Chapter 19
Urban Form and Road Safety: Public and Active Transport Enable High Levels of Road Safety

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19.1 Introduction

Road traffic injuries are estimated to be the ninth cause of death with over 1.2 million deaths each year globally (WHO 2015). Over half of the health burden of traffic crashes can be attributed to deaths; the other part results from disability following injuries (Dhondt et al. 2013). Injuries sustained in road crashes are the main causes of death among those aged 15–29 years (WHO 2015). Moreover, some children involved in a traffic crash experience post-traumatic stress disorder, and the death of a child is associated with increased mortality from both natural and unnatural causes in parents (Li et al. 2003; Salter and Stallard 2004). Action is needed to reduce this massive and largely preventable human toll. Investing in road safety would also lower perceived risks that may deter potential cyclists and pedestrians and thereby prevent them from enjoying the associated health benefits of physical activity (Götschi et al. 2016). And it almost goes without saying that there would be significant economic benefits associated with reduced traffic fatalities and improved public health; the current economic burden of traffic crashes is approximately 3% of gross domestic product (GDP) worldwide (WHO 2015). Clearly there is a social and economic imperative to take action in every community to address this road safety problem.

More than half a century ago, Perry (1939) and Buchanan (1963) already suggested that road safety could be improved via urban form, also known as the built environment of our community development patterns; however, the lure and benefits of private auto use historically obscured any social and economic externalities

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M. Nieuwenhuijsen, H. Khreis (eds.), *Integrating Human Health into Urban and Transport Planning*, https://doi.org/10.1007/978-3-319-74983-9_19

caused by traffic crashes. More recently, amid Brundtland Commission (1987), WHO (2004) and other increasingly vocal global health authorities, the need to reconsider and reduce these negative impacts of auto-oriented communities has again been raised. The problem is of course that in the intervening decades since Buchanan (1963) first warned us, much of our urban form, at least in higher-income countries, has already been built in an auto-oriented development pattern. Once built, these sprawling, low-density and freeway-accessed suburbs are not easily reversed. For example, a single intersection or roadway can be retrofitted within a short time for traffic calming, for instance, converted into a safer roundabout and/or 1-way, narrower, lower-speed couplets; however, it takes much longer and costs prohibitively more (not to mention the social upheaval involved) to overnight retrofit the built form of an entire auto-oriented community. It may take perhaps as long as an entire generation to make any substantive changes! Fortunately, there are some general principles that, if employed successfully, may help to address our current built urban form and road safety problems.

Urban form mostly affects road safety indirectly via travel behaviour such as modal choice and route choice (Van Wee 2009; Schepers et al. 2014). Understanding the indirect relationship between road safety and urban form is not only important for traffic safety but also for the health impact of traffic in general. While the optimization of intersection design may have a largely isolated road safety effect, changing urban design and networks affects other externalities of traffic. For example, suppose we build a network of well-designed bicycle infrastructure to travel to a city centre. This would encourage cycling which may affect road safety, but it will also reduce air and noise pollution by cars and increase physical activity (Nieuwenhuijsen and Khreis 2016). A bicycle path physically separated from the vehicle carriageway would increase separation between cars and cyclists, and reduce cyclists' exposure to noise, buffeting, and exhaust (Schepers et al. 2015b). In this chapter we discuss how urban form affects road safety to inform integrated cross-disciplinary planning efforts and health impact assessments, in the hopes that application of this knowledge and its associated planning principles will help to improve the overall health outcomes of traffic (Khreis et al. 2016; van Wee and Ettema 2016).

19.1.1 The Impact of Urban Form on Travel Behaviour

It is well established that travel behaviour is affected by urban design (Ewing and Cervero 2010). As urban form encompasses a myriad of components, the impact is often described using the '5Ds': land use density and diversity, design (of networks and street patterns), distance to transit, and destination accessibility (Cervero and Kockelman 1997; Ewing and Cervero 2010; Handy 2017). Lower densities (e.g. a sprawling city) and monofunctional land use increase travel distance and thereby travel time to potential destinations and vice versa (depending on the available mode network continuity and infrastructure systems). Unless high-quality public transit is heavily subsidized, the private car is the only economically viable form of transport to travel longer distance criss-cross trips in low-density suburban sprawl communities within travel time budgets typically available (Mokhtarian and Chen 2004). Apart from typical geographic considerations (e.g. terrain, climate), increased travel distance is a daunting factor for cyclists and even more for pedestrians (Heinen et al. 2010). On the other hand, more sustainable forms of development, such as higher densities and land use diversity, decrease trip length and thereby contribute to more active transport.

