Integrating safety and human factor issues into road geometric design guidelines

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ABSTRACT

"Safe System" is a novel approach to road safety and represents a radical evolution in strategies for further improving road safety outcomes. "Vision Zero" and "Advancing Sustainable Safety", recently developed in Sweden and the Netherlands, are two breakthrough paradigms of such an approach, including provisions aiming at road design, shifting a major share of the safety responsibility from road users to those who design the road transport systems. "Human Factors Guidelines for Road Systems", an ongoing publication (8) which aims to provide the best factual information and insight on the characteristics of road users to facilitate safe roadway and operations decisions, is a benchmark current development for a safe user centered roadway design. In Road Safety Audits and Road Safety Inspections, considerations of safety and human factors have already been exploited. Specific guidelines and recommendations have also been developed to accommodate older road users, a group which is of growing importance.

Roadway designers, who bear a major responsibility for the safe roadway design, should have a thorough understanding of the safety implications of their design decisions. Unfortunately, this kind of knowledge is limited among roadway designers due to the lack of appropriate professional training on safety and human factor issues, as well as the pertinent inadequacies in the University curricula. Consequently, there is an urgent need to aid roadway design engineers, in order to become familiar with current safety and human factors recent developments. The authors think that a promising way in achieving this objective is the effective integration of safety and human factors issues into road geometric design guidelines.

In order to identify how safety and human factor considerations have been integrated in road geometric design guidelines, a critical review of current design policies in the United States of America, Germany, Canada and Australia was carried out and showed that these considerations have been incorporated to a varying degree into design guidelines. However, there are several areas of road geometric design that have to be enriched accordingly. On the basis of this review and the aforementioned recent developments, a framework is suggested and discussed that will contribute to integrating the existing knowledge regarding safety and human factors issues into road geometric design guidelines.

INTRODUCTION

‘Safe System’ is a novel approach to road safety in several countries and represents a radical evolution in strategies for further improving road safety outcomes **(*1*)**. In a ‘Safe System’, road safety problems are treated by considering the interaction of several components of the transport system rather than by implementing individual countermeasures in relative isolation; such a system assumes the development of high levels of local and national coordination. Most importantly Safe Systems approach address prevailing attitudes and cultural influences on safety behavior amongst transport planners and road users and connects safety with wider transport and societal issues (*1*)**.** In his classic publication, Shinar (*2*) suggests that *“Safety is maximized when all efforts are coordinated and safety systems are user-centered. Organization-wide, on a national basis, setting a difficult but achievable concrete goal for crash reduction is a key element in a crash countermeasure program*”.

Swedish Vision Zero (*3*) is such a breakthrough Safe System approach, based on the ethical standpoint of zero fatalities and serious injuries in road accidents. In essence, Vision Zero alters the view on responsibility for planners, roadway design engineers, decision makers, authorities as well as and the users; responsibility is attributed to all levels of decision making, planning and acting and the user. The most radical element of Vision Zero is that the Swedish State has declared that life and health are not allowed in the long run to be traded off against benefits of the road transport system (such as increased capacity and mobility and so on). In effect, this removes serious injury and death from benefit-cost analyses as in Johnston (*4*). It is worth noting that Prof. M. Sandel of Harvard University (*5*) strongly disapproved and rejected the inclusion of a human life price whose value can’t be captured in monetary term in cost benefit analyses. The ‘Netherlands Sustainable Safety Vision’ (*6*) constitutes also a state-of-the art Safe System approach, whose goal is to prevent crashes and, where this is not feasible, to minimize the probability of severe injuries. This is achieved by following a “human” oriented pro-active approach, which recognizes people’s physical vulnerabilities, along with their capabilities and desired courses of action. Infrastructure and vehicles are expected to meet these human requirements. Furthermore, the education system should prepare and test individuals with respect to their driving behavior. By following such an approach, road safety becomes less dependent on the individual choices of road users and responsibility not only lie with road users but also with those related to the transportation infrastructures, vehicles and the education system (*6*). Furthermore, based on “Vision Zero” and “Advancing Sustainable Safety” rationale, the Safe System approach has also been formally adopted by Austroads and forms a key component of the Australian National Road Safety Strategy (*7*). New Zealand is also likely to adopt this vision (*7*). In the USA, several State Departments of Transportation, particularly Utah, Washington and Minnesota have already started applying the Vision Zero approach.

