functional performance and safe driving practices,
- The provision of practical driver training or behavioural skills directly associated with driving,
- Increased self-awareness of fitness to drive, and
- Improvements in functional areas considered to be necessary pre-conditions for safe driving.

Wouters and Welleman (1988), **regarding older pedestrian safety education**, emphasized the need to address:

- Loss of function issues,
- Compensatory behaviour, and
- Reduced exposure to certain situations with increased risk which cannot be alleviated by functional declines and compensation behaviour

In the USA, National Safety Council (1989) presented some **key measures for older drivers** that should be targeted in educational programs:

- Adoption of proper search behaviour - stopping at the kerb and looking for approaching and turning traffic, especially at pedestrian crossings and at intersections,
- Visibility - wearing of bright clothes during the day and retro-reflective materials at night to increase conspicuity and to be seen when moving from behind parked cars, and
- Understanding the meaning of the flashing 'Don't Walk' sign.

Regarding **PTWs**, a recent European study drafted a list of **educational interventions** (2BESAFE, 2012) which include signposts, displays, roadside boards and bills alongside dangerous roads, events promoting motorcycle safety, educational brochures, shocking films concerning motorcycle safety, using community collaboration to promote motorcycle safety, using peer activities to promote motorcycle safety, integrated road safety education programmes, peer activities to prevent drink riding, programmes to increase awareness on safety helmet use and the promotion of protective equipment.

Literature has emphasized the need to address **older transit users' safety issues** through education and training (GOAL, 2013b). Fiedler (2007) provides a series of recommended measures to improve the safety of older transit users; these include **drivers' training** related to their driving behaviour in order to assure the comfort and safety of older passengers and training related to the general expected behaviour of older passengers due to age-related issues. **Training programs should extend to older passengers on how to prevent accidents, how to use public transport and to the stations' staff to learn how to improve the security and safety for older people** (Fiedler, 2007).

**Effectiveness:** In general, evidence has shown that educational programs:

- Increase awareness and driver's knowledge (Eby et al., 2003),
- Increase self-reporting and safe behaviour on the road (Owsley et al., 2003),
- Improve on-road evaluation scores (Marottoli et al., 2007).

According to Preusser et al. (2008) and Eby et al. (2009), there is a **knowledge gap concerning the core outcomes of educational programs**, e.g. the amount of knowledge acquired, changes in behaviours due to the program and changes in motor vehicle crash/injury/risk. While such educational and training programs have been suggested and some implemented, very few have been evaluated which makes it **difficult to measure their efficacy** (Duperrex, Bunn, & Roberts, 2002). Preusser et al. (2008) reviewed a variety of behavioural interventions targeting older drivers and formulated a listing according to their effectiveness. The results indicated that none of them had been proven to work or to be efficient, whereas the effects of the majority of the analysed interventions were of an unknown/uncertain nature.

A recent **cognitive training research** demonstrated **positive results to several mobility functions**, including driving safety, driving difficulty, driving cessation, and gross motor function (Ross, Schmidt, & Ball, 2013). Unfortunately, the same does not apply to educational interventions that are more influential to certain ages and especially to those with the greatest disability (Ross et al., 2013). Roge et al. (2014) developed a **visual field training programme targeted to older drivers' ability to detect vulnerable road users** (pedestrians and PTWs) in a simulated car-driving task. They concluded that **elderly drivers who received training were better able to detect pedestrians in the road environment**. Ichikawa et al. (2015) underlined that retraining strategies in Japan for older drivers have limited effect to the at-fault motor vehicle collisions and need to be reconsidered. Tuokko et al. (2015) tested **intervention strategies aiming to change cognitive processing** as measured by consciousness raising and attitudes toward driving after participating in educational interventions for older adults. The results indicated that the participants were open and willing to change their driving behaviour after the experiment. Findings showed that there is limited evidence that visual and physical retraining improved older drivers' skills.

Dunbar et al. (2004) emphasize the lack of educational and training programmes dedicated to older pedestrians. Evaluations suggest that even if such programmes affect knowledge, they may not affect practical behaviour since there is little direct evidence linking them to behavioural changes or reduced accident risk. Dunbar et al. (2004) comment that **information campaigns for drivers aimed to understand the difficulties of older pedestrians are particularly important**, yet not influential enough to directly reduce crash risk. Related to PTWs, ETSC (2008) emphasizes the need to update existing training schemes dedicated to PTWs in which the focus lies on hazard recognition, risk assessment and vehicle control.

#### 4.2.1.1 Retraining Programs

**Re-training strategies** mainly focus on **helping older road users** to develop compensating mechanisms **to overcome age-related declines**. Retraining courses are systematically used in many OECD countries. The topics covered address (OECD, 2001):

- the effects of ageing and associated impairments on driving,
- the effects of medication and alcohol on driving,
- advice on physical fitness and diet, traffic laws, including the role of new traffic control devices and new highway elements,
- aspects of vehicle design and technology to improve safe driving, and
- advice about defensive driving and self-regulation through the adaptation of driving patterns to minimise accident involvement.

**Effectiveness:** Simoes (2003) marks that **cognitive training** of older adults has been shown to improve cognitive targeting abilities and reduces and prevents declining cognitive performance. **Educational interventions** were shown to increase driving awareness and safe driving behaviour, but did not reduce collision involvement of older drivers (Kua, Korner-Bitensky, Desrosiers, Man-Son-Hing, & Marshall, 2007). Korner-Bitensky et al. (2009) provide evidence that **retraining programs targeted at older users may exhibit encouraging positive results** - at some level - including changes in driving performance and most impressively, in at-fault crash levels. Findings state that cognitive training by computer simulations may improve older drivers memory, attention and motor control tasks which are used when driving (Cassavaugh & Kramer, 2009). The OECD report on older road users and re-training concludes that the effectiveness of classroom-based courses on crash involvement reduction has yet to be evaluated (OECD, 2001).

#### 4.2.1.2 Education and training dedicated to urban road network

Urban environments are complex due to signalization, signs, markings and, in general, the traffic rules a road user has to understand and follow. The amount of attention required to navigate in urban road networks is increased in relation to other environments. **In complex situations, attention allocation and information processing abilities even become more demanding with age, particularly for older drivers with declines in vision, physical abilities, psychomotor coordination and cognition**. As a result, proposed guidelines should aim to:

- Inform and train older road users about new traffic rules and situations and road layouts in urban and rural areas
- Provide refresher courses on traffic rules in urban and rural areas

**Effectiveness:** Romoser and Fisher (2009) assessed the effects of active and passive training to enhance the behaviour of older road users at intersections. Compared with passive training, **active training is a more effective strategy for increasing older drivers' awareness while driving at intersections**. Romoser and Fisher (2009) conducted an experiment on both older and younger drivers and concluded that older drivers looked less often when performing a turning manoeuvre than younger drivers. However, active training increased a driver's probability of looking for a threat during a turn by nearly 100% in both post-training simulator and field drives. Those receiving passive training or no training showed no improvement. As a result, active training is a more effective strategy for increasing older drivers' likelihood of looking for threats during a turn when compared to passive training.

Dommes and Cavallo (2012) organized a 6 months experiment involving different age groups of older pedestrians. The results indicated no differences between age groups related to their decision making at street crossings leading to assume that a clear change towards more safe decision making was achieved. Nevertheless, the experiment showed that the ability to improve age-related problems such as perceptual and cognitive difficulties was not improved with the proposed educational and training method.

#### 4.2.1.3 Promoting specialized clothing

**Visibility aids,** such as reflective garments **enhance the conspicuity of pedestrians and cyclists** and thus, attracts the driver's attention to their presence (Osberg et al., 1998). Guidelines have suggested the **promotion of wearing bright clothes during the day and retro-reflective materials at night** to increase conspicuity as a measure to increase older pedestrian safety (Dunbar et al., 2004; National Safety Council, 1989). There are **technological innovations**, such as protective clothing, that might help to reduce accident risk or moderate injuries for older people (Dunbar et al., 2004). According to NCHRP (2004) and Tyrrel et al. (2009), wearing retro-reflective materials, particularly materials that highlight a person's shape and extremities, makes pedestrians more easily detectable in low light conditions since they can be detected from a greater distance than pedestrians in normal clothes.

**<u>Effectiveness:</u>** Sayed and Mefford (2004) found that **pedestrian conspicuity is significantly affected by the retroreflective trim, trim colour, location in the road environment and driver age**. Retroreflective patches have been found to roughly double the distance at which participants, travelling as passengers beside the driver, detected a pedestrian standing at the roadside at night (Luoma, Schumann, & Traube, 1996; Shinar, 1984; Shinar, 1985). Harrell (1994) provided evidence that drivers were more likely to stop for a brightly clothed pedestrian than for the same person when he was wearing a drab jacket.

### 4.2.2 Raising Awareness

Older road users need information on the physical and cognitive changes that go with ageing and on the implications of ceasing to drive (DaCoTA, 2012a). **Issues that should be taken into consideration relate to**:

- Effect of functional limitations (cognitive, sensory, physical) on abilities
- Increased vulnerability, and the importance of using protection devices.
- Influence of age-related illnesses and prescribed medication on driving abilities.
- Vehicle equipment and technologies which are available to make driving easier
- Possible decision to no longer drive a car: making this debatable, and discussing the roles that relatives and family doctor can play
- Proper search behaviour on the road, at pedestrian crossings and at intersections
- How and where to seek and access mobility alternatives to the car.
- Bus drivers to pay attention to avoid that older road users fall inside the bus.

Recognition of declining sensory and cognitive abilities by the individual driver is essential to effective rehabilitation. Dunbar et al. (2004) suggested **that specific advice may be useful for older pedestrians**. These may relate to information about the effects of alcohol, medication and specific medical conditions, specific functional declines that can occur, or the importance of vision and hearing checks and their potential relevance to pedestrian behaviour. Other helpful types of information include the benefits of walking for health, guidance on the ways to modify pedestrian activity to increase safety, advice on when to seek additional support and advice of how to make yourself conspicuous (Dunbar et al., 2004).

In relation to advanced technologies, Simoes (2003) emphasizes the **need to develop educational programs to familiarize older road users with telematics systems** in order to use them to slow down and/or prevent age-related declines in cognitive abilities, particularly those involved in driving. Advanced Driver Assistance Systems (ADAS) may facilitate the above through displaying the road speed in the vehicle with additional speed cues, displaying road signs in the vehicle, the use of Night Vision systems and so on (Musselwhite & Haddad, 2007).

Moreover, an issue for which it is **essential to raise the awareness of older road users** is **driving secession and the shift to alternative modes of transportation**. A critical issue in driving secession is the recognition that they are no longer safe drivers (Eby et al., 2009). Dickerson et al. (2007) emphasize several open issues related to driving cessation, such as the need for a consistent model of transition between cars and other transportation alternatives that would take drivers safety and transportation options into consideration and help older road users to smoothen the transition from driving to other transportation alternatives. Furthermore, they emphasize the need to address the declines associated with older road users in relation to the transportation services. Little has been done in the United States to address the need for a safe infrastructure that includes sidewalks, road crossings, and traffic signals for pedestrians and bicycle lanes and road crossings for bicyclists (Eby et al., 2009).

In relation to public transport, according to a recent report, **the provision of elderly-friendly bus services is considered as a priority** (SaMERU, 2013). Based on a survey among older road users, some **interventions to improve bus services include** navigational aids to assist older passengers, demand responsive flexible transport services as well as low-floor buses and ramps provided for passengers with severe mobility difficulties. In the same study, bus driver training and evaluation should be designed in such a way that the older passenger is placed in the centre of the bus drivers' attention. Awareness raising campaigns among other passengers in order to avoid conflicts and to enhance the understanding of older peoples' needs are described in Fiedler (2007).

In the GOAL report (GOAL, 2013a), the importance of delivering information to older citizens on walking and cycling choices through internet, proper maps, signage and handheld device services for raising awareness is emphasized. Similar results have been proposed for public transport users (GOAL, 2013b).

Participatory models in campaign design are quite efficient in raising awareness of older road users (Levi, De Leonardis, Antin, & Angel, 2013). The resulting campaigns may include educational brochures, messages, graphics etc. that are suited for older people and may efficiently address knowledge and attitudes.

**Effectiveness:** The National Safety Council (1989) through its **program 'Walk Alert Pedestrian Safety'** developed a set of key countermeasures that were explained to older pedestrians through educational programs. Some key safety interventions include messages such as "Stop at the curb," "Look left, right, and left again before crossing," Look over your shoulder at intersections for turning vehicles;' "Move out to where you can see," and "Wait until new green signal (or walk signal) ". **A significant reduction in pedestrian/traffic collisions was noted in the cities in which the messages were applied**. Hoekstra and Wegman (2011) provided a review on the effectiveness of road safety campaigns. Peden et al. (2004) argued that road safety campaigns are to influence and raise awareness only if they are applied together with other measures such as proper legislation and enforcement.

#### 4.2.2.1 Strategies for defensive driving

Education and training are usually required for older drivers to adopt self- regulatory behaviour (Oxley et al., 2013). Owsley et al. (2004) evaluated an educational intervention programme that promoted safe-driving strategies among visually impaired, high-risk older drivers and concluded that the specific intervention did not enhance driver safety. However, the self-reported results of the older drivers indicated that they avoided challenging driving situations, decreased their driving exposure and increased their self-regulatory behaviour.

Dunbar et al. (2004) underline that **advice on how to maintain their performance through functional compensation is not enough** since compensation that engages their capacity for cognitive control may eventually compromise their ability to respond quickly to unexpected events.

Evidence has shown that older drivers who were expected to self-regulate their behaviour, failed to do so due to the lack of up-to-date driving experience and confidence and give up driving at an unnecessarily early stage (Oxley et al., 2006). Literature identifies the **need for awareness, education and training programs, with a particular focus on the sub-groups of older drivers** who may benefit greatly from driver education and training programs (Oxley et al., 2013).

**Effectiveness:** Levasseur et al. (2015) conducted a study to assess the **impact of potential educational interventions on older adults**. They concluded that such intervention tools **increase the interest, openness, and knowledge about the abilities and compensatory strategies** of older drivers, as well as the awareness of the changes that could negatively impact safe driving and enhanced utilization of compensatory strategies.