As walking (and to a lesser extent cycling) is an important access mode for public transport, the modal shares of active transport modes tend to be correlated (Pucher 2004). Mavoa et al. (2012) found that, with proper community planning and design, walking accessibility to destinations via public transit can be significant. So-called transit-oriented development (TOD) aims for high densities and mixed (diverse) land use within 5–10 min walking distance of key public transport stations (Pucher 2004; Bach et al. 2006). Not surprisingly, cities everywhere with high population densities have a substantial model share of public transport, e.g. the share excluding walking amounts to 81% in Hong Kong and 64% in Paris (Sun et al. 2014).

Urban design also must consider network design and street network structure (Handy 2017) and their influence on travel time via resistance along their links. High-end mobility facilities such as freeways, arterial roads, bus rapid transit (BRT), and heavy rail systems allow for high capacity, speed, and performance resulting from low intersection/stop densities over longer distances within the same travel time budget. Network design can also be used to influence the competitiveness of each mode compared to others in terms of travel distance and time, e.g. shortcuts for walking and cycling where drivers have to make detours (Rietveld and Daniel 2004; Frank and Hawkins 2008; Levinson 2012; Schepers et al. 2013).

Individual travel behaviour results in traffic volumes, a modal split, and distribution of traffic over time and space (Van Wee 2009). The 5Ds help describe and predict to which transport mode(s) an urban area is most oriented.

19.1.2 Indicators to Study the Impact of Urban Form on Road Safety

Which indicator is best used for a study of road safety depends on the objective of the comparison (i.e. the policy issue) at hand (Hakkert and Braimaister 2002; Götschi et al. 2016). At an aggregated level, numbers of fatalities per capita, per-total road lane kilometres (TLKM), or per-vehicle kilometre travelled (VKT) are common indicators for road safety (Lovegrove and Sayed 2006). Fatalities per TLKM or per VKT can be misleading as these exposure measures in the denominator (of the risk indicator) can change, without any real safety improvements. For example, if fatal collision counts remained constant while more roads and/or more vehicle kilometres were driven, it would reduce fatalities per VKT and per TLKM. And if fatalities rose at the same rate as exposure, it would appear that the level of safety was unchanged when in reality fatalities were rising. Perhaps more alarming, if fatalities remained constant while vehicle-kilometres decreased, for example, due to transit-oriented developments and reductions in driving, it would actually appear as if safety were worsening, as the ratio of fatalities per VKT would increase! Clearly, fatalities per VKT and per TLKM could mask, or completely discount, the potential safety and sustainability benefits of more dense transit- and bicycle-oriented developments that reduce VKT, serious collisions, pollution emissions, energy consumption, and space needed for roads. Moreover, planning for cycling and walking that relies on off-road paths and/or car-free exclusive networks would offer comparable or even higher levels of human scale and safer accessibility using less vehicle kilometres (Cervero and Day 2008; Karou and Hull 2014).

So what is the fairest way to measure road safety that also considers the benefits of active transport at an aggregated, area-wide, and macro-level? Macro-level, collision prediction models (CPMs) that evaluate road safety in terms of vehicle-related collisions per unit time period are dominated by a non-linear, exponential association with these same exposure-based independent variables VKT and to a lesser extent TLKM (Lovegrove and Sayed 2006; Lovegrove 2007). These widely accepted definitions of traffic crashes focus on (motor) vehicle crashes occurring on public roads but exclude those crashes where vehicles have not been involved, i.e. pedestrian falls (SWOV 2010b). Methorst et al. (2017) have recently criticized this exclusion. They estimated that 86 pedestrians died on public roads in the Netherlands in 2011 due to falls where no vehicles were involved, which is significant when compared to the 520 police-recorded vehicle crash-related deaths (SWOV 2017). However, to date, these CPMs have only been able to be reliably fit to, and be used to predict, data related to collisions involving vehicles, for two reasons. First, data on pedestrian falls and, to a lesser extent, single-bicycle crashes is scarce. Second, exposure measures for these non-vehicular modes differ from traditional VKT and TLKM and have been difficult to predict and assess (Elvik 2009; Wei and Lovegrove 2012). Thus, other measures are needed to evaluate the road safety benefits of increased walking and bicycling.