Apart from ‘Safe System’ another area of recent research on traffic safety is that of “human factors”. Indeed, the need for a user-centered and behavioral approach has been emphasized in recent research, specifically regarding highway design and operation. “Human Factors Guidelines for Road Systems”, an ongoing publication (8) which aims to provide the best factual information and insight on the characteristics of road users to facilitate safe roadway and operations decisions, is a benchmark current development for a safe, user centered roadway design. The Human Factor Guidelines reports that “*existing references applicable to road system design do not provide highway designers and traffic engineers with adequate guidance for incorporating road user needs, limitations and capabilities when dealing with design and operational issues*”. Further, “*misperceptions, slow reactions, and poor decisions are the* *products of a poor match between the needs and capabilities of drivers and the task demands that they face on the roadway. A more driver-centered approach to highway design and operation will promote continued improvements in highway safety*".

On the other hand, the Highway Safety Manual (*9*) provides highway engineers with a synthesis of validated highway research and proven procedures for integrating safety into both new and improvement projects. It also provides practitioners with enhanced analytic tools for predicting and measuring the success of implemented safety countermeasures. After using the HSM to develop possible design alternatives to improve safety on an in-service or planned intersection or section of roadway, the practitioner may then use the Human Factor Guidelines to enhance the possible solutions (*8*). However, it has to be emphasized that substantive safety cannot be achieved by simply basing it on model predictions of crashes without considering roadway users limitations and capabilities in the design and operation of roadway facilities.

In addition to the above, a substantial increase in both the number and proportion in total population of older adults expected for most developed countries, will definitely affect road safety in the years to come; as indicated by Staplin (*10*), from a designer's perspective, the "target driver" of the early 21st century will be over than 65. In particular, a significant feature of the aging process is the increased inter-individual variability. The normal aging process leads to a functional decline in vision, memory, physical strength, and flexibility needed for safe driving, but at rates that vary widely between individuals; the large variability in driving skills among them has been recognized whereas only a small portion of older drivers is significantly deficient in driving-related activities. Specific guidelines (*10*) and recommendations have been developed to accommodate older road users.

The European Commission recently issued a directive (*11*) requiring the establishment and implementation of procedures relating to road safety impact assessment, Road Safety Audits, the management of road network safety and safety inspection by the member states. This Directive shall apply to roads which are part of the trans-European road network, whether they are at the design stage, under construction or in operation. However, Safety principles and analysis of design features from a road user perspective have already been successfully applied in Road Safety Audits, which allows the opportunity, at various highway design stages, to highlight potential safety problems for road-users through identifying which elements of design contribute to unsafe behavior (*9*). Different Road Safety Assessment Programs (RAP) namely EuroRAP, AusRAP, USRAP, iRAP, etc, have been recently developed (Road Assessment tests were initiated in 2002 in Sweden, England and the Netherlands). The intention is to classify road sections according to their level of safety and assign star ratings similar to EuroNCAP crashworthiness Programme for cars.

It has to be noted that roadway design guidelines have not yet incorporated to a satisfactory extent safety and human factor research findings (*8*). Recent remarkable developments in road safety have, among all, a tremendous effect to road design, by forcing planners, design engineers and decision makers to cope and be consistent with a large number of design guidelines and safety manuals. Indeed, continuous evolution of knowledge in the field of road safety has a considerable effect to highway design. Roadway designers, who bear a major responsibility for the safe roadway design, should have a thorough understanding of safety and human factor issues. Unfortunately, this kind of knowledge is limited among roadway designers due to the lack of appropriate professional training, as well as the pertinent inadequacies in the University curricula. Consequently, there is an urgent need to guide roadway design engineers, in order to become familiar with current safety and human factors recent developments. The authors think that a promising way in achieving this objective is the effective integration of safety and human factors issues into road geometric design guidelines. In that context, this paper explores safety and human factors considerations in selected current road geometric design guidelines and then suggests a comprehensive framework for incorporating these issues into the Road Geometric Design Guidelines. In addition, a discussion on items related to the suggested framework is offered.

SAFETY AND HUMAN FACTORS CONSIDERATIONS IN CURRENT GEOMETRIC DESIGN GUIDELINES

AASHTO Policy on Geometric Design of Highways and Streets (*12*)

Regarding safety and human factor considerations, AASHTO highway geometric design policy contains two units for "Driver Performance" and "Safety". The Driver Performance Unit includes references in a descriptive way, on Older Drivers, the Driving Task, Information System and Information Handling, Drivers Error, Speed and Design and Design Assessment. A brief record from recent research studies concerning older drivers is included in the Drivers Error Section. A significant human factor consideration in AASHTO guidelines is the provision of decision sight distance, in which drivers must make complex or instantaneous decisions, while information is difficult to perceive, or when unexpected or unusual driving maneuvers are required.