#### 4.2.2.2 Self-evaluating and improving their skills

Self-evaluation is the key component towards increasing driver's self-awareness and general knowledge about driving-related declines in abilities that may affect driving. Scully et al. (2010) review existing training programs and self-evaluation materials available for older drivers. Jones et al. (2012) underline that a more intensive program is more effective and that **driving safety programs focused on behaviours to self-evaluate driving abilities continue to be needed** in order to help older drivers to remain safe on the road as they age. The involvement of health care providers in such efforts may be an untapped potential.

Information on functional impairments, self-awareness and compensation and high-risk scenarios can also be used to identify advice that is useful for older pedestrians (Dunbar et al., 2004).

**Effectiveness:** Owsley et al. (2003) stated that drivers who received the visual training intervention were more likely to accept that their vision may be impaired, to avoid challenging driving situations and to perform self-regulatory behaviour, compared to a control group. In general, evidence shows that **older drivers are reluctant with the programs to assess their driving performance**; most drivers (of any age) tend to rate their driving as good or above average and are unwilling to have their driving assessed because they fear potential negative ramifications.

### 4.2.3 Rehabilitation

Rehabilitation refers to the regaining of prior functioning. Rehabilitation is seen as the means to reverse the effects of certain declines related to older road users. This is mainly done through medical intervention, exercise or cognitive rehabilitation programs (Marottoli et al., 2007). **Driver rehabilitation has the potential to improve on-road safety**. Unsworth and Beker (2014) provide a concise review of the interventions used by occupational therapists to improve on-road fitness-to-drive and underlines that few interventions are commonly reported. Yet, limited evidence of their effectiveness to fitness-to-drive improvement is available. Regarding PTWs, a recent European study drafted a list of educational interventions and targeted rehabilitation programs, such as rehabilitation of severe violators and of traffic-psychological assessments of drink-driving (2BESAFE, 2012). These interventions were not dedicated to older drivers.

**Effectiveness:** Current evidence on their effectiveness is sparse, but sufficiently encouraging to warrant further investigation of rehabilitation interventions aimed at older drivers (Kua et al., 2007). Several intervention approaches have been documented in literature with various and conflicting results. Eby et al. (2003) showed that three quarters of the participants reported being more aware of factors that could influence on-road driving performance after the completion of a self-assessment instrument "The Driving Decisions Workbook", followed by an on-road assessment. Mazer et al. (2003) trained older drivers with a stroke. The training was targeted at visual processing speed, divided attention, and selective attention. The performance of the participants in the programme was compared to the performance of older drivers that undertook a traditional vision-perception treatment programme. The on-road assessment showed that there were no significant differences between the intervention and the control groups. Roenker et al. (2003) have studied older drivers with reduced information processing skills and showed that individualized and non-individualized computer based training programmes had a similar effect to the driving skills of participants.

Bédard et al. (2004) concluded that in on-road assessments, there is no significant difference between those that undertook an educational re-training program and those with no intervention. Recent efforts have investigated whether cognitive functioning can be restored through training. There is **strong evidence that proper and intensive training can improve cognitive functioning** (Eby, Molnar, & St. Louis, 2008). Kua et al. (2007) concluded that there is only limited evidence that cognitive retraining can improve driving.

Anschutz et al. (2010) proposed an individualized on-road re-training program with use of a verbal cueing device "The Electronic Driving Coach". Cox et al. (2010) showed that the driving performance (on-road assessment) significantly improved when elderly road users with traumatic brain injury undertook Virtual Reality Driving Simulation Training. Klonoff et al. (2010) developed a study involving participants that had brain injury with cognitive retraining tasks, including completion of a behavioural checklist and a working alliance. The on-road assessment showed that nearly half of the participants were cleared to drive at the discharge time from the program. Gamache et al. (2011) showed that **older drivers with a traumatic brain injury**

**displayed significantly improved driving,** with respect to reduced cognitive load, less jerky speed profiles, better vehicle control and positioning after an individualized simulator driver training program. Hitosugi et al. (2011) developed a controlled experiment in "The Honda Driving Simulator" to test collision avoidance, reaction and braking times for elderly who had a stroke and healthy elderly road users. The participants in the control group demonstrated improved collision avoidance, reaction and braking times with repeated training within the session.

Sung et al. (2012) showed that after a computer based simulation training program, older drivers with spinal cord injury displayed a significant increase in total driving time, more precise driving behaviour and less speed variations than before the training.

Betz et al. (2014) assessed the older drivers' opinion on the effectiveness and barriers to the utilization of driver rehabilitation programs. Results showed that the average cost for a complete evaluation was $400, whereas 36% of DRPs reported no third-party reimbursement. The costs along with the lack of awareness of the programs' benefits are the major barriers in the acceptability of rehabilitation programs.

Porter (2014) reviewed programs related to health-promotion or community context for older drivers. Findings indicate that solely classroom-based education programs do not appear to reduce crashes or improve on-road driving performance of older drivers. Instead, **road training combined with classroom-based education has an improved effect to road safety**. Moreover, physical training seems to have a positive effect on the road safety of older drivers, while education programs for visually impaired drivers are less important in reducing crash rates. Limited knowledge can be inferred from programs/interventions for patients who have had strokes.

## 4.3 Licensing & Enforcement

### 4.3.1 Licensing Renewal, Screening and Assessment

Drivers' license renewal policies in the United States vary across States in terms of the length of the renewal cycle, requirements for accelerated renewal for older drivers and other renewal provisions (Goodwin et al., 2013). A similar diversification policy applies to the EU Member States and Australia and is extensively discussed in Siren and Haustein (2015). NHTSA (2010) proposes the development and promotion of driver licensing policies as one of the three main initiatives in its 5 year safety plan. Licensing is a major concern for PTW drivers with a high degree of diversification along EU countries but limited information about older PTW drivers is available (2BESAFE, 2012). A study in the framework of the EU funded project 2BESAFE (2012) proposed an extensive list of such measures focused on licensing.

To ensure safe road users, much concern has been placed to re-licensing procedures for older drivers. Currently, **varying age-based license renewal procedures exist on a country or regional level**, with a range of screening tests to determine fitness to drive (age based screening, mandatory versus voluntary assessments, medical screening and fitness to drive). This diversification imposes difficulties in assessing the effectiveness of such strategies.

**Screening and assessment are two complementary tasks** (GOAL, 2013a):

- Screening results in detecting at-risk older drivers;
- Assessment procedures to provide an in-depth analysis of the extent and the causes of observed impairments to assist the decision making process in order

to establish if and in which circumstances an older driver should continue to drive.

Evidently, **licensing should be based on both tasks**. In view of the above, OECD (2001) emphasized the effectiveness of multi-tiered assessments not solely based on age but on the ability to drive safe. **Licensing authorities should also play a more advisory role**, rather than taking mere decisions on whether to renew a license or not (Edwards et al., 2008; Staplin & Lococo, 2003).

**Effectiveness:** Several studies have investigated the effects of licensing on older drivers (Grabowski, Campbell, & Morrisey, 2004; Hakamies-Blomqvist, Johansson, & Lundberg, 1996; Lange & McKnight, 1996; Langford, Bohensky, Koppel, & Newstead, 2008a; Langford, Fitzharris, Koppel, & Newstead, 2004; Langford, Fitzharris, Newstead, & Koppel, 2004; Levy, Vernick, & Howard, 1995; Mitchell, 2008; Siren & Haustein, 2015). Siren and Haustein (2015) provide a concise review of the relation between safety or mobility outcomes and different license renewal procedures for older drivers.

The CONSOL study reports that no evidence can support the assumption that general age-based assessments have any safety benefits, but other specific areas of improvement were identified for USA practice, for example in-person renewal (as opposed to renewal by mail) and restricted driving (CONSOL, 2013b). Evidence from EU Member States shows that **age-based license renewal is associated with neutral outcomes at best, or may be linked to negative safety effects for older people**. These negative side effects are mainly due to the shift from the car to other modes of transport (walking, cycling) that are not supported by the proper infrastructure for older users (Siren & Haustein, 2015).

Preusser et al. (2008) underlined that **license renewal policies for elderly drivers that require in-person license renewal are likely to be an effective measure to increase older driver safety**. Another study emphasized that a smooth transition from driving to other means of transportation can be achieved through license renewal (Braitman, Chaudhary, & McCartt, 2010).

Siren and Meng (2012) provided evidence that cognitive screening does not produce safety benefits. Goodwin et al. (2013) underlines that license renewal is beneficial for older users' safety as it implicitly reduces the driving exposure of older drivers.

Regarding the mandatory nature of screening schemes, Mitchell (2008) underlined that those that had the most lenient screening procedures also had the lowest collision rates among older drivers. Siren and Haustein (2015) emphasize that **EU policies of screening and license renewal are not based on solid evidence and that strict age-related screening policies have large societal and private costs with possible negative effects to safety**. An Australian study in provinces with and without mandatory testing for licensing older drivers reported that the mandatory testing did not improve crash rates (Langford et al., 2008a; Langford, Fitzharris, Koppel, et al., 2004; Langford, Fitzharris, Newstead, et al., 2004). A similar Canadian study assessed the crash rates of older drivers for different licensing systems with respect to strictness in testing and reported no significant influence of licensing systems to crash rates involving older drivers (Tay, 2012). A study in the US showed that stricter rules for licensing of older drivers had either a negative effect on the safety of the younger group, or a positive effect on the safety of the older group (Grabowski et al., 2004). Similar findings are reported for other counties (Grabowski et al., 2004; Hakamies-Blomqvist et al., 1996; Langford, Fitzharris, Koppel, et al., 2004; Langford, Fitzharris, Newstead, et al., 2004).

Eby et al. (2008) showed that tools for self-screening of older drivers are to identify impairments rather than fitness to drive.

Langford and Koppel (2006b) tested two different arguments for and against regular age-related assessment and concluded that **unsafe drivers can best be identified through a more strategic approach, relying upon referral of identified at-risk drivers for a multi-tiered assessment**, instead of through mandatory age-based assessment. The CONSOL report comments on the political nature of age-related screening as a safety policy related to older drivers with undesired cost-benefit aspects and redefines the nature of such schemes as advising rather than enforcing tools to prolong driving, but also detecting at-risk drivers (CONSOL, 2013b).

Licensing restrictions for older drivers may lead to lower crash risks (NCHRP, 2004). **Restrictions to licensing usually reduce crash rates** (Langford & Koppel, 2011). Moreover, license renewals, especially those that are conducted with vision tests have been found to be effective in identifying people whose driving skills may be impaired (NCHRP, 2004). Bohensky et al. (2008) explain that vision testing for license renewal does not adequately explain unsafe driving performance as differences were observed across vision requirements for the selected jurisdictions. These differences will possibly reflect the equivocal and inconclusive findings which link specific visual functions and impairments with crash risks.

### 4.3.2 Enforcement

For **older drivers**, law enforcement encompasses three aspects (Goodwin et al., 2013):

- Enforce traffic laws,
- Identify drivers with potential driving impairments and refer them to licensing agencies, and
- Provide information and education.

In particular, active publicized enforcement of seat belt use laws can help to increase belt use for older drivers and occupants. Traffic stops and crash investigations provide excellent opportunities for officers to observe and evaluate driving behaviour. Regarding information and education, there are various examples where law enforcement representatives interact with public or private authorities through talks, courses and other initiatives (Stutts, 2005).

**Enforcement is linked to the graded (graduated) licensing system** which involves the introduction of certain driving restrictions as older people's abilities decline (Fildes, 1997). In such systems, enforcement becomes difficult as the number of restrictions increases.

For PTWs, there are four key areas where enforcement plays an important role in reducing road deaths: speeding, drink driving, seatbelt and helmet use. Enforcement activities are usually linked to educational and training schemes. ETSC (2008) states that enforcement activities should be optimized and justifiable. Attention should be given to the appropriate use of helmets, the visibility of license plates and improvement of speed detection technologies. Haworth (2012) emphasizes the need to develop more effective forms of enforcement to reduce illegal risk taking by PTW-riders.

**<u>Effectiveness:</u> Law enforcement officers provide more than one-third of all referrals to licensing agencies for driver screening and assessment**, whereas costs vary depending on the nature and scope of activities (Goodwin et al., 2013). OECD (2001) reports that countries without mandatory re-licensing procedures, rely heavily on physicians and law enforcement agencies to refer "unfit" older drivers for assessment. The consequent variety of expectations, practices and legal protection illustrates the lack of standardisation in this area.

### 4.4 Vehicle & ITS technologies

Since 1996, the European Commission regulates that the car manufactures need to apply minimum requirements regarding the safety of car occupants (CEE 96/79, CEE 96/27…). In this context, several technical solutions were developed and are now applied within the automotive market. These passive safety solutions can no longer be considered as innovative, because these solutions are already present in all vehicles. Therefore, these technologies will not be discussed in this section. Instead, the focus of this section lies on the **effectiveness of Advanced Driving Assistance Systems (ADAS)** with respect to elderly driver safety.

Advanced Driver Assistance Systems (ADAS) have first appeared in the 1990's and their market has been constantly growing from the 2000's. Their introduction is linked to the interest for all drivers and to the availability of the corresponding technology (e.g. ADAS involving vehicle detection were introduced when the radar technology was available for automotive). The first ADAS were informative and addressed simple situations. Then more and more active systems arose and covered more situations, with a trend towards autonomous driving which could be considered as the "ultimate" ADAS.

Different kinds of ADAS have been reviewed. The results will be presented by type of assistance considering the sub-task supported by ADAS or the type of driving scenario: lateral/longitudinal control, intersection, parking, night vision and navigation. A detailed overview of the different ADAS technologies can be found in Annex 11 of the Annex report.