The Safety section of the AASHTO policy includes several qualitative recommendations primarily regarding crashes avoidance through better designing of various features and elements of the roadway. The AASHTO's Green Book **(***12***)** reports that these concepts have been incorporated in geometric design guidelines presented in the policy. However, there is no provision for quantitative instructions in achieving a balance between the expected 85th percentile speed and the design speed, particularly on two-lane rural roads. Furthermore, in AASHTO policy, consistency is recognized as one of the general controls for Horizontal Alignment but it is described only in a qualitative way. However, in the United States several methods have been developed in order to evaluate speed consistency similar to those which have been implemented in Canada, Germany and Australia.

An essential requirement in AASHTO guidelines refers to the need of "Assessment of Design" in terms of information provision, with emphasis given on the viewpoint of unfamiliar drivers as well as on the visual quality of the road. It is noted that AASHTO's suggestion of using three dimensional models in the design of interchanges should be extended to the design of highway sections (*13*), especially for evaluating combinations of horizontal and vertical alignment, since models can be "*useful in communicating the designer's ideas to lay groups and others who are not trained to visualize three dimensions from the plans*". (*12*).

German Guidelines for Freeway Geometric Design (*14*)

German Guidelines for freeways (*14*) have in essence adopted the sustainable safety principle of Predictability of road course and road user behavior by a recognizable road design that support road user expectations through consistency and continuity in road design (self-explanatory roads). This objective has been achieved through the introduction of the "design class" concept. Three different design classes are provided in RAA Guidelines (*14*) namely EKA 1 for long distance freeways, EKA 2 for regional freeways and EKA 3 for urban freeways. In each design class, design elements and specifically cross sections are best suited to each other. These contribute to a self explanatory driver perception of the roadway, while between different design classes design elements differ significantly. Consistency controls regarding the radii of consecutive horizontal curves and the minimum radii requirements for tangent-to-curve sequences are also provided in the guidelines as well.

There are also two important safety and consistency related geometric design developments in RAA Guidelines regarding stopping sight distance and superelevation. These constitute considerable changes regarding previous German road geometric design Guidelines and U.S., Canadian and Australian Guidelines as well.

Stopping sight distance

Recent research findings regarding actual deceleration rates resulted in adopting a constant deceleration rate of $a = 3.7\ m/s^2$ to estimate required stopping sight distance in RAA Guidelines. A value of $a = 4.3\ m/s^2$ will be adopted for new roads some years later when almost all vehicles will be equipped with an anti-block system (ABS) (*15*). Resulting required stopping sight distances are reduced compared to former German guidelines.

Superelevation design.

In line with early research suggestions (*16*) a superelevation rate – radius of curve diagram has been developed to calculate superelevation rate for radii of curves exceeding minimum values.

On-going research in Germany focuses on better understanding human factors issues in order to incorporate these considerations into road geometric design models (*15*).

Geometric Design Guide for Canadian Roads (*17*)

The Canadian Design Guide (Vol. 1, "Principles of Design") includes an outline of the evolving philosophy of the approach to geometric design with an emphasis on safety. The concept of the "design domain", i.e. a range of values that a design parameter might take, is introduced to replace the previous concept of the "design standards" and it is underlined that the Guide doesn't attempt to establish "standards" and thus, this term is not used. The intention in introducing the new concept of the Design Domain is *"to provide designers with a greater opportunity to exercise their critical engineering judgment – with better information on which to base that judgment."* **(***17***)**. To help roadway designers apply the design domain concept, up to four levels of guidance are offered:

1. numerical guidance determining upper and lower bounds of the design domain
2. a description of the main characteristics of the design domain and often "heuristics" methods of a qualitative nature using reasoning and past experience to promote understanding in applying suitable solutions to design problems
3. where available, data for the quantitative evaluation of safety performance using collision rates
4. frequently, relevant worked examples.

Two critical remarks in the Introduction of the Guide which clearly emanate from E. Hauer's work (*18*), (*19*), state that "*Design dimensions that do not meet standards do not necessarily result in an unacceptable design – and dimensions that meet standards do not* *guarantee an acceptable design*" and "*The notion of 'safe' (or collision-free) road is a myth. Design should be viewed instead as a process that can result in roads being 'more safe' or 'less safe*".

In the Canadian Guide, factual knowledge about the relationship between safety and basic road features is attempted to be compiled and presented for designers of Canadian roads. However, it is mentioned that "*in many respects this field of research is in its infancy*". Safety implications of design features are addressed where meaningful data have been found, promoting in effect a safety conscious design. A brief human factors section is included in the Guide summarizing driver expectancy and reaction and an appropriate design response. Decision sight distance is also analyzed in the corresponding sight distance section. Special attention is given to design consistency, specifically cross section consistency, operating speed consistency and driver workload consistency. The Guide indicates that "*the aim of Canadian Designers must be to achieve consistency in design of each classification of road, in each different type of terrain, regardless of location. This objective is a primary justification for the existence of this Guide*". Nevertheless, the Canadian Guide lacks of specific references to human behavior and especially older drivers' behavior.