#### 4.4.1 ADAS for Intersection

**Older drivers are overrepresented in intersection accidents** compared to younger drivers. This accident risk increases dramatically for most intersection maneuvers after the age of 75. About one half of all fatalities for drivers aged 80 years and older occurred at intersections, compared with 23% of the drivers younger than 50 years (Insurance Institute for Highway Safety, 2000). Thus, older drivers are more likely to be killed in such traffic crashes. **Intersections are challenging situations for ADAS, because sensors with a very wide field of view, a long range and a very good understanding of the intersection geometry are required**.

**The first generation of Intersection Assist Systems addresses simple scenarios**, using onboard sensors such as a camera and/or a navigation system. For example, the driver is warned if he approaches a red traffic light, a stop sign, or a crossing pedestrian.

**The second generation of Intersection Assist Systems will address more complex scenarios**; when the communication between vehicles (**Car2car**) or between vehicle and infrastructure (**Car2x**) will be available. This communication needs a radio system in each vehicle and in the infrastructural objects, using a standardized protocol. The driver will be warned if another vehicle is about to cross just in front of him and the vehicles may brake automatically to avoid the collision.

**Five different intersection assistance ADAS system are analysed**:

- A support system to prevent left-turn collisions and collisions with crossing pedestrians (Daimon & Kawashima, 2003);
- An advanced in vehicle information system using a head-up display format (Caird, Chisholm, & Lockhart 2008). They evaluated two visual forms of safety messages: "prepare to stop" (a traffic light inside a rectangle) and "signals ahead" (a traffic light inside a diamond);
- A time gap assistant system using a head-up display (Gelau, Sirek & Dahmen-Zimmer, 2011);
- A device mounted in the high centre position of the dashboard which provided an in-vehicle message to select a gap for left turn across path / opposite direction (LTAP/OD) manoeuvres (Bougler et al., 2005);
- A simulated driver assistance system that provides prior knowledge on the next traffic situation by informing the driver about one of four aspects of that particular situation (Davidse, 2006):
    1. whether the driver has right of way,
    2. whether it is safe to join or cross traffic,
    3. whether the driver will have a good view of crossing traffic, and
    4. whether there are any deviating traffic rules or road situations (e.g., different speed limit or one-way street).

All of the information was communicated orally. The information was only provided if it was relevant with a maximum of one message per intersection. The participants of all studies can be classified as "younger older" drivers. Gelau et al. (2011), Davidse (2006) and Bougler et al. (2005) reported participants over 80 years old with a maximum of 88. But the mean range was from 68.2 to 75.5 years of age. Caird et al. (2008) and Daimon et al. (2003) reported studying participants under 80 years of age.

<u>**Effectiveness:**</u> **Information provision by all systems was proven to be effective**. No negative effects on safety were found. The studies observed an increase in the frequencies of stopping with short yellow onsets, an improved stopping accuracy, **shorter accepted safe time gaps**, a 10% reduction of accepted unsafe time gaps or distance between vehicles, **a reduction in speeds at intersections**, safer decision making, fewer route-errors and less deceleration manoeuvres of other drivers with right of way. When **advanced warning signs** were provided, drivers' were 2 times more likely to stop at the intersection compared to the baseline scenario. The **accepted time gap was reduced to 1.5s for older drivers** (Caird, Chisholm, & Lockhart 2008).

**Drivers' were 5 times more likely to anticipate a traffic light change** when the **advanced warning sign** was displayed compared to the baseline drivers (Caird, Chisholm, & Lockhart 2008). They anticipated by removing their foot earlier from the accelerator pedal. The PRT (pedal release time) was not greater as drivers anticipated and reduced their approaching speed.

**Older drivers spent a significantly lower percentage of the total number of fixations on the HUD**, compared to the younger drivers. Almost no glances to the in-vehicle display were made during the trial with the device. In the Japanese study from Daimon et al. (2003) (a left-hand driving country), drivers were given multiple information cues but older drivers did not seem to have any techniques for turning right. Therefore, the information provided by the two support systems failed to help them select safe gaps and resulted in decision delays. Furthermore, older drivers exhibited greater horizontal gaze variability and lower vertical gaze variability. In 24.6% of in-vehicle sign presentations, no fixations to the Head-Up Display were measured. Peripheral detection and non-use of the HUD are possible explanations.

**Providing information reduced the perceived mental workload when making a left turn** (Daimon & Kawashima, 2003). The movement of oncoming vehicles could be perceived more clearly when information was provided than when information was not provided. But there is no effect on the subjects' perception of the movement of crossing pedestrians (Daimon & Kawashima, 2003). **Older drivers prefer a unique localization when multiple information systems were provided**.

**Benefits:** **Intersection ADAS** seems to be useful by drawing attention of the driver to oncoming traffic, to pedestrians and to the potential changing status of traffic lights while approaching the intersection. Overall, they seem to be **efficient to improve safety at intersection by permitting safer decisions**.

They also provide **support to older drivers to prevent red-light running**. A dominant explanation for **age-related changes in cognition**, which have received a lot of support, comes from inhibition deficit theory. According to this theory, with aging, it becomes **increasingly difficult for the older drivers to be able to cognitively suppress automatic or engaged action** and react quickly by braking at short yellow light onsets. With such **ADAS** older drivers adopt anticipatory behaviours with lower overall approaching speeds and remove their foot earlier from the accelerator pedal. While performing a **left turn**, they will also be **able to adopt shorter gaps** in a safer manner. Some older drivers are stressed and anxious while driving because they are afraid of not being able to operate as quickly and as efficiently as other drivers. Moreover, they can take inappropriate decisions under time pressure provided by other road users. **Using an intersection ADAS may reduce their stress, anxiety and could also facilitate their integration in traffic**.

**Ranking:** For these solutions, the **average price** offered by the market is between **500 and 1000 euros.** This will decline rapidly over the next five years, when these systems will be more widespread. The INTERSAFE-2 Project (Roessler, Westhoff, & Sick, 2010) estimates **a gain of 40% for injured people and 20% for fatally injured people in Europe**.

### 4.4.2 ADAS for headway control

Older drivers are involved in accidents related to headway control like failure to yield (Braitman, Kirley, Ferguson, & Chaudhary, 2007). There is an **age-related** decline in processing speed and cognitive inhibition that causes **slow reaction times** in response to changes in the lead vehicle's speed (Hakamies-Blomqvist, Siren, & Davidse, 2004). There are also age-related changes in sensory processing and perceptual processing that can result in **performance decrements** in detecting impending collisions during decelerations.

**Headway control systems** are mainly dedicated to car following situations at higher speeds, but technology improvements also lead to applications for lower speeds. The Headway Monitoring and Warning function **displays the current time headway to**

**the preceding vehicle and warns if it falls below a tuneable threshold** (typically 1 to 2 s).

The **Advanced Emergency Braking System** (AEBS) addresses imminent collisions in front of the vehicle. It first issues a Forward Collision Warning (FCW, visual, audible and/or haptic), it improves the braking if the driver brakes (Brake Assist System), and brakes automatically to avoid or mitigate the collision. Three main generations are available:

- Generation 1: limited braking on moving vehicles;
- Generation 2: improved deceleration and detection of moving and stationary vehicles;
- Generation 3: strong deceleration and detection of vehicles and pedestrians.

For the third generation, the pedestrian detection systems must be capable of distinguishing pedestrians or other vulnerable users from other objects within complex environments and to assess the relative velocity of the pedestrian.

Three different ADAS systems for headway control were analysed:

- **Adaptive cruise control (ACC)**: this system maintains a set speed and, when applicable, adjusts the speed to maintain a specified distance from a lead vehicle. When following another vehicle, the ACC system will automatically slow down or speed up in responses to changes in the lead vehicle's speed (Jenness et al., 2008a).
- **Forward crash warning (FCW)**: is an in-vehicle electronic system that monitors the roadway in front of the host vehicle and warns the driver when a potential collision risk exists. The FCW alert in this study is also augmented with a haptic brake pulse (Nodine et al., 2011).
- **Headway detection and alerting device (HDAD)**: is a laser technology-based device that detects the Time Headway (TH) of the driver's car to the lead vehicle. In this study conducted on a fixed base driving simulator, an experimental TH device was used; during the driving scenarios if a driver's TH falls below a predefined minimum, usually 1.5 to 2 s, the device emits an alerting signal (generally an auditory alarm) (Maltz et al., 2004).

Nodine et al. (2011) included "young" older drivers as participants. Maltz et al. (2004) presented a heterogeneous group of older drivers which cannot be classified as very old drivers but the mean age was 74 with some participants over the age of 80. Finally, Jenness et al. (2008a) present results obtained with younger and very old drivers.

<u>**Effectiveness:**</u> The studies observed that **older drivers maintained a more constant driving speed and headway when using the systems**. A "safe" range (>2s.) is also maintained under distraction. The mean time headway is not significantly different between the control group, the young group and the older group (between 3.2s. and 3.5s.). Drivers respond to forward threats more quickly when they received FCW alerts (Nodine et al., 2011).

There is an overall **good acceptance** of such ADAS. Older drivers are more likely to report usefulness, effectiveness, an increase in driving safety, and in their awareness. ADAS for headway control have **positive effects on safety with more constant speeds and following distances** (Jenness et al., 2008a; Nodine et al., Maltz et al., 2004). It is also observed that older drivers reduced headways and could increase speeds. Nevertheless, the headway remains within a safe range.

Overall, ADAS for headway control have positive safety aspects, particularly when older drivers **have to react to forward threats** by adopting fast and assertive responses following FCW alerts. **Older drivers responded less to the false alarms when they were distracted than when there was no distraction**, whereas younger drivers responded more to the false alarms when they were distracted than when they were not distracted. However as other research pointed out, **older drivers have longer headways and are not a homogeneous group**. Therefore, the **safety benefits** of these systems for older drivers **could be expected to be lower** than for younger drivers.

**Recommendations:** **The hearing ability or capacity of drivers decreases with aging**. Systems that rely on auditory messages need to take this into account. Older drivers may not be able to distinguish and respond to sounds as easily and fast as younger drivers. **Head up displays could be a good alternative** by providing a visual signal to the driver. Haptic solution could also be applied but in a more restrictive manner to incite the driver to adopt the desired behaviour such as slowing down to keep a safe distance.

Older drivers are particularly **anxious to violate the speed limits**. As a consequence they **spent more time fixating at the speedometer display**. They are afraid to miss a speed limit sign and thus they spent more time looking for it. Thus, this could have a negative effect on safety by **diverting their attention** from the driving scene. Accident data analyses tend to show that such behaviours are not too dangerous, principally because they adopt slower speeds with a safer headway. An ADAS solution for older drivers which could have an important comfort effect could be to **provide the speed limit of their driving area in real time**. This function could be achieved by an automatic speed limiter. Such systems could lead to an improved attention to the driving scene.

**Ranking:** These systems are already widespread and even the most sophisticated systems cost around €250. Regan et al. (2001) explains that **it costs older drivers more effort to get acquainted with this kind of technology**. Furthermore, rear-end crashes are not very frequent among the elderly which reduces their overall effectiveness.

### 4.4.3 ADAS for lateral control

Safety while driving depends on the driver capacity to visually gather relevant information from the roadway environment. In a lane changing situation the principal information comes from the rear view. **Older drivers** are known to **have** difficulty with neck rotation which leads to **difficulties to check blind spots** (Di Stefano & Macdonald, 2003). Nevertheless, in lane changing collisions, older drivers are more likely to be not responsible.

There are several types of systems providing assistance to the driver in case of lateral displacement. **Lane Departure Warning (LDW)** warns the driver if the vehicle deviates laterally from its lane (Visvikis, Smith, Pitcher, & Smith, 2008). In the same situation, **Lane Keeping Assist (LKA)** slightly turns the steering wheel to keep the vehicle in its lane (Visvikis et al., 2008). **The Lane Centring Assist** helps the driver to keep the vehicle centred in its lane, by applying a light steering torque. The current functionalities of LDW and LKA will be extended to rural road operation without line markings (Visvikis et al., 2008). These functions generally use a video camera to detect the lane markings in front of the vehicle. The **Blind Spot Detection** system

(BSD) warns the driver when a vehicle is in its blind spot , whereas the Lane Change Assist (LCA) warns the driver if he intends to change lanes when a vehicle is approaching from the rear in the next lane (Visvikis et al., 2008). The BSD generally uses rear lateral ultrasonic sensors (same technology as for the Park Assist). The Lane Change Assist typically uses rear lateral radar sensors

**Effectiveness:** Older drivers (60-70 years old) **maintain a better lane position** with fewer lane deviation (21% decrease), and cautionary and imminent lane-departure alert. This result is also significant for young drivers (Visvikis et al., 2008). In case of a conflict during a lane change to the left, the lane incursion time decreases significantly. The ADAS tested has no effect on lane deviation duration.

As for young drivers, lane change/merge near-crash rates did not decrease for older drivers. Nevertheless, older drivers present less near-crash events without the system. There was an overall good acceptance of the ADAS tested in this experiment (Nodine et al., 2011). Older drivers were more likely to report usefulness, effectiveness, an increase in their driving safety, and in their awareness.

**Imminent and cautionary lane departure warning appears to be an efficient ADAS to prevent or abort near-crash events and to improve lane positioning**. Lane change/merge warning or blind spot monitoring have a minor impact on safety with a greater turn signal effectiveness and faster response to lane change conflicts (Visvikis et al., 2008). One explanation is that older drivers are not very concerned with these driving situations as they are not involved in such accidents. They are cautious drivers who are less likely to be involved in distracted driving activities such as using a cell phone, texting, eating or drinking. Nevertheless, **the ADAS tested are accepted by elderly and are able to compensate some impairments particularly those related to lane changing**. Blind spot monitoring could only be viewed as a comfort system by older drivers. This system was well accepted and is the favourite system of elderly.

**Ranking:** This group of systems provides the greatest benefits for the elderly. The study on lane departure warning and lane change assistant systems by Visvikis, Smith, Pitcher, & Smith (2008) gives a very good overview of these systems concerning their effectiveness and public support. The cost varies from €250 to €1000 depending of the options selected (Average market value).