Austroads Guide to Road Geometric Design (*20*)

Australian Road Geometric Design Guide is one of the eight interrelated guides that comprise the Austroads Guide to Road Design. Geometric Design Guide (Part 3), (*20*), is concerned primarily with the horizontal and vertical alignment design along with roadway cross-section. Part 1, "Introduction to Road Design" (*21*) discusses the concepts of context-sensitive design along with design domain and geometric design consistency. Part 2, "Design considerations" (*22*), addresses the objectives of new and existing road projects. Specific objectives related to geometric design are included in Part 3 "Geometric Design" (*20*) along with a comprehensive reference to the extended design domain values which could be used for various geometric design elements. It is worth-mentioning that the new Australian Geometric Design Guide philosophy and principles are similar to those of the Canadian Guide, though applications of safety conscious design are not included.

A remarkable development in the Australian Guide (*20*) is the explicit adoption of the Safe System approach to road design which is linked to the Australian Road Safety Strategy. However the pertinent section is brief and rather isolated from the other sections of the Guide, since Safe System approach has not been specifically addressed in the various geometric design features sections. In the Australian Guide it is noted that safer road user behavior, safer speeds, safer roads and safer vehicles are the four key elements that make a Safe System. Maximum values of speed, above which the chances of surviving a crash decrease, are also included in the Guide.

Safety and human behavior issues are discussed in the coordination of horizontal and vertical alignment section as well as in the curvilinear alignment design section of the Australian Guide. In the authors' view coordination of horizontal and vertical alignment is addressed in a very constructive and comprehensive qualitative way, significantly helping the roadway designer to achieve a successful design. In the curvilinear alignment in flat terrain sections considerations of visual requirements and the effect of speed on perception and vision are examined, leading to the adoption of a suitable range of pertinent horizontal curves radii. However, it has to be noted that Australian Road Geometric Design Guide lacks specific references to older driver behavior.

Observations

The review of the aforementioned guidelines indicates that safety and human factors issues are only briefly addressed and in a rather qualitative way. Canadian guidelines provide – where available – a quantitative evaluation of safety performance; however, as noted in the Introduction, substantive safety cannot be achieved by simply basing it on model predictions of crashes, without considering the needs, limitations and capabilities of roadway users. On the other hand, existing guidelines lack the explicit reference of Safe System approach and they also lack an adequate reference to road user behavior, older driver issues and Road Safety Audits. It is noted that only in the new Australian Geometric Design Guide (2009) is there a brief and rather isolated description of the Safe System approach requirements, specifically those related to speed.

Having completed this review, it has to be stressed that road design engineers besides safety and human factors issues must always contemplate three-dimensional roadway appearance. In the landmark publication "The paved ribbon: The Esthetic of Freeway design" (*23*) essential principles for achieving this goal are addressed in a manner which constitute in the authors' view, a road geometric design paradigm. Careful grading (*24*) and proper three-dimensional design (*25*) could provide an alignment fitted in harmony to the landform contributing to a self-explanatory and safer roadway design as well.

INTEGRATING SAFETY AND HUMAN FACTOR ISSUES INTO ROAD GEOMETRIC DESIGN GUIDELINES

Recent developments in road safety, have a considerable effect on road design and a great potential in leading to a significant improvement in road safety. Roadway designers, who bear a major responsibility for the safe roadway design, should have a thorough understanding of safety and human factor issues. Unfortunately, this kind of knowledge is limited among roadway designers due to the lack of appropriate professional training on safety and human factor issues, as well as the pertinent inadequacies in the University curricula. Consequently, there is an urgent need to guide roadway design engineers, in order to become familiar with current safety and human factors recent developments. The authors think that a promising way in achieving this objective is the effective integration of safety and human factors issues into road geometric design guidelines. A suggested framework is shown in Figure 1.

Topics regarding Safe System approach, user-centered design and Road Safety Audit constitute the proposed material to be intergraded in road geometric design guidelines to guide road designers. The specific guidance information should be constructively selected by the road geometric design guideline committees according to the specific conditions of the various national road networks. Project teams of road geometric design guidelines and Human Factor Guidelines should collaborate to achieve an optimal selection. A possible way in facilitating the selection of safety principles and human factor information to be integrated into road design guidelines, is to directly involve road designers and road safety auditors taking into account their perceptions on the matter. The integration of the guidance information should be implemented in a concise and comprehensive manner into selected chapters of the road design guidelines and not in appendices and/or separate volumes (17). An outline of the suggested topics considered as fundamental knowledge for road designers, along with relevant references is provided in the following section.