### 4.4.4 ADAS for curve control

Compared to other younger drivers, **older drivers** are generally more cautious and adopt lower speeds. They are underrepresented in speeding accidents. However, they are **involved in speeding-related accidents related to speed-adaptation failures or failing to yield**. When the traffic speed is constrained by road conditions such as traffic density or time of the day, older drivers seem to have more difficulties to adapt their driving speed to the situation. **Electronic Stability Control (ESP)** addresses the loss of control on a curve. This system has been developed to help drivers to manage potential dangerous situations if a bend in the road is taken too fast. The system intervenes in the braking repartition system and helps to maintain the vehicle on the trajectory defined by the steering angle given by the driver.

**Effectiveness:** This system shows a significant improvement in safety and an overall good acceptance and perceived effectiveness among users. **The overall effectiveness for older drivers remains quite moderate**. This could be explained by the fact that older drivers present the lower speed segment when entering a curve.

This fact is easily compensated by the fact that this system became mandatory in 2012 on all new vehicles.

**Ranking:** ESP can be regarded as the most efficient system of this family. Being mandatory since 2012, on all new passenger cars in Europe, the cost could be estimated to €0 for the client.

### 4.4.5 ADAS for navigation

In the specific area of cognition there is an **age-related decrease in spatial cognitive abilities**. Those changes lead to difficulties in accurately forming a mental representation of a spatial environment and efficiently navigating in those environments (Hakamies-Blomqvist, Siren, & Davidse, 2004). In interaction with visual or hearing problems**, older drivers experience navigation difficulties**. They make more navigation-related errors than younger drivers.

**Navigation systems help drivers to follow the optimal road from their initial position to a programmed destination**. The driver programs the destination by entering the address or the GPS coordinates. He can also select a Point Of Interest (POI), e.g. official buildings, hotel/restaurants, gas station… The navigation system displays a map of the road ahead and the path to the destination. At each intersection, it shows the path to follow. It also displays the distance and estimated time to the destination. Traffic information can be used to propose another route if relevant. Real-time traffic information is generally provided through FM radio signals. The navigation system is also a source of information for other ADAS (e.g. speed control systems) (Jenness, Lerner, Mazor, Osberg, & Tefft, 2008c).

**Effectiveness:** Only 4 % of the older drivers felt that the navigation system made them less safe while **39% of respondents thought that they were safer**. 73% of older drivers either disagreed or strongly disagreed with the statement that using a navigation system distracts them too much from the driving task. **Older drivers perceived the navigation system as less distracting than using a paper map or road atlas**. Older drivers use their navigation system less frequently than younger respondents; 74% of them use it less than once a month or one to three times per month (Jenness et al., 2008c).

80% of the older drivers evaluate their risk of getting lost as lower with the navigation system. The GPS enables them to drive in unfamiliar places, to drive more often at night, to drive more often in heavy traffic, or to drive alone. Older respondents were more likely than younger respondents to prefer listening to spoken directions, while younger respondents were more likely to prefer viewing directions on the navigation screen (Jenness et al., 2008c).

The system is also perceived as able to help them not getting lost. However, for older drivers a real perceived effectiveness for their mobility is related to the use of such a system. The results show that a large majority of older drivers use the system less than once a week which is really weak. Only a few older drivers thought that GPS enables them to drive in unfamiliar places. A possible explanation is that people limit the number of trips with ageing because they are retired. But some researches have shown that mobility is not reduced and those aged 75 or above often make everyday trips. Another explanation is that navigation systems are not designed for this specific population, and thus, are difficult to use. 26 % of older drivers thought that their system was too complex. The results indicate that **older drivers compared to younger drivers have more trouble with the visual displays.** 32% of older drivers report difficulties with sun glare or reflections on the navigation screen which make it difficult to see maps or directions (Jenness et al., 2008c).

**Recommendations:** Navigation systems are important to preserve mobility while aging and could lead to safer driving trips by preventing distraction. The first thing to do is to **simplify the ergonomics of the navigation system**. Using a display in the windshield or head-up displays (HUD) could be a possible solution to the age-related problem of divided-attention. As older drivers have longer fixation times on the display **the system must be able to relocate their attention to the driving scene**. A head up display could be supported with a specific hearing system designed to access the optimal range of frequency for older drivers.

**Ranking:** Even if these systems are becoming more and more popular in cars, with a high level of public support (estimated by expert) and a low price (below €500 for the most expensive and more and more often standard on the vehicle), the **effectiveness of these systems is quite low**. Indeed, navigation systems do not address older driver exposure to crashes directly but could have an **indirect result by giving them a sense of confidence for driving in certain areas**, weather and lighting conditions or traffic conditions where they would otherwise not drive (Jenness et al., 2008c).

### 4.4.6 ADAS for parking

Parking is a very complex manoeuver for a lot of drivers and especially for older people as they have difficulties with turning their head, neck, shoulders or body (Di Stefano & Macdonald, 2003). **Older driver's main errors** while parking are related to **visual scanning** (limitations of neck motion range) and **manoeuvres when leaving the park space**. They also encounter difficulties in their interaction with others during parking manoeuvres and more particularly with pedestrians (Kubitzki & Janitzek, 2009). **Older drivers often experience parking accidents**. This type of accident has less relevance for safety in term of severity since these are generally material-damage-only crashes. However, this particular manoeuver creates a lot of stress among older persons. They could restrict their driving to some destinations because of parking difficulties.

**Park assist enhances the driver's visibility in parking manoeuvers**. When using ultrasonic sensors, park assist indicates the distance between the rear or front bumper and close objects on the screen or via related sounds. Optionally lateral ultrasonic sensors can achieve a park slot measurement and indicate if the park slot is long enough for the vehicle (Jenness, Lerner, Mazor, Osberg, & Tefft, 2007).

When using a rear camera, the park assist shows the view from the rear bumper, revealing blind zones. Optionally the predicted path of the vehicle is overlaid in the picture. Several cameras can also be mounted around the vehicle and deliver a 360° surround view (Jenness et al., 2007). **By combining park assist with an electrically powered steering, the vehicle parks automatically.** In the future, the full automatic park assist will even manage the accelerator, brakes and gearbox during the parking manoeuvers. Remote parking will allow the driver to leave the vehicle and park it with a remote control. With valet parking, the vehicle will drive autonomously in a parking area and park in a free slot.

**Effectiveness:** Older drivers are less likely to report that they unintentionally backed into something or had a close call while driving their vehicles. 50% of them perceived the effectiveness of a backing aid system for detecting a child immediately under the rear bumper (Jenness et al., 2007). In the survey, older drivers reported more hearing problems and are also less likely to be aware of warnings and limitations about their system (Jenness et al., 2007). **The ADAS seems to be complex for older drivers with hearing or visual problems** (position of the display, sun glare).

**Ranking:** Park assist is becoming a standard for passenger vehicles and could be useful in very specific situations. But, like the navigation systems, there are **only few positive aspects regarding safety for elderly** (Jenness et al., 2007). These systems have a moderate average price of below €500 and a low public support.

### 4.4.7 ADAS for night driving

Deficits with aging include the ability to adapt to changes in light, night-time visual acuity and sensitivity to glare. Furthermore, **cataract which affects glare sensitivity, and night vision is prevalent while aging and is associated with increased accident risk** (DaCoTA, 2012a; Charlton et al., 2010). However, older drivers are not overinvolved in accidents at night. Older drivers tend to avoid night driving as a compensation strategy for visual impairments (Baldock et al., 2006).

**Night Vision systems** help the driver to detect danger by displaying an improved quality image compared to the human perception (Jenness, Lerner, Mazor, Osberg, & Tefft, 2008b). The infra-red camera detects the heat of vehicles, pedestrians, animals… and enhances them on the picture displayed on an on-board screen.

**High Light Assist** detects the situations when the driver should change from head lights to cruise lights and vice versa and automatically performs these actions (Jenness et al., 2008b). Most recent developments are considering additional situations like for example cities, lighted areas…. Furthermore, a better localization of the light sources (other vehicles) and the new generation of LED headlights allow to adapt the light beam shape and intensity in order to limit glaring effects when preserving a good visibility.

**Effectiveness:** A large-scale introduction of night vision enhancement systems will lead to an increased mobility for older drivers and thus their quality of life. But too few studies have been conducted up to now to have a clear vision of the changing driving habits of elderly with this type of system.

**Recommendation:** Advanced headlamps provide a significant support for driving at night. However, other types of systems focusing on pedestrian detection at night or an enhancement of visibility of the driving scene from a camera could also be interesting to investigate.

**Ranking: Night vision ADAS could be a useful system for elderly** and can assist them efficiently during night trips at a high price (~€2000 on market). However, the global efficiency of the system is quite low since older drivers restrict themselves not to drive during the night (Bayly, Fildes, Regan, & Young, 2007).

### 4.4.8 ADAS for driver monitoring

Driver monitoring approaches in the car industry takes place in the recent history of the Intelligent Transport Systems (ITS) centred on the development of « Adaptive » assistances. In this area, adaptive means devices being able to adjust the driving aid to the current driving context and to the specific drivers' status and current needs, at a given time (Bellet, Bailly-Ansuni, & Boy, 2011). Driver monitoring may provide two types of technological approaches.

The first one are **autonomous** ADAS systems to assess specific drivers' states and to warn them of the criticality of these states. A typical example of these devices are **Driver Drowsiness/ Sleeping Monitoring Systems** (Boverie, Giralt, & Le Quellec, 2008), aiming to diagnose drivers' low vigilance states in real-time and to display this information to them or to take control over the car.

The second approach is to **design embedded diagnosis functions to monitor the driver and to provide real-time diagnosis towards all other type of driving aids**, in order to activate these aids when required and / or to adapt Human-Machine Interactions modalities according to the specific status of the driver and/or the situational context (Amditis, Pagle, Joshi, & Bekiaris, 2010; Bellet & Manzano, 2007; Engström et al., 2006). The aim is to design Human-Machine Interaction managers able to observe car drivers, to diagnose driving errors, inadequate behaviours, non-voluntary risk taking, or all other **critical consequences of erroneous Situation Awareness** of the driver due to misperceptions or misunderstandings of the traffic situation.

**Ranking:** While this type of ADAS can provide valuable assistance for the elderly (and medically fragile people), it is a **technology that is developing less quickly**. The risk of accidents due to drowsiness or faintness stays far below 5%. These systems cost around €1000.

### 4.4.9 Autonomous Vehicle

All the major players in the automotive industry agree that the mobility of tomorrow will inevitably come with **the autonomous vehicle**. All car manufacturers turned to this new challenge that already exists in its first stage in our cars. This autonomous vehicle can be considered the ultimate ADAS in its "final" version as it will allow drivers to move safely from one point to another.

All studies agree that the autonomous vehicle will appear in several steps (Bilger, 2013; Litman, 2015; Wallace & Silberg, 2012):

- The first one is to **combine ACC Stop&Go with Lane Centring Assist**, resulting in partially automated driving at low speeds and in specific areas (the driver still monitors and takes over when necessary).
- A second possible step is the **Platooning**: a first vehicle is driven by a driver (typically a professional driver in a truck) and several vehicles follow in a highly automatic mode (no monitoring by the driver, but he takes over to change paths, exit the highway…).
- The last step is the **full autonomous driving** with all the driving tasks automated: navigation, vehicle control, and parking. It will regroup all other intelligent transport systems.

Several studies have already examined the technical development process (Bilger, 2013; Litman, 2015; Wallace & Silberg, 2012). In the "Autonomous vehicle implementation prediction" study (Litman, 2015) the scope for this ultimate ADAS shows only modest impacts on transportation planning factors such as road and parking supply and public transit demand for the next few decades. This is mainly explained by the fact that, **it will probably be 2050 before a middle-income family can afford to buy an autonomous vehicle**. An additional cost of €3000 could be expected for this technology compared with a classic vehicle. Beside this, the autonomous vehicle encounters a high public support even if some people stay suspicious regarding the risks of hacking or electronic failure.

**Recommendation:** Fully automated vehicle technologies will create safety benefits for older drivers as the sensory, cognitive and psychomotor abilities of the driver can be compensated for by these vehicles. As a result, elderly will stay mobile. Furthermore, driving automation technologies encompass six levels ranging from no automation to full automation (SAE, 2014). In that respect special attention should be paid to the older driver when the technology is situated in the intermediate level of market introduction (i.e. level 2 ‘partial automation’ and level 3 ‘conditional automation’) since these technology levels still require that the driver is capable to intervene if necessary. Therefore, it needs to be carefully analyzed and monitored to what extent older drivers are still capable to quickly intervene in the driving task if this is required.

# 5. Synthesis

This chapter summarizes the results of the bottom-up and top-down approach to select the most promising countermeasures to increase the road safety of older road users.

This chapter proceeds as follows. Section 5.1 starts with the selection of the most promising countermeasures from the perspective of older road users. Subsequently, suitable policy actions on EU-level are identified and formulated for each promising countermeasure (5.2).

## 5.1 Selection of most promising countermeasures

The **bottom-up approach** identified several potentially interesting countermeasures that could result in road safety benefits for older road users while the **top-down approach** established specific countermeasures targeted at the specific risks of older road users. In order to **identify the most promising countermeasures**, the countermeasures were scored based on the following four dimensions (see methodology section 2.2.2):

- Effectiveness
- Public support
- Costs
- Importance

Furthermore, weights were assigned to these dimensions to obtain a composite score for each countermeasure. It should be noted that for some countermeasures the scorings are not based on empirical studies but on expert judgements because the effects of certain countermeasures on older road users' safety are not always available from existing research. Consequently, the scoring needs to be interpreted with caution. The detailed calculations for identifying the most promising countermeasures by countermeasure area can be consulted in Annex 12 of the Annex Report. Based on these calculations, a top four of most promising countermeasures is selected for each countermeasure area. This top four is presented in the following sections.

### 5.1.1 Infrastructural interventions

The top four of most promising infrastructural countermeasures is presented in table 8. From this table it is apparent that the **most promising countermeasures** for older road users are a combination of infrastructural interventions in the area of **highway design, traffic control, urban and rural networks**.