Safe System Approach

Strategies

The basic strategy of a ‘Safe System’ (*1*) is to ensure that in the event of a crash, the impact remains below the threshold likely to produce either death or serious injury with all parts of the system aiming at eliminating fatalities and serious trauma arising from road crashes. The need to provide a safe transport system to accommodate human errors, as well as that even prevention efforts are undertaken road users will remain fallible and crashes will occur, is also emphasized (*1*). Swedish Vision Zero (*3*) and Dutch Sustainable Safety (*6*) are two examples of Safe System Strategy.

Vision Zero Philosophy

Vision Zero philosophy puts forward the idea of shared responsibility among the various actors of the road transport system, and most notably stresses that those who design the road transport system bear the ultimate responsibility for safety (*3*). Thus, as far as the road infrastructure is concerned, the provision of a forgiving road environment (i.e. by dividing traffic on higher speed roads, clear guidance, and road and roadside treatments) and safe speeds to reduce unacceptably high risk, is a critical task to road designers. Further, the establishment of effective procedures of comprehensive management and communication between all actors, which have a role in determining the safe functioning of the transport system, becomes a concern. As it is stressed in Vision Zero, there are established maximum speed values based on the design of modern vehicles and roads, which are fundamental to road infrastructure design. For instance, most people survive if they are hit by a car traveling at 30km/h but not if the car travels at 50km/h; also, a safer car protects passengers at speeds up to 65-70km/h in a head-on collision and at speeds up to 45-50km/h in side impact collision, assuming seat belt usage (*3*).

Sustainable Safety Principles

Five principles derived from Sustainable Safety vision are considered crucial for a safe traffic system (*6*). These principles have been translated into Dutch road design guidelines on a large scale and applied in practice (*6*). According to the Sustainable Safety vision, an inherently safe traffic system is attained in such a way, that it is in compliance with human needs. These principles are the functionality of roads, homogeneity of mass and/or speed and direction, recognition and predictability of roads and behavior, physical and social forgivingness of the road layout and of road users, and state awareness by the road user.

According to the principle of functionality, roads have distinguished functions in order to prevent unintended use and to reduce potential collisions with possible severe outcome. The principle applies in the categorization of roads at a network level as well as the definition of characteristics of the road types. In the homogeneity principle, when the physical vulnerability is being recognized, large differences in speed, direction, and mass have to be avoided. The aim is to reduce crash severity when crashes cannot be prevented. In this sense the provision of safe speeds is a key element in road design. As for the predictability principle, it aims at preventing human error. This is achieved by offering a road environment that is recognizable and predictable through consistency in road design and continuity in road course to support road user expectations. Predictability is related to the essential features of road types as well as road users’ expectations.

The forgivingness principle is important in providing road environment. In the case of a road user mistake, the road environment has to be forgiving, in the sense that the road user "should not be punished by death or serious injury". Dividing traffic by higher speeds and safe roadside design are among the designer's tasks in which that principle is applied. The principle of state awareness is based on the assumption that a road user in order to drive safely is able to assess well his/her capability and make the necessary adjustments to cope with task requirements determined by environmental factors (*6*). It is recognized that the road user has influence both on his capability (e.g. staying alerted or well educated) and task demands, for example by speed choice (*26*).

User Centered Design

Adapting Roadway Environment to User Needs, Limitations and Capabilities

The safe system approach introduces the concept of user centered design; roads, traffic control devices, and vehicles should be designed for the road user. The application of human factors knowledge in road design has now become more necessary than ever in the effort to achieve crash reduction (*8*), (*27*). The aim of road design is to reduce human error and injury by designing according to human characteristics and limitations. Road user's mistake, means that he did not perform his task as expected (*8*). When task demands exceed drivers' capabilities and needs, performance deteriorates and a failure is possible (*26*). Drivers can make errors due to diminished capability factors like inattention (*2*), (*28*) -being often an effect of factors such as fatigue, alcohol or drugs consumption, distraction-, limited information processing capacity, confusion (e.g. when their expectations are violated) and poor judgments regarding speeds and gaps. Applying human factors knowledge to road design and operation, road user error is understood and anticipated (*8*).

An essential element in the application of human factors approach for a user oriented design is to provide to the designer a clear understanding of the driving task especially from the user's point of view (*8*). Through task analysis the demands that are imposed to the road user are defined and the information the user needs to accomplish the task is highlighted (*29*), (*30*). These elements should be considered along with the capabilities, knowledge, and motivations of the range of potential users with the ultimate goal to lessen performance error.

Various existing models provide a theoretical framework in understanding drivers' behavior (*31*). Recently the motivational model developed by Fuller (*26*), (*32*) recognizes workload (difficulty) as the important regulating mechanism for driver behavior; according to Fuller's task-capability interface (TCI) model, drivers seek difficulty homeostasis (rather than risk homeostasis) and this homeostasis is mainly achieved through adaptation in speed. In the TCI model the distinctions between strategic decisions, tactical decisions and operational decisions are retained, in terms of both controlling task demand and capability. The general principle proposed by TCI model is that drivers are motivated to maintain a preferred level of task difficulty.

A forgiving design aims to reduce the probability of error, and to reduce the consequences of error when it does occur (*6*). Additionally, providing positive guidance in information placement and self – organising roads (a term also used for self-explanatory roads) the appropriate driver's behaviour (e.g. speed, path choices) is induced. Interestingly, Shinar (*2*) reports that "…drivers are extremely flexible and adaptive, so that changes in vehicles, roadways and regulations will invariably result in changes in driver behavior as well". The behavioral adaptation (*31*) is a concept tackled in behavioral studies and transportation science, relevant to the application of risk countermeasures. Therefore, it has to be a concern for those who are responsible for roadway design and operation. As an example, it is mentioned that when the driving task becomes more easy due to changes in the alignment (straight instead of curved), workload might decrease and speed might be increased as a consequence.

Accommodating Older Drivers
To apply user centered approach in design means that the range and complexity of road user needs, capabilities and behaviour are taken into account. However, historically, transport system planning and design has not considered older drivers (*33*). Age-related sensory, cognitive physical and health disorders pose elderly drivers at greater risk when interacting with their environment (*33*). Specific Handbooks and Recommendations (*10*), (*33*), (*34*) have been developed to accommodate older road users needs and limitations. These publications are considered as a supplement to existing standards and guidelines in the areas of highway geometric design, operation and traffic control devices. Road designers should design roadway and roadway features consistent to older road users' expectations, giving them more time and information and providing the possibility to carry out the driving task in a self-paced way.

Safety Audits

Aim and Underlying Concepts
A Road Safety Audit (RSA) is a formal examination of a future road or traffic project or an existing road, regarding its crash potential and safety performance, by an independent, qualified team and is most effective when applied in the design process. RSA goes beyond the regular checking of project's safety by the designer and should be applied as common practice at various design stages. A number of related guides have been published: the recent Australian RSA guide (*35*) explicitly adopts the Safe System approach to road safety, especially as far as the safety principles to be applied.

Safety Principles
Road Safety Audit is a road safety field where safety and human factors principles are applied. An outline of these principles contains provision for self-explanatory roads, forgiving road environment and safe speed environment, and catering for all road users as well (*27, 28, 35, 36*).

Road designers should aim to provide a road environment that is forgiving to human error with adequate protection to road users from hazards and through positive guidance and proper information handling, therefore reinforcing their expectations. Speed management is a crucial element of the Safe System approach. Consequently, designing for safe speeds, impact speeds in the event of a crash should be below the level of human physical tolerance so as to prevent serious injury or death. Design principles of safe integration and separation of road users can be applied in the framework of speed management in conjunction with the principle of design self-explanatory roads that induce the appropriate road user behaviour, especially in terms of safe speeds. In road design the needs of the road users should be considered. Especially roadway and roadway features should be designed to accommodate the functional limitations that accompany ageing. In applying principles of information handling, road users limitations and needs such as workload constraints, visual and information processing limitations, should be considered.

DISCUSSION

Some aspects of the suggested framework, which should be addressed in the course of integrating safety and human factor issues into geometric design guidelines are discussed in the following paragraphs.

The Safe System approach is already applied in Sweden, the Netherlands, Australia and several States of the USA. In the authors' view, this safety strategy will eventually prevail internationally, over other approaches which consider safety as simply one of the various roadway design objectives. However, the real challenge, for those who conceived this vision and for the academic community, lies in exploring ways to effectively implement this approach in countries with poor safety records. An adequate transition period, from the existing poor safety situations to the desired safety level, should be provided in order for the appropriate measures to be planned, designed and built-up.

Speed management is a crucial component of the Safe System approach and has a considerable contribution in reducing both road user errors and the safety outcomes when errors are made. Managing the inter-relationship amongst travel speed, road infrastructure design, human tolerance and vehicle safety is fundamental to the Safe System approach. Understanding the reasons for lower speed limits is required in achieving pubic and political support, especially in countries (e.g. South Europe) in which drivers' attitudes, motives and cultural environment are rather negative towards speed limit compliance. The public and policy makers need to be well informed about actual risks when using the road, and the need for lower speed limits in certain road environments. Speed environment created as previously described, could also accommodate older drivers limitations.