**Table 8: Top four of most promising countermeasures within countermeasure area 'infrastructure'**

| Infrastructure | Total score |
|---|---|
| Reducing the speed of other traffic or excluding motor vehicles entirely from areas with many pedestrians | 4,14 |
| Use of protected-only operations at signalized intersections in urban areas | 3,86 |
| Self-explaining roads | 3,84 |
| Lower design speeds on interurban connecting roads and motorways | 3,78 |

Interestingly, these **measures** are also **targeted at the most important risks** of the elderly in traffic, i.e. **functional limitations and physical vulnerability**. The measures 'lower design speeds on interurban connecting roads and motorways' and 'reducing the speed of other traffic or excluding motor vehicles entirely from areas with many pedestrians' especially target the physical vulnerability of the elderly, while also taking the functional limitations of the elderly into account. 'Self-explaining roads' and 'Use of protected-only operations at signalized intersections' aim to decrease the complexity within the road environment which is a very crucial aspect for elderly road users. Furthermore, these measures also result in safety gains for all (elderly) road user types.

### 5.1.2 Education & Training

Table 9 illustrates that the most promising countermeasures within 'education & training' are those **aimed at raising awareness** about age-related illnesses and medication, self-regulation, functional limitations and the elderly's physical vulnerability.

These are very useful initiatives, because if older road users are personally at risk; this is mainly due to health-related conditions (physical and cognitive) or the use of (multi)medication that can affect their perceptual-motor abilities and/or their ability to compensate for these increased risks. Therefore, the **older road user himself needs**:

- To be aware about the potential problems and increased accident risks associated with ageing;
- To (learn to) compensate for potential age- or medical related perceptual-motor deficits that may affect one's safety.

Subsequently, national governments and other stakeholders also need to be made aware about older road user safety.

**Table 9: Top four of most promising countermeasures within countermeasure area 'education & training'**

| Education and training | Total score |
|---|---|
| Raise awareness about the influence of age-related illnesses and prescribed medication on driving abilities | 4,49 |
| Raise awareness of self-evaluating and improving their skills | 4,37 |
| Raise awareness of the effect of functional limitations (cognitive, sensory, physical) on abilities | 4,35 |
| Raise awareness about increased vulnerability and the importance of using protection devices | 4,05 |

Unfortunately however, experience shows that most people who are affected by awareness raising initiatives are already aware about their problems and thus are less in need of such initiatives. The **real challenge** is therefore **to make those people aware who are most in need of such initiatives**.

### 5.1.3 Licensing & Enforcement

Table 10 summarizes the top four of most promising countermeasures for older road users within the countermeasure area 'licensing & enforcement'. Since the elderly are more risk-aversive compared to other age groups, the **emphasis** within this countermeasure area primarily **lies on licensing**.

**Table 10: Top four of most promising countermeasures within countermeasure area 'licensing & enforcement'**

| Licensing and enforcement | Total score |
|---|---|
| License restrictions | 2,73 |
| License Renewal Policies: In-Person Renewal, Vision Test | 2,62 |
| Licensing screening and testing | 2,61 |
| Law enforcement roles | 2,11 |

### 5.1.4 Vehicle & ITS technologies

Vehicle and ITS technologies is a generic term that encompasses passive and active safety systems. Both safety systems produce safety benefits for older road users by supporting them in another way. Subsequently, these safety systems also have different deployment requirements. Therefore, it was opted to identify two different types of most promising countermeasures:

- **Measures that are implemented right now**. These are low-cost and easy to implement measures by which safety gains can be quickly achieved. This category contains the most promising **passive safety systems** (see table 11).
- **Measures that should be implemented in the (near) future**. These are high-cost measures of which the standard deployment in all vehicles depends on the maturity of the technology (technological advances) and requires economic incentives. This category includes the most promising **active safety systems** (see table 12).

The table below provides an overview of the most promising passive safety measures for elderly road users. **Passive safety systems** help to reduce the consequences of a crash without requiring any action of the road user. For the elderly, these systems are especially important since they can **compensate for their age-related physical vulnerability**.

**Table 11: Top four of most promising passive safety countermeasures within countermeasure area 'vehicle & ITS technologies'**

| Vehicle & ITS technologies | Total score |
|---|---|
| Safety belt + Belt Force limiter | 2,94 |
| Frontal airbag | 2,72 |
| Seat belt reminder | 2,59 |
| Safety helmet | 2,46 |

At the moment, vehicle manufactures already implement these passive systems in their cars due to the fact that they receive higher EuroNCAP-scorings when their cars are equipped with passive safety technologies. Therefore, the deployment of these systems in vehicles is mainly driven due to the fact that all these systems are already established in the European market (whether or not compulsory); low production costs; their proven efficiency and high user acceptability. As a result, the current trend within these passive safety systems regarding the older road user is to optimize what already exists instead of focusing on innovations. With this in mind, these passive safety countermeasures will not be further regarded as most promising (future) countermeasures for which EU policy actions are required.

The most promising active safety measures for older road users are presented in table 12. **Active safety systems** intervene before a crash occurs in order to help avoid crashes. These systems can help the elderly to stay mobile in a safe way by assisting them to **compensate for their age-related functional declines**.

**Table 12: Top four of most promising active safety countermeasures within countermeasure area 'vehicle & ITS technologies'**

| Vehicle & ITS technologies[1] | Total score |
|---|---|
| Active Pedestrian Protection System | 2,36 |
| Autonomous Vehicle | 2,35 |
| Lane Change Assistant/Lane Change Decision Aid | 2,21 |
| Intersection Control | 2,14 |
| [1] Applications that are already subject to on-going EU actions were ruled out of the selection process | |

The following most promising active safety systems for elderly road users have been identified:

- **Active Pedestrian Protection System**: a driving assistance system designed to alert drivers of a potential collision with a pedestrian by alerting the driver about the presence of pedestrian and initiating automatic emergency braking if the driver does not brake in time to avoid a collision. This system especially assists older drivers with a decline in sensory abilities and prevents vehicle-pedestrian crashes. This technology is mostly optional available in all vehicles.
- **Autonomous Vehicle**: a vehicle that is able to perform all the tasks of driving and navigation autonomously since it performs (all) driving tasks by itself without intervention of the driver. This active safety system assists older drivers with a combination of sensory, cognitive and psychomotor declines and can prevent all crash types. However, this technology is still under development.
- **Lane Change Assistant/Lane Change Decision Aid**: a system that alerts the driver of a possible collision with another road user (i.e. blind spot) during a lane change manoeuvre without actively intervening. This system assists older drivers with sensory and cognitive declines. This technology is mostly optional available in all vehicles.
- **Intersection control system**: a system which is designed to alert the driver of a possible collision with another road user when crossing an intersection by informing the driver of possible interactions with other road users. This system assists older drivers with sensory declines. However, this technology is still under development.

## 5.2 General recommendations and policy actions for most promising countermeasures

A range of regulatory and non-regulatory policy instruments are at the disposal of the European Commission (European Commission, 2015b):

- Legally binding rules;
- 'Soft' regulation;
- Education and information;
- Economic instruments.

These different types of policy instruments can also be combined to reach the objectives of a certain intervention (i.e. the implementation of a certain countermeasure).

The **traditional law instruments** (regulations, directives and decisions) have a **strong impact,** when they are fully adopted, since they prescribe the required behaviour of organizations or individuals. However, these instruments need several years to prepare and implement, while **'soft' regulation or non-binding instruments** can be implemented more rapidly. These instruments are **more flexible** and thus provide **more autonomy** for the Member States and other key stakeholders. It is, however, crucial that the involved actors support these 'soft' regulation instruments in order to be effective. These **'soft' regulation instruments include a range of policy instruments,** such as recommendations, technical standards, "pure" voluntary bottom-up initiatives (self-regulation) to legislation-induced co-regulatory actions (European Commission, 2015b).

Instruments within the field of '**education and information'** are used to reach EU objectives by informing citizens, consumers, producers and other actors. **This type of policy instrument includes** information and publicity campaigns, training, guidelines, disclosure requirements, and/or the introduction of standardised testing or rating systems (European Commission, 2015b). These instruments can be used to enhance public support for legislative and soft-regulation instruments. Furthermore, these are **cost-effective and flexible instruments** that can be easily adjusted to changing situations.

Finally, **economic instruments** are used to **enforce compliance to EU-legislation**. These instruments include sanctions (i.e. taxes, fines and penalties), subsidies and incentives and legal actions (European Commission, 2015b).

The following sections provide an overview of the most appropriate policy actions on EU-level for the different countermeasure areas. For each policy action, objectives are formulated for the most promising countermeasures within each countermeasure area.

### 5.2.1 Infrastructural interventions

Infrastructural interventions consist of two components (OECD, 2001):

- The physical infrastructure needed to guarantee safe mobility;
- The policy and regulatory frameworks required to provide equitable access to the physical infrastructure.

Due the **subsidiarity principle**, the **European Commission cannot decree infrastructural interventions** on the level of urban and rural roads (i.e. the road environments that are most often used by the elderly). However, the European Commission still has the power to formulate recommendations and to provide subsidies.

The **objective of the EU** in this area should be to **recommend changes in infrastructure design to better meet the safety needs of older road users**.

Appropriate actions to achieve this objective include:

1. Soft regulation
   - Recommend that elderly road user safety requirements are taken into account in the planning, pre-design and design stage, when new infrastructure for urban and rural areas infrastructure is being developed and that the best and most appropriate technologies are applied in the implementation phase in order to meet the elderly's requirements.
   - In collaboration with Member States, planners and designers, the Commission needs to recommend the setting-up of a global strategy for the implementation of age-friendly road infrastructure design concepts in urban and rural environments. This is very important to adopt a 'design for all' methodology since infrastructure improvements made specifically to accommodate older road users will benefit all age groups.
   - Recommend that intersections in urban networks should be treated with priority.
   - Recommend the development of self-explaining and forgiving roads in urban and rural environments.
   - Recommend the development of standards in the area of age-friendly road design.
   - Recommend to separate vulnerable road users from motorized traffic and/or introduce low design speeds in areas with many vulnerable road users.
   - Recommend to introduce lower design speeds on interurban connecting roads and motorways.
   - Stimulate voluntary initiatives between Member States, road infrastructure experts and user associations to define how elderly road user safety should be implemented in new road infrastructure projects and how the current road infrastructure should be adapted to meet the elderly's needs.
   - Encourage national governments, universities and road infrastructure experts to identify the road infrastructure improvements in urban and rural areas that will keep older road users safe and mobile.

**Table 13: Relevant policy actions for most promising infrastructural interventions**

| EU policy instruments | | Infrastructural interventions | | | |
|---|---|---|---|---|---|
| | | **Reducing the speed of other traffic or excluding motor vehicles entirely from areas with many pedestrians** | **Use of protected-only operations at signalized intersections in urban areas** | **Self-explaining roads** | **Lower design speeds on interurban connecting roads and motorways** |
| **Legally binding rules** | Regulations | | | | |
| | Directives | | | | |
| | Decisions | | | | |
| **Soft regulation** | Recommendations | x | x | x | x |
| | Technical standards | | | | |
| | Self-regulatory or voluntary initiatives | x | x | x | x |
| | Legislation-induced co-regulatory actions | | | | |
| **Information instruments** | Information and publicity campaigns | x | x | x | x |
| | Training | x | x | x | x |
| | Guidelines | x | x | x | x |
| | Introduction of standardised testing or rating systems | | | | |
| **Economic instruments** | Taxes/charges/fees/fines/penalties | | | | |
| | Subsidies and incentives | x | x | x | |
| | Labelling schemes | | | | |

2. Information instruments
   - Promote the application of relevant principles of road infrastructure safety for older road users through the exchange of best practices between Member States.
   - Increase the importance of (elderly) road safety elements in the guidelines for holistic urban management.
   - Formulate guidelines to separate vulnerable road users from motorized traffic and/or introduce low design speeds in areas with many vulnerable road users. Clear regulations should also be developed and applied in situations where this is not possible.

- Provide trainings, focusing on age-friendly infrastructural design concepts, to the officials of the infrastructure and transport authorities. These trainings can address the importance of protected-only operations, lower design speeds on interurban connecting roads and motorways, self-explaining roads and the separation of vulnerable road users from motorised traffic.
- Inform and train elderly road users in refresher courses on (new) traffic rules and modern road infrastructure concepts such as shared space, self-explaining and forgiving roads.

3. Economic instruments
   - Finance national road infrastructure projects focusing on the implementation of age-friendly traffic control operations at intersections.
   - Finance national road infrastructure projects focusing on the creation of self-explaining and forgiving road infrastructure, both in urban and rural environments.
   - Finance national road infrastructure projects focusing on separating the road infrastructure between vulnerable road users and motorized traffic.
   - Promote research on elderly safety implications related to the introduction of modern road infrastructure concepts such as shared space.
   - Stimulate further research in the area of self-explaining and forgiving roads in order to establish the impact of these measures in urban and rural road networks on the safety of older road users.

### Action plan

Infrastructural interventions focusing on **protected–only operations at signalized intersections**, **lower design speeds** and **reducing the speed of or excluding motor vehicles from areas with many pedestrians** already have a proven effectiveness. Therefore, the first action should be to **educate and inform** national governments and officials of infrastructure and transport authorities by the exchange of best practices between Member States, formulating implementation guidelines and providing trainings on age-friendly infrastructural design concepts. Secondly**, soft-regulation instruments** can be applied in the form of recommendations and voluntary initiatives. For instance, the European Commission can recommend the implementation of these infrastructural measures; the setting up of a global strategy for the implementation of age-friendly road infrastructure design concepts and/or to stimulate voluntary initiatives between Member States; road infrastructure experts and user associations to define how elderly road user safety should be implemented in new road infrastructure projects and how the current road infrastructure should be adapted to meet the elderly's needs. After this step, **economic instruments** should be applied to finance national road infrastructure projects focusing on age-friendly infrastructural interventions.

**Self-explaining and forgiving roads** is a broad infrastructural design concept of which the effects are not fully understood. For this intervention the initial focus should be to use **economic instruments** to finance further research in order to establish the impact of these measures in urban and rural road networks on the safety of older road users. Following this, **information instruments** should be applied to inform elderly road users and disseminate best practices across officials of national infrastructure and transport authorities. With respect to **elderly road users**, these information instruments should focus on training initiatives in the form of refresher courses. The information dissemination process for **officials of national infrastructure authorities** could focus on best practices and guidelines to implement age-friendly self-explaining and forgiving road design concepts. As a final step, **soft regulations** in the form voluntary initiatives and recommendations can be applied to introduce standards for age-friendly road design or to recommend the implementation certain self-explaining and forgiving road concepts in urban and rural networks.

### 5.2.2 Education & Training

Since **national, local and regional governments** are authorized to address the safety needs of older road users, it is crucial to ensure that all stakeholders are familiar with the elderly's safety and mobility requirements and have access to the instruments needed to promote them. Besides informing the stakeholders and encouraging them to act, it is **also pivotal to inform, educate and train older road users about his (individual) safety risk** so that he or she can proactively act.

Education, publicity and training are important tools to share and disseminate information and best practices concerning the elderly's safety needs. As stated in the OECD report (2001): *"Education, publicity and training efforts endeavour to raise public awareness of the mobility requirements and safety problems of older people, to support the planning and implementation of measures promoting older people's mobility and safety and to change the road safety habits of both older people and other road users"* (p.111).

These instruments typically include campaigns, training initiatives, and educational projects. An important prerequisite to be successful (i.e. to make sure that the efforts of the older road users and stakeholders do not stop at becoming aware), is that these **awareness raising initiatives need to be combined with other initiatives targeted at addressing the safety and mobility of older road users.**

As follows, the **objective of the EU** should be to **create additional awareness about older road user safety at different governmental levels** (EU, national, regional, local) so that these institutions can take action to design education, awareness and training initiatives targeted at older road users and key stakeholders.

**Table 14: Relevant policy actions for most promising education and training interventions**

| EU policy instruments | | Education & Training | | | |
|---|---|---|---|---|---|
| | | Raise awareness about the influence of age-related illnesses and prescribed medication on driving abilities | Raise awareness of self-evaluating and improving their skills | Raise awareness of the effect of functional limitations (cognitive, sensory, physical) on abilities | Awareness about increased vulnerability and the importance of using protection devices |
| Legally binding rules | Regulations | | | | |
| | Directives | | | | |
| | Decisions | | | | |
| Soft regulation | Recommendations | x | x | | |
| | Technical standards | | | | |
| | Self-regulatory or voluntary initiatives | x | x | x | x |
| | Legislation-induced co-regulatory actions | | | | |
| Information instruments | Information and publicity campaigns | x | x | x | x |
| | Training | x | x | x | x |
| | Guidelines | x | x | x | x |
| | Introduction of standardised testing or rating systems | | | | |
| Economic instruments | Taxes/charges/fees/fines/penalties | | | | |
| | Subsidies and incentives | x | x | x | x |
| | Labelling schemes | | | | |

In line with this objective, the appropriate actions include:

1. Soft regulation
   - Add a recommendation to the Driving License Directive to include education/training/ awareness initiatives within the national licensing policies.
   - To recommend national, local and regional governments together with health care workers and research institutes to design education, training and awareness initiatives aimed at improving the awareness of age-related,

illness-related deficits and prescribed medication and their potential effects on road user safety among the elderly and relevant stakeholders so they can act proactively.

- To recommend national, local and regional governments to design education and awareness initiatives aimed at sensitizing elderly road users in becoming aware of their own limitations by self-evaluation and improving their skills or adjusting their behaviour.
- Encourage national governments, to develop a long-term approach to improve the public awareness of elderly road users' mobility and safety needs.
- Stimulate voluntary initiatives between national governments, heath care and social programme workers to identify, develop and demonstrate training initiatives that can reduce the probability of age-related functional impairments.
- Support the introduction of standardized medical protocols to systematically assess the influence of age-related illnesses, functional limitations and prescribed medication on driving abilities. The results of these tests permit to design tailored-made educational and training initiatives to meet the individual needs and requirements of the older road user.

2. Information instruments
    - Promote the application of relevant education, training and awareness raising initiatives for older road users, national governments and health care workers through the exchange of best practices between Member States.
    - Educate health care workers to increase their own knowledge and awareness about age-related deficits or medication that may have an impact on road user safety and to proactively share this information and discuss these risks with the older road user.
    - Train elderly in recognizing their deficits and to adjust their behaviour accordingly which will result in more effective self-regulation of older road users and improved road user behaviour.
    - Train governments and health care workers in raising awareness about the influence of age-related illnesses and prescribed medication on driving abilities.
    - Train governments and health care workers in raising awareness about the effect of functional limitations (cognitive, sensory, and physical) on abilities.
    - Inform older road users about their increased age-related fragility and about the importance of using protection devices. These information initiatives should be combined with a practical training aimed at the correct usage of these protection devices.
    - Provide guidelines for health care workers to raise awareness about the influence of age-related illnesses and prescribed medication on driving abilities.
    - Provide guidelines for governments and health care workers to raise awareness about the effect of functional limitations (cognitive, sensory, and physical) on abilities.
    - Provide guidelines for governments and health care workers to develop training initiatives aimed at stimulating self-evaluation among elderly road users.

- Provide guidelines for governments, automotive industry and health care workers to raise awareness about age-related increased fragility and to develop trainings for the correct usage of protection devices.

3. Economic instruments
   - EU, national and regional governments in collaboration with the insurance sector should stimulate older road users to participate in awareness raising, educational and/or driver training activities, e.g. by offering financial incentives.
   - Subsidize national/regional education, publicity and training initiatives targeted at older road users.
   - Encourage health programmes that help reduce fragility.

### Action plan

The following action plan should be used to create additional awareness about older road user safety among different governmental levels, health care workers and the older road user himself.

A first step should be to **educate and inform** national, local and regional governments and health care workers about the safety risks of older road users. These instruments should be implemented first to increase public support for legislative and/or soft-regulation instruments within this area. **Health care workers** should be educated about age-related deficits or medication that may have an impact on road user safety so that they increase their own knowledge and awareness about these safety issues and can act proactively. Furthermore, the **representatives at different governmental levels and health care workers** can be educated and informed by the exchange of best practices within the area of education, awareness and training initiatives targeted at older road users and key stakeholders; formulating guidelines for developing effective campaigns; training initiatives and educational projects and providing trainings targeted on how to raise awareness. Subsequently, **elderly road users** should also be educated and trained in recognizing their deficits, estimating the effects of medication on driving abilities, adjusting their behaviour accordingly and the correct usage of protection devices.

As a final step **soft-regulations** should be implemented. For instance the **European Commission** should formulate and add a **recommendation to the Driving License Directive** to include education/training/ awareness initiatives within the national licensing policies. Other soft regulation instruments include **voluntary initiatives** between national governments, older people's organisations, health care workers and research institutes to identify, develop and demonstrate education and training initiatives to increase road user safety among the elderly. These soft-regulation instruments should be combined with **economic instruments** such as taxes or subsidies to incentivise the required actions from the Member States.

### 5.2.3 Licensing & enforcement

Due to convenience, comfort and safety reasons, the car is still and will probably remain the most preferred transportation mode by the elderly. Therefore**, future older driver programmes should support continued driving for as long as drivers are capable to meet specific medical and safety criteria**. In that respect, programmes entailing **gradual license restrictions** provide promising prospects to fulfil the elderly's safety and mobility needs.

In order to be non-discriminatory, these license restrictions need to be imposed based on **screening and assessment procedures for re-licensing in which the focus lies on health issues and not on age** since age-based license renewal is associated with neutral outcomes at best, or may be linked to negative safety effects for older people. These negative side effects are mainly due to the fact that age-based license renewal policies stimulate a modal shift among the elderly from driving to unprotected and less safe transportation modes (walking and cycling) that are not supported by the proper infrastructure for older users (Siren & Haustein, 2015). Furthermore, it is the biological and not the chronological age that determines how certain functional declines manifest themselves, as well as the pace at which this decline evolves. As such **license renewal policies based on health issues** provide the opportunity to create **tailored solutions** for the heterogeneous group of (older) drivers.

Screening and re-licensing procedures for older drivers have also been the subject of intense debate. However, in order to be successful **re-licensing procedures should include both screening and assessment procedures** (CONSOL, 2013b). In that respect, the listed countermeasures in table 15 should be combined in order to develop on effective, efficient and non-discriminatory re-licensing procedure.

**Gradual license restrictions** also **need to be enforced** in order to be successful. Health care workers, friends, family and law enforcement officers need to alert and inform older drivers when their driving fitness may be questionable and refer them to licensing agencies for driver screening and assessment. Subsequently, **the task of licensing agencies must be extended** from identifying at-risk drivers to helping them to maintain safe driving for as long as possible and assisting them in transitioning to non-driving when they are no longer able to drive safely (Eby et al., 2009).

As follows, the **objectives of the EU** should be to extend the idea of non-discriminatory gradual license restrictions, to design a re-licensing procedure based on screening and assessment procedures specifically tailored to target those drivers that are considered to be at higher risk and to develop a community-based referral system to support this license policy.

Suggested actions to achieve this objective include:

1. Legally binding rules
    - Create a uniform arrangement across the Member States concerning the decision on fitness to drive. The decision with respect to driving cessation and/or restrictions should not be based on age or on the diagnosis of any particular diseases, but on a judgement of health and functional abilities required for safe driving. This should be added to the Driving License Directive.

- Encourage driving license restrictions[1] for unfit drivers of all age groups when it is established that they pose risks to themselves and other road users. This should be added to the Driving License Directive.
- Create a uniform arrangement across the Member States with respect to in-person license renewal policies. This should be added to the Driving License Directive.

**Table 15: Relevant policy actions for most promising licensing & enforcement interventions**

| EU policy instruments | | Licensing & Enforcement | | | |
|---|---|---|---|---|---|
| | | **License restrictions** | **License Renewal Policies: In-Person Renewal, Vision Test** | **License screening and testing** | **Law enforcement roles** |
| **Legally binding rules** | Regulations | | | | |
| | Directives | x | x | | |
| | Decisions | | | | |
| **Soft regulation** | Recommendations | | | x | x |
| | Technical standards | x | x | x | |
| | Self-regulatory or voluntary initiatives | | | x | |
| | Legislation-induced co-regulatory actions | | | | |
| **Information instruments** | Information and publicity campaigns | x | x | x | x |
| | Training | | x | x | x |
| | Guidelines | x | x | x | x |
| | Introduction of standardised testing or rating systems | x | x | x | |
| **Economic instruments** | Taxes/charges/fees/fines/penalties | | | | x |
| | Subsidies and incentives | | | x | |
| | Labelling schemes | | | | |

[1] Restrict the license (restrict driving to specific times or distances, require adaptive vehicle equipment,…) or shorten the renewal cycle.

2. Soft regulation
    - Recommend research institutes, licensing agencies and health care workers to identify specific medical and safety criteria for any type of gradual license restrictions.
    - Recommend research institutes, licensing agencies and health care workers to identify and develop standardized protocols including tests of sensory, cognitive and psychomotor functions for license screening and testing.
    - Recommend research institutes, licensing agencies and health care workers to identify and develop standardized protocols for license renewal policies.
    - Recommend the establishment of multi-disciplinary medical advisory boards in each Member State engaged in the evaluation of driver performance and development of licensing policies.
    - Health care workers should offer the possibility and motivate the elderly's participation in self-assessment and voluntary testing initiatives for the early detection of driving deficits.
    - National governments should organize and promote the possibilities for voluntary driver self-assessment and training, but only to establish if further testing is necessary instead of determining license implications.
    - Recommend the establishment of specialised and certified mobility centres with multidisciplinary professionals (driving instructors, psychologists, physicians, etc.) to perform medical and driving tests and provide individually tailored trainings.
    - Stimulate the development of a community-based referral system involving physicians, health care professionals, police, friends and families of older drivers and older drivers themselves to identify high-risk drivers, encourage them to test their driving abilities and provide tailored solutions.
    - Implement fitness-to-drive issues in the formal medical training of physicians and other health professionals.

3. Information instruments
    - Inform (older) unfit drivers to participate in voluntary driver assessments such as online checklists or tests to raise awareness about the effects of functional limitations on driving abilities.
    - Inform health care professionals, licensing agencies and law enforcers about new developments in license restriction, renewal, screening and testing and the appropriate actions that are expected of them.
    - Train licensing agencies to help maintain safe driving for as long as possible and assisting drivers in the transition to non-driving besides only focusing on identifying at-risk drivers.
    - Provide standardized training and education for health care professionals, law enforcers and licensing personnel on fitness-to-drive.
    - Train licensing personnel in providing (tailored) license screening and testing.
    - Provide guidelines for health care professionals, licensing agencies and law enforcers to refer/report drivers for license screening and testing and provide immunity for those reporting.
    - Provide guidelines for license renewal policies.
    - Educate and train physicians, friends and families of older drivers to support the transition from driving to other transportation modes.
    - Support the introduction of standardized medical and driving protocols with respect to license restrictions, license renewal and license screening and testing.

- Stimulate (older) drivers to have an open mind about possibilities offered for self-assessment or voluntary driver testing, or to discuss one's personal situation with family and/or health care professionals (doctor, occupational therapist, pharmacist).

4. Economic instruments
    - EU, national and regional governments in collaboration with the insurance sector should stimulate (older) road users to participate in driver training and license screening and testing programmes, e.g. by offering financial incentives.
    - Penalize identified at-risk or unfit (older) drivers who refuse to participate in driver training and license screening and testing programmes.
    - Encourage national, regional and local governments to provide adequate alternative means of transportation for (older) road users who are no longer able to drive.
    - Encourage research institutes, licensing agencies and health care workers to explore the prediction of non-fitness to drive in order to establish testing standards by differentiating safe from at-risk driving.
    - Encourage research institutes to produce scientifically sound criteria (neuropsychological tests, medical tests and driving tests) to evaluate driving abilities (including compensation behaviour) and risks.

### Action plan

The following action plan should be implemented to apply the licensing and enforcement initiatives.