Despite the widespread acknowledgement that roadway user is a central component of a Road System and his/her needs, limitations and capabilities should always be considered in the design and operation of roadway facilities, many road designers do not have a clear understanding of what human factors is and how its principles are relevant to their work *(8)*. A suitable way to enhance safety knowledge and to provide human factors training to road design engineers is to exploit the Road Safety Audit process. This could be achieved by feeding back the knowledge gained from audits into road design professionals *(35)*. In this way, road designers anticipate the safety issues, learn from the Road Safety Audit process and design in safety features from the start. This feedback could also create a mutual understanding and a consensus between designers and auditors. Further, Road Safety Audit contributes to the development of a "safety by design" culture among roadway and traffic engineers as well as within organisations *(36)*.

Education, an inherently sustainable process, is vital in preparing road users to share safety responsibilities in a Safe System context. An appropriate and well designed traffic education program should be implemented starting from primary school, continuing through to secondary school, and concluding with a comprehensive driver education and behind the wheel training. The Sustainable Safety principles of state awareness and forgiving traffic behavior can be constructively addressed in the education program especially in the final phase. Forgiving road user behavior (social forgivingness) could ameliorate the effects of other road users' errors (*6*). It is underlined that well educated and trained road users could be effectively involved in the Road Safety Audit and highway projects development process (*12, 37, 38*), thus contributing to a more user friendly design.

REFERENCES

1. *Towards Zero: Ambitious Road Safety Targets and the Safe System Approach.* OECD/ITF, 2008.
2. Shinar, D. *Traffic Safety and Human Behavior.* Elsevier, the Netherlands, 2007.
3. *Safe Traffic. Vision Zero on the Move.* Swedish Road Administration, Borlänge, 2006.
4. Johnston, I. *Highway Safety.* In Fwa, T.F. The Handbook of Highway Engineering. Taylor & Francis Group, Boca Raton, FL, 2006.
5. Sandel M., Reith Lectures 2009: A New Citizenship. *Lecture 4: A New Politics of the Common Good.* 30th June 2009. Available at http://downloads.bbc.co.uk/rmhttp/radio4/transcripts/20090630_reith_anewpolitics.rtf. Accessed 3rd, September 2009.
6. *Advancing Sustainable Safety. National Road Safety Exploration for 2005-2020.* SWOV Institute for Road Safety Research, the Netherlands, 2006.
7. Turner, B., M. Tziotis, P. Cairney and C. Jurewicz, *Safe System Infrastructure National Roundtable Report. Research Report ARR 370.* ARRB Group Ltd, 2009.
8. Comprehensive Human Factors Guidelines for Road Systems. NCHRP Web-only document 70 (Project 17-18(08)). TRB, Washington D.C., 2005. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_ w70.pdf Accessed May 4th 2009.
9. *Highway Safety Manual.* Draft Report. Transportation Research Board National Research Council, Washington D.C., 2005.
10. Staplin, L., Lococo, K., Byington, S. *Older driver highway design handbook.* Federal Highway Administration, Mc Lean ,VA, 2001
11. Directive 2008/96/EC of the European Parliament and of the Council on Road Infrastructure Safety Management. Official Journal of the European Union 29.11.2008. L319/59 - L319-67.
12. *A Policy on Geometric Design of Highways and Streets.* American Association of State Highway and Transportation Officials, Washington D.C., 2001.
13. Kanellaidis, G. Human Factors in Highway Geometric Design. *ASCE Journal of Transportation Engineering*, Vol. 122, No 1, 1996, pp.59-66.
14. FGSV. *Richtlinien für die Anlage von Autobahnen* RAA - R1. Forschungsgesellschaft für Strassen- und Verkehrswesen (FGSV), e.V., Köln., 2008.
15. Brilon, W. and C. Lippold. A New Concept for Highway Design Guidelines in Germany. CD-ROM. Proceedings of 3rd International Symposium on Highway Geometric Design, Chicago, 2005.
16. Kanellaidis, G. Aspects of highway superelevation design. *ASCE Journal of Transportation Engineering*, Vol. 117, No 6, 1991, pp.624-632.
17. *Geometric Design Guide for Canadian Roads.* Transportation Association of Canada (TAC), Ottawa, 1999.
18. Hauer, E. Safety in Geometric Design Standards. Proceedings of the 2nd International Symposium of Highway Geometric Design, 1999.
19. Hauer, E. The Road Ahead. *Journal of Transportation Engineering*, Vol.131, No 5, 2005, pp.333-339.
20. *Guide to Road Design. Part 3: Geometric Design*. Austroads, Sydney, 2009.
21. *Guide to Road Design. Part 1: Introduction to Road Design*. Austroads, Sydney, 2003.
22. *Guide to Road Design. Part 2: Design Considerations*. Austroads, Sydney, 2003.
23. Tunnard, C. and B. Pushkarev. *Man-made America: Chaos or Control? An inquiry into Selected Problems of Design in the Urbanized Landscape.* Yale University Press, 1963.
24. Kanellaidis, G. Grading design of side slopes fitting roadside topography. *ASCE Journal of Transportation Engineering*, Vol.122, No 1, 1996, pp.87-90.
25. Taiganidis J. and G. Kanellaidis. Approximate perspective design of roads. *ASCE Journal of Transportation Engineering*, Vol.125, No.4, 1999, pp.314-323.
26. Fuller, R. Towards a general theory of driver behaviour. *Accident Analysis & Prevention*, Vol. 37, Is. 3, 2005, pp. 461-472.