The first action with respect to **license restrictions, license renewal policies and law enforcement** should be to apply **information instruments** to create public support for the legislative and soft regulation instruments that will be introduced in a later phase. For instance, **health care professionals, licensing agencies and law enforcers** should by informed about new developments and the appropriate actions that are expected of them. Standardized training and education initiatives on fitness-to-drive and guidelines for license renewal, enforcement and restrictions should also be provided. Furthermore, **elderly drivers** should also be stimulated to create an open mind about possibilities offered for license restrictions, or to discuss one's personal situation with family and/or health care professionals. As a next step, **soft regulation instruments** such as **technical standards and recommendations** can be used to identify and develop standardized protocols for license restriction and renewal and to introduce specific medical and safety criteria for license restrictions, to establish multi-disciplinary medical advisory boards in each Member State engaged in the evaluation of driver performance and development of licensing policies. As a final step, **legally binding rules** focussing on a uniform arrangement across Member States with respect to license renewal policies and license restrictions for unfit drivers should be included to the **Driving License Directive**. Economic instruments in the form of tax reductions or penalties can be coupled to these binding rules to incentivise that the Member States will take action.

Currently, a lot of uncertainty exists about the effectiveness of different **license screening and testing approaches**. Therefore, the first step should focus on **financing research** to explore the prediction of non-fitness to drive in order to establish testing standards by differentiating safe from at-risk driving and to produce scientifically sound criteria (neuropsychological tests, medical tests and driving tests) to evaluate driving abilities (including compensation behaviour) and risks. Secondly,

**information instruments** should be applied to educate and train health care professionals, licensing agencies, law enforcers and older drivers about license screening and testing procedures. Regarding **older drivers**, these information instruments should focus on informing them about the possibilities for self-assessment or voluntary driver testing and encouraging to them to take these tests in order to raise awareness about the effects of functional limitations on driving abilities. The **information dissemination process for health care professionals, licensing agencies and law enforcers** could focus on informing them about new developments in license screening and testing and the appropriate actions that are expected of them; informing them about the guidelines and procedures to report fitness-to-drive issues; introducing standardized medical and driving protocols with respect to license screening and testing and training them to apply these protocols. Thirdly, **soft-regulation instruments** in the form of **voluntary initiatives, recommendations and technical standards** should be introduced to identify and develop standardized protocols for license screening and testing, to organize and promote the possibilities for voluntary driver self-assessment and training and stimulate the development of a community-based referral system to identify high-risk drivers, encourage them to test their driving abilities and provide tailored solutions. Finally, **legally binding rules** focussing on creating a uniform arrangement across Member States concerning the decision on fitness to drive should be included to the **Driving License Directive**. **Economic instruments** in the form of tax reductions or penalties can be coupled to these binding rules to incentivise that the Member States will take action and to encourage that drivers participate in (voluntary) driver training and license screening and testing programmes.

### 5.2.4 Vehicle & ITS technologies

In recent years, vehicle manufacturers have also focused on the development of **advanced vehicle technologies or driver assistance systems**. Selected vehicle models are already equipped with certain ADAS or active safety technologies. However, the **deployment rate is still low** for most applications. The further deployment of these systems will require more efforts than for passive safety systems since these systems are **technology-dependent, high cost measures** of which the effectiveness is permanently fine-tuned. Currently, these technologies are developed without applying a **user-centered approach for older drivers**. This should be the norm given the reasoning that **if a certain ADAS-system can be easily used by older drivers, it will produce safety benefits for all drivers**.

In contrast with passive safety technologies, it is very **complicated to stimulate the deployment of active safety systems through legislation** due to the swift technological and market developments in this area. As a result, these developments will most certainly outrun the legislative process. Furthermore, **mandatory fitment of specific types of active safety systems** in all vehicles necessitates that the technology is mature, cost-effective and has a proven safety-efficiency. At the moment, this stage has not been reached for the selected most promising active safety technologies.

Therefore, the **objective of the EU** within the area of **active safety technologies** should be aimed on giving the right stimulus to **design and inform older road users about effective vehicle safety technologies** to better protect the older road user and to **stimulate the development and deployment of elderly-adapted ADAS**[2] by the automotive sector.

Suggested actions to achieve this objective include:

1. Soft regulation
   - Recommend the development of better active vehicle safety standards for older and more vulnerable road users by including the elderly within the design process.
   - In collaboration with the automotive industry, the Commission needs to propose the setting-up of a global strategy of action on elderly-adapted ADAS technologies to organize and stimulate the development of elderly-adapted ADAS technology standards addressing the functional limitations of older road users.
   - Stimulate voluntary agreements between members of the vehicle technology and manufacturing sector to switch the focus from the vehicle to the needs of the (older) drivers within the design and development process.
   - Introduce a standardized testing procedure to systematically asses the usability and effectiveness of advanced vehicle technologies for older drivers. This should be done by including elderly safety in EuroNCAP testing.

2. Information instruments
   - Dissemination of best practices concerning effective vehicle technologies for the elderly and elderly-adapted ADAS technologies across the vehicle technology and manufacturing sector.
   - Educate and train older people on the correct usage of active safety technologies (elderly-adapted ADAS technologies).
   - To inform older road users about effective active safety technologies to better protect the older and more vulnerable road user.
   - Formulate guidelines for the development of assistive in-car technologies to minimize the information overload of these technologies for older drivers.

3. Economic instruments
   - Subsidize R&D of active safety technologies focusing on older drivers.
   - Award subsidies for the deployment of active safety technologies focusing on older drivers.
   - Stimulate research addressing current technical and user-friendly limitations of active safety technologies for older drivers.
   - Explore the potential benefits and drawbacks of (semi-) automated driving in extending the driving life of older road users by offering assistance to compensate for functional limitations.
   - Encourage the further development of crash avoidance systems, such as intersection or lane change assistants.
   - Investigate the impact of mandatory active pedestrian protection systems for all new vehicles.

[2] Elderly-adapted ADAS (E-ADAS): adaptive driving aids specifically dedicated to older drivers.

**Table 16: Relevant policy actions for most promising active safety countermeasures**

| EU policy instruments | | Active safety measures | | | |
|---|---|---|---|---|---|
| | | **Active pedestrian protection system** | **Autonomous vehicle** | **Lane change assistant/ lane change decision aid** | **Intersection control** |
| **Legally binding rules** | Regulations | | | | |
| | Directives | | | | |
| | Decisions | | | | |
| **Soft regulation** | Recommendations | x | x | x | x |
| | Technical standards | x | x | x | x |
| | Self-regulatory or voluntary initiatives | x | x | x | x |
| | Legislation-induced co-regulatory actions | | | | |
| **Information instruments** | Information and publicity campaigns | x | x | x | x |
| | Training | x | x | x | x |
| | Guidelines | x | x | x | x |
| | Introduction of standardised testing or rating systems | x | x | x | x |
| **Economic instruments** | Taxes/charges/fees/fines/penalties | | | | |
| | Subsidies and incentives | x | x | x | x |
| | Labelling schemes | | | | |

## Action plan

The automotive market is characterized by swift technological and market developments resulting in new and/or improved advanced driver assistance systems. Due to this swiftness, the policy actions for the most promising countermeasures should be implemented in a certain order.

In general, the first action should be to **finance research** focusing on identifying the current technical and user-friendly limitations and benefits of ADAS for older drivers in order to identify the safety-benefits for older drivers and potential points for improvement.

Currently, **lane change assistant systems and active pedestrian protection systems** are already implemented in the vehicle models of the premium vehicle brands. In that respect the technology is already mature enough to be implemented but **economic instruments** can still be used to also implement the technologies in non-premium vehicle brands. However, initially the focus should lie on applying **information instruments** to inform elderly drivers and disseminate best practices across the vehicle technology and manufacturing sector. With respect to **elderly drivers**, these information instruments should focus on informing them about the safety benefits of these active safety technologies and educating and training them on the correct usage of these technologies. The information dissemination process within the **vehicle technology and manufacturing sector** could focus on best practices concerning effective vehicle technologies for the elderly and elderly-adapted ADAS technologies and guidelines to develop assistive in-car technologies that minimize the information overload. As a final step, **soft regulations** in the form of technical standards, voluntary initiatives and recommendations can be applied to introduce elderly-adapted ADAS technology standards or to recommend the mandatory implementation of active pedestrian protection and lane change assistant systems to all new vehicles.

**Intersection control systems and autonomous vehicles** are relatively new technologies that are still in a developmental phase. Since, these technologies are too premature for full deployment; the first step should be to apply **economic instruments** to stimulate research to explore the potential benefits and drawbacks of these technologies for elderly drivers. Following this, **soft-regulations** should be used in the form of **voluntary initiatives.** These initiatives should be set up between members of the vehicle technology and manufacturing sector and should focus on switching the attention from the vehicle to the needs of the (older) drivers by including elderly within the design and development process. Subsequently, **information instruments** targeted at elderly drivers and the vehicle technology and manufacturing sector should be implemented. Concerning, **elderly drivers** these information instruments should focus on informing them about the safety benefits of these active safety technologies and (in a later phase) educating and training them on the correct usage when the technologies are available. Within the **vehicle technology and manufacturing sector** the focus should lie on disseminating best practices, guidelines and technical standards concerning elderly-adapted ADAS technologies. Finally, **soft-regulations** in the form of recommendations and technical standards can be implemented to support the full deployment when the technology for **intersection control systems and autonomous vehicles** is mature.

## 5.3 Recommendations for action

Additional to the specific actions by countermeasure area, the ElderSafe project formulates the following recommendations for action with respect to the overall road safety policy for elderly road users. A multi-actor approach is necessary to keep older road users safe and mobile.

**Health care workers**

- To increase their own knowledge and awareness about age-related deficits or medication that may have an impact on road user safety;
- To pro-actively share information and discuss about such risks with the older road user;
- To offer possibilities and motivate the participation in self-assessment and voluntary testing for the early detection of driving deficits;
- Train elderly in recognizing their deficits and to adjust their behaviour accordingly which will result in more effective self-regulation of older road users and improved road user behaviour;
- Inform older road users about their increased age-related fragility and about the importance of using protection devices. These information initiatives should be combined with a practical training aimed at the correct usage of these protection devices.

**Vehicle technology and manufacturing sector**

- To design and inform older road users about effective vehicle safety technologies to better protect the (older) vulnerable road user;
- To design smart vehicle safety technologies adapted to the needs and individual characteristics of different driver groups, such as the higher physical vulnerability of the older driver and passengers (i.e. design for all);
- Educate and train older people on the correct usage of active safety technologies (elderly-adapted ADAS technologies);
- To systematically assess the usability of advanced vehicle technologies for older drivers.

**Local and regional governments**

- To design education and awareness campaigns aimed at improving the awareness of age-related, illness-related deficits and prescribed medication and their potential effects on road user safety;
- To provide safe, easy-to-use and comfortable transportation alternatives for (older) road users who are no longer able to drive;
- To create self-explaining and forgiving road infrastructure, both in urban and rural environments;
- To organize and promote possibilities for voluntary driver self-assessment and training;
- To formulate guidelines to separate vulnerable road users from motorized traffic and/or introduce low design speeds in areas with many vulnerable road users. Clear regulations should also be developed and applied in situations where this is not possible;
- To inform and train elderly road users in refresher courses on (new) traffic rules and modern road infrastructure concepts such as shared space, self-explaining and forgiving roads;
- To establish specialised and certified mobility centres with multidisciplinary professionals (driving instructors, psychologists, physicians, etc.) to perform medical and driving tests and provide individually tailored trainings;

- To develop a community-based referral system involving physicians, health care professionals, police, friends and families of older drivers and older drivers themselves to identify high-risk drivers, encourage them to test their driving abilities and provide tailored solutions;
- To implement fitness-to-drive issues in the formal medical training of physicians and other health professionals;
- To provide standardized training and education for health care professionals, law enforcers and licensing personnel on fitness-to-drive;
- To provide guidelines for health care professionals, licensing agencies and law enforcers to refer/report drivers for license screening and testing and provide immunity for those reporting.

**Research institutes**

- To better understand the accident circumstances in which older road users are involved and propose effective countermeasures;
- To produce scientifically sound criteria (neuropsychological tests, medical tests, driving test) to evaluate driving abilities (including compensation behaviour) and risks;
- To explore the impact of innovative transportation means such as electric vehicles, pedelecs (e-bikes) and intelligent bikes on elderly safety;
- To explore the exposure patterns of elderly road users;
- To evaluate the effectiveness of countermeasures to improve older road user safety;
- To explore the prediction of non-fitness to drive in order to establish testing standards by differentiating safe from at-risk driving.

**Insurance sector**

- To stimulate older road users to participate in awareness raising, educational and/or driver training activities, e.g. by offering financial incentives.

**European Commission**

- To create additional awareness about older road user safety at different governmental levels (EU, national, regional, local);
- To stimulate Member States to address older road user safety in their national mobility plans;
- To exchange information on best practice countermeasures to increase older road user safety;
- To stimulate scientific research in the area of older road user safety;
- To include (older) vulnerable road user safety in vehicle safety testing standards;
- To monitor that interventions aimed to increase the safety and mobility of elderly road users are not discriminatory;
- To promote urban road safety policies within sustainable urban mobility plans;
- To develop stronger policies for traffic safety of pedestrians and other VRUs;
- To explore the potential benefits and drawbacks of (semi-) automated driving for older road users;
- To increase the importance of (elderly) road safety elements in the guidelines for holistic urban management;
- Add a recommendation to the Driving License Directive to include education/training/ awareness initiatives within the national licensing policies;
- To encourage health programmes that help reduce fragility;

- To introduce a standardized testing procedure to systematically asses the usability and effectiveness of advanced vehicle technologies for older drivers. This should be done by including elderly safety in EuroNCAP testing;
- To create a uniform arrangement across the Member States concerning the decision on fitness to drive. The decision with respect to driving cessation and/or restrictions should not be based on age or on the diagnosis of any particular diseases, but on a judgement of health and functional abilities required for safe driving;
- To create a uniform arrangement across the Member States with respect to license renewal policies;
- To introduce standardized medical and driving protocols with respect to license restrictions, license renewal and license screening and testing.

**The older road user himself**

- To be aware about the potential problems and increased accident risks associated with ageing;
- To (learn to) compensate for potential age- or medical related perceptual-motor deficits that may affect one's safety;
- To have an open mind about possibilities offered for self-assessment or voluntary driver testing, or to discuss one's personal situation with family and/or health care professionals (doctor, occupational therapist, pharmacist);
- To prepare the transition from driving to life-after-car.

# 6. Conclusions

In the coming years, Europe is facing a significant shift in the age distributions of populations. **By 2050, one in four people will be aged 65 or over**. This increase in the older population coincides with an increase in older road users since far more elderly people will actively participate in traffic. As a result, the **road safety situation of the elderly** will also change since the normal ageing process makes people more prone to **experience functional declines** that can make **driving a car** more difficult. However, the **fatal accident risk for elderly cyclists and pedestrians** is many times higher than for elderly car drivers. Therefore, the challenge lies in making the European traffic safety policy and the transportation system '**silver proof**'.

In the light of these challenges, this report has explored the **road safety risks and main trends** for all older road user groups (drivers, passengers and pedestrians). It has also attempted to identify the **most promising current and future countermeasures** aimed at increasing road safety for all (older) road user groups in **order to develop a proactive strategy** to enhance the road safety of the elderly in the (near) future.

On this basis, the following conclusions highlight, the most important risk factors and policy and research recommendations to provide comfortable, safe and lifelong mobility for the future generations of elderly.

## 6.1 Key safety issues of elderly road users

Risk factors can make a considerable contribution to crashes or injuries. The risk factor analysis revealed that the road safety problem of elderly road users has three dimensions, not independent of each other: exposure, accident risk and injury risk. Within these three dimensions, the following **thirteen risk domains for elderly** road users in Europe are identified:

1. Exposure
    - Urban roads;
    - Rural roads;
    - Transportation mode: car driver, car passenger, PTW-user, pedestrian, cyclist and public transport user.
2. Accident risk
    - Illnesses/functional limitations;
    - Medication;
    - Risk taking/distraction;
    - Self-regulation.
3. Injury risk
    - Fragility.

However, it is not always straightforward to reduce or eliminate the negative effects of certain risk domains since interventions in some risk domains may receive a strong public support or result in greater safety benefits. Therefore, the **following risk domains** require **prior attention** because they have the **strongest impact on the reduction of serious traffic casualties** among the elderly, and because they receive a strong support by the public in terms of countermeasures:

1. Fragility
2. Illnesses and functional limitations
3. Urban roads
4. Pedestrians (i.e. walking as a transportation mode)
5. Medication

## 6.2 Policy recommendations to enhance the safety of the elderly

Unless there is a fundamental reconsideration of the road traffic system to guarantee that the safety and mobility needs of elderly road users are met, the risk associated with older road users will aggravate in light of the expected demographic changes. Therefore, measures targeting these risk factors are of great interest to the safety of elderly road users and should be a key priority of any policy. In order to meet the safety and mobility needs of elderly road users in the (near) future a **comprehensive and proactive strategy** is required which will encompass policy at EU, national, regional and local levels and includes **a package of measures** composed of:

- Infrastructural interventions;
- Education & training;
- Licensing & enforcement;
- Vehicle & ITS technologies.

The key policy priority in the (near) future is that this package of measures should be based on a **"design for all" approach**. This approach takes the specific needs, opportunities and limitations of different road users into account. As a result, these measures will not only enhance the road safety and mobility of the elderly; younger road users will also benefit from an age-friendly design.

### 6.2.1 Infrastructural interventions

Creating and providing a **safe road environment** can significantly improve the safety and mobility of elderly road users. Additionally, improvements in infrastructure and road design can realize immediate **safety benefits and cost-effective results**. Several interventions in road design have the potential to improve the safety of elderly road users, however, only a handful seems to address the most important risk factors of elderly people. It is recommended:

- To separate vulnerable road users from motorized traffic and/or introduce low design speeds in areas with many vulnerable road users.
- To develop self-explaining and forgiving roads in urban and rural environments.
- To reduce conflicts between VRU's and vehicles and between vehicles at intersections in urban networks.
- To use protected-only operations at signalized intersections in urban areas.
- To develop standards in the area of age-friendly road design.

### 6.2.2 Education and training

The safety benefits of educational and training programs are difficult to assess. However, **creating a better awareness** among the elderly of health and medical conditions and functional abilities that affect their driving, age-related vulnerability, and the adoption of self-regulation strategies will remain a **key policy priority** in the (near) future. Therefore, it is recommended to:

- Train elderly in recognizing their deficits and to adjust their behaviour accordingly which will result in more effective self-regulation of older road users and improved road user behaviour.
- Inform older road users about their increased age-related fragility and about the importance of using protection devices. These information initiatives should be combined with a practical training aimed at the correct usage of these protection devices.
- Introduce standardized medical protocols to systematically assess the influence of age-related illnesses, functional limitations and prescribed medication on driving abilities. The results of these tests permit to design tailored-made

educational and training initiatives to meet the individual needs and requirements of the older road user.

### 6.2.3 Licensing and enforcement

As the number of elderly people will increase in the future, most will have a driving license, access to a car and will prefer to drive in old age. Therefore**, future older driver programmes should support continued driving for as long as drivers are capable to meet specific medical and safety criteria**. In that respect, programmes entailing **gradual license restrictions** provide promising prospects to fulfil the elderly's safety and mobility needs. Therefore, it is recommended to:

- Create a uniform arrangement across the Member States concerning the decision on fitness to drive. The decision with respect to driving cessation and/or restrictions should not be based on age nor on the diagnosis of any particular diseases, but on a judgement of health and functional abilities required for safe driving.
- Establish specialised and certified mobility centres with multidisciplinary professionals (driving instructors, psychologists, physicians,…) to perform medical and driving tests and to provide individually tailored trainings.
- Stimulate the development of a community-based referral system involving physicians, health care professionals, police, friends and families of older drivers and older drivers themselves to identify high-risk drivers, encourage them to test their driving abilities and provide tailored solutions.
- Inform (older) unfit drivers to participate in voluntary driver assessments such as online checklists or tests to raise awareness about the effects of functional limitations on driving abilities.
- Train licensing agencies to help maintain safe driving for as long as possible and assisting drivers in the transition to non-driving besides only focusing on identifying at-risk drivers.
- Provide guidelines for health care professionals, licensing agencies and law enforcers to refer/report drivers for license screening and testing and provide immunity for those reporting.
- Encourage research institutes to produce scientifically sound criteria (neuropsychological tests, medical tests and driving tests) to evaluate driving abilities (including compensation behavior) and risks.

### 6.2.4 Vehicle & ITS technologies

Interventions within the area of vehicle and ITS technologies provide potential to enhance the safety of elderly road users since **advanced vehicle technologies or driver assistance systems** can help the elderly to stay mobile in a safe way by assisting them to **compensate for their age-related functional declines**. Currently, these technologies are developed without applying a user-centered approach for older drivers. Therefore, it is time to design an **age-friendly vehicle**. It is recommended to:

- Develop better active vehicle safety standards for older and more vulnerable road users by including the elderly within the design process.
- Introduce a standardized testing procedure to systematically asses the usability and effectiveness of advanced vehicle technologies for older drivers. This should be done by including elderly safety in EuroNCAP testing.
- Educate and train older people on the correct usage of active safety technologies (elderly-adapted ADAS technologies).

- Encourage the further development of crash avoidance systems, such as intersection and lane change assistants and active pedestrian protection systems.
- Explore the potential benefits and drawbacks of (semi-) automated driving in extending the driving life of older road users by offering assistance to compensate for functional limitations.

### 6.2.5 Preserve and enable lifelong mobility

Infrastructural interventions, education & training initiatives, licensing restrictions and vehicle & ITS technologies can only compensate for reduced fitness to drive to a certain degree. Furthermore, mobility, health and well-being are intertwined since the **loss of mobility is connected with declines in life quality, functional independence and physical and mental health**. Therefore, elderly safety and mobility should be balanced equally in the development of an elderly transport safety strategy. Thus, maintaining the mobility of elderly who quit or are forced to cease driving will be a **key policy priority** in the (near) future. This should be realized by **providing alternative transport options and services**. These measures must be taken now in order to cope with the expected increases in the elderly population. Therefore, all policy levels and key stakeholders must work together to support the elderly by:

- Expanding and improving conventional public transport services adapted to the elderly's travel patterns.
- Offering safe, affordable, reliable, accessible transportation alternatives to elderly people before they are forced to cease driving.
- Training and informing elderly people about how to use these alternative transport options and services.
- Health care workers, licensing agencies, friends and families of older drivers should help the older driver to prepare the transition from car driving to life-after-car.

Finally, the older road user himself should have an open mind about his life-after-driving and should also consider life-decisions that can positively affect mobility into old age such as relocating to urban areas.

## 6.3 Recommendations for action

Additional to the specific actions by countermeasure area, the ElderSafe project formulates the following recommendations for action with respect to the overall road safety policy for elderly road users. A multi-actor approach is necessary to keep older road users safe and mobile.

**Health care workers**

- To increase their own knowledge and awareness about age-related deficits or medication that may have an impact on road user safety;
- To pro-actively share information and discuss about such risks with the older road user;
- To offer possibilities and motivate the participation in self-assessment and voluntary testing for the early detection of driving deficits;
- Train elderly in recognizing their deficits and to adjust their behaviour accordingly which will result in more effective self-regulation of older road users and improved road user behaviour;
- Inform older road users about their increased age-related fragility and about the importance of using protection devices. These information initiatives should

be combined with a practical training aimed at the correct usage of these protection devices.

**Vehicle technology and manufacturing sector**

- To design and inform older road users about effective vehicle safety technologies to better protect the (older) vulnerable road user;
- To design smart vehicle safety technologies adapted to the needs and individual characteristics of different driver groups, such as the higher physical vulnerability of the older driver and passengers (i.e. design for all);
- Educate and train older people on the correct usage of active safety technologies (elderly-adapted ADAS technologies);
- To systematically assess the usability of advanced vehicle technologies for older drivers.

**Local and regional governments**

- To design education and awareness campaigns aimed at improving the awareness of age-related, illness-related deficits and prescribed medication and their potential effects on road user safety;
- To provide safe, easy-to-use and comfortable transportation alternatives for (older) road users who are no longer able to drive;
- To create self-explaining and forgiving road infrastructure, both in urban and rural environments;
- To organize and promote possibilities for voluntary driver self-assessment and training;
- To formulate guidelines to separate vulnerable road users from motorized traffic and/or introduce low design speeds in areas with many vulnerable road users. Clear regulations should also be developed and applied in situations where this is not possible;
- To inform and train elderly road users in refresher courses on (new) traffic rules and modern road infrastructure concepts such as shared space, self-explaining and forgiving roads;
- To establish specialised and certified mobility centres with multidisciplinary professionals (driving instructors, psychologists, physicians, etc.) to perform medical and driving tests and provide individually tailored trainings;
- To develop a community-based referral system involving physicians, health care professionals, police, friends and families of older drivers and older drivers themselves to identify high-risk drivers, encourage them to test their driving abilities and provide tailored solutions;
- To implement fitness-to-drive issues in the formal medical training of physicians and other health professionals;
- To provide standardized training and education for health care professionals, law enforcers and licensing personnel on fitness-to-drive;
- To provide guidelines for health care professionals, licensing agencies and law enforcers to refer/report drivers for license screening and testing and provide immunity for those reporting.

**Research institutes**

- To better understand the accident circumstances in which older road users are involved and propose effective countermeasures;
- To produce scientifically sound criteria (neuropsychological tests, medical tests, driving test) to evaluate driving abilities (including compensation behaviour) and risks;
- To explore the impact of innovative transportation means such as electric vehicles, pedelecs (e-bikes) and intelligent bikes on elderly safety;
- To explore the exposure patterns of elderly road users;
- To evaluate the effectiveness of countermeasures to improve older road user safety;
- To explore the prediction of non-fitness to drive in order to establish testing standards by differentiating safe from at-risk driving.

**Insurance sector**

- To stimulate older road users to participate in awareness raising, educational and/or driver training activities, e.g. by offering financial incentives.

**European Commission**

- To create additional awareness about older road user safety at different governmental levels (EU, national, regional, local);
- To stimulate Member States to address older road user safety in their national mobility plans;
- To exchange information on best practice countermeasures to increase older road user safety;
- To stimulate scientific research in the area of older road user safety;
- To include (older) vulnerable road user safety in vehicle safety testing standards;
- To monitor that interventions aimed to increase the safety and mobility of elderly road users are not discriminatory;
- To promote urban road safety policies within sustainable urban mobility plans;
- To develop stronger policies for traffic safety of pedestrians and other VRUs;
- To explore the potential benefits and drawbacks of (semi-) automated driving for older road users;
- To increase the importance of (elderly) road safety elements in the guidelines for holistic urban management;
- Add a recommendation to the Driving License Directive to include education/training/ awareness initiatives within the national licensing policies;
- To encourage health programmes that help reduce fragility;
- To introduce a standardized testing procedure to systematically asses the usability and effectiveness of advanced vehicle technologies for older drivers. This should be done by including elderly safety in EuroNCAP testing;
- To create a uniform arrangement across the Member States concerning the decision on fitness to drive. The decision with respect to driving cessation and/or restrictions should not be based on age nor on the diagnosis of any particular diseases, but on a judgement of health and functional abilities required for safe driving;
- To create a uniform arrangement across the Member States with respect to license renewal policies;
- To introduce standardized medical and driving protocols with respect to license restrictions, license renewal and license screening and testing.

**The older road user himself**

- To be aware about the potential problems and increased accident risks associated with ageing;
- To (learn to) compensate for potential age- or medical related perceptual-motor deficits that may affect one's safety;
- To have an open mind about possibilities offered for self-assessment or voluntary driver testing, or to discuss one's personal situation with family and/or health care professionals (doctor, occupational therapist, pharmacist);
- To prepare the transition from driving to life-after-car.

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