27. Fuller R. and Santos J.A. *Human Factors for Highway Engineers.* Pergamon, the Netherland, 2002.
28. Dewar, R. and P. Olson, *Human factors in Traffic Safety*. Laywers & Judges Publishing Company, Inc., Tucson, 2007.
29. Knoblauch, R., Nitzburg, M., Seifert, R. *An Investigation of Older Driver Freeway Needs and Capabilities*. Federal Highway Administration, McLean VA, 1997.
30. Vardaki, S. An investigation of older driver actual and perceived behavior on freeways. *Transportation Research Record, Journal of the Transportation Research Board*, No.2078, 2008, pp.41-47.
31. Weller, G., Schlag, B., Gatti, G., Jorna, R., Van de Leur, M. Road Infrastructure Safety Protection - Core-Research and Development for Road Safety in Europe; Increasing safety and reliability of secondary roads for a sustainable Surface Transport (RIPCORD-ISEREST) Project, Deliverable: *Human Factors in Road Design. State of the art and empirical evidence,* 2006.
32. Fuller, R. and Santos, J.A. *Human Factors for Highway Engineers*, Chapt.1, Psychology and the highway engineer, 1st Ed., Pergamon, Oxford, 2002.
33. *Road Safety Environment and Design for Older Drivers.* Report AP-R169, Austroads, Sydney, 2000.
34. Staplin, L., K. Lococo, S. Byington and D. Harley. *Guidelines and Recommedations to Accommodate Older Drivers and Pedestrians.* FHWA-RD-01-051. McLean, VA, 2001.
35. *Guide to Road Safety. Part 6. Road Safety Audit.* Austroads, Sydney, 2009.
36. *Road Safety Audit.* The Institution of Highways & Transportation, London, 2008.
37. Kanellaidis, G. Aspects of Road Safety Audits. *ASCE Journal of Transportation Engineering*, Vol. 125, No 6, 1999, pp.481-486.
38. Neuman, T.R., P.E.M. Schwartz, L. Clark and J. Bednar. *A Guide to Best Practices for Achieving Context Sensitive Solutions.* NCHRP REPORT 480. TRB, Washington D.C., 2002.

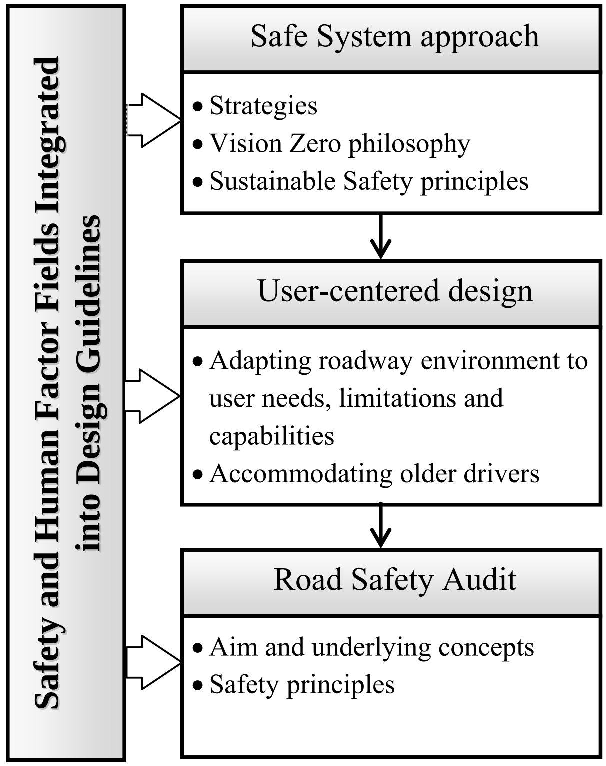

FIGURE 1 Suggested framework for integrating safety and human factor issues into road geometric design guidelines.