One possibility is to recall that average daily travel time remains constant, with many researchers observing that, regardless of travel mode, humans often travel a minimum of 10–20 min to reach desired destinations (Mokhtarian and Chen 2004). And while urban sprawl and more road mileage and more driving within this time budget have created additional exposures to risk (e.g. VKT), on the other hand, increased population density and land use diversity and quality transit service can also improve the walking and cycling accessibility of important activities (e.g. parks), facilities (e.g. jobs, schools), and services (shopping, doctors) within this same time budget. As such, a more inclusive measure of road safety that accounts for the human scale walking and bicycling modes, at an aggregated level, would be deaths per 100,000 population and is the main indicator used to study the impact of urban form on road safety in this context.

19.2 Modal Split and Developments Oriented Towards Specific Transport Modes

To illustrate road safety for the aforementioned transport mode orientations, we collected data on a sample of large, high-income cities from developed countries around the world (see Appendix for an explanation of data methodology). Figure 19.1 and Table 19.1 show that the number of fatalities per 100,000 population in large cities is much lower than the overall rate of the country in which they are situated. This result and an association between density and road safety were also found in other studies (Ewing and Dumbaugh 2009; Houwing et al. 2012; Kegler et al. 2012; Ryb et al. 2012), suggesting that as density increases, so does safety. Moreover, we observe that safer cities tend to be located in safer countries and vice versa, that is, countries with fewer overall fatal crashes per 100,000 population tend to see that same trend in their cities. For comparison, we have shown the middle-sized Dutch new towns including Almere, Houten, Lelystad, Nieuwegein, and Zoetermeer; these are discussed in more detail in Sect. 19.3.4. Transit-oriented and bicycle-oriented cities in Table 19.1 seem to have reached comparable levels of road safety, whereas road safety in car-oriented cities seems worst. Drawing conclusions from this small sample of cities should be done with some caution, but larger studies also found lower death rates in cities with higher modal shares of public transport and cycling (Marshall and Garrick 2011; Litman 2012; American Public Transportation Association 2016).

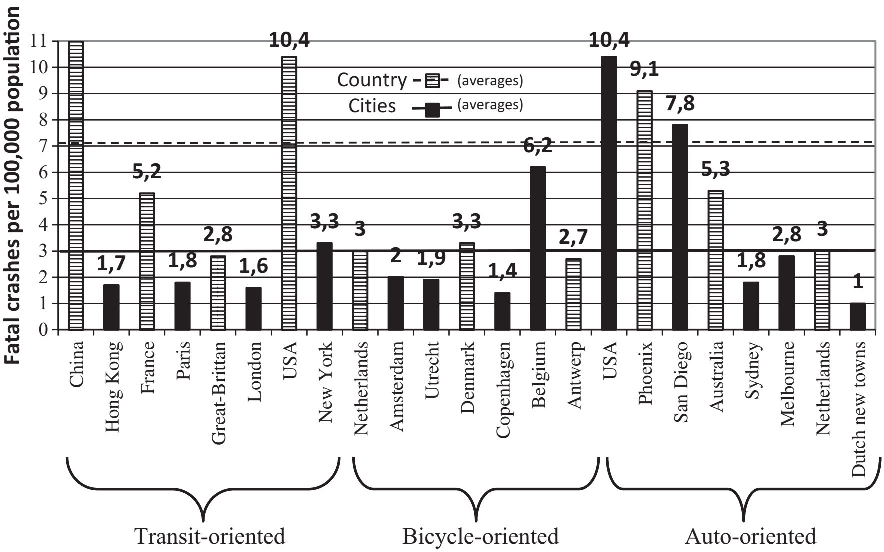

Fig. 19.1 Recorded deaths per 100,000 population in 2011–2015 in large, high-income cities, and, for comparison, in Dutch middle-sized, new towns (far right)

Table 19.1 Modal share, population statistics, and death rate in large, high-income cities and in middle-sized, Dutch new towns

Jurisdiction	Modal shares				Pop. (×1000)	Density per km² (×1000)	Fatalities per 100,000 pop'n
	Walk, %	Bike, %	Transit, %	Auto, %			
Public transport (transit)-oriented cities							
Hong Kong	NA	1	**81**	18	7167	6.5	1.7
Paris	15	5	**59**	20	2241	21.3	1.8
London	21	2	**44**	34	8428	5.5	1.6
New York	10	1	**55**	29	8550	10.9	3.7
Bicycle-oriented cities							
Amsterdam	4	**40**	29	27	838	5.0	2.0
Utrecht	3	**34**	24	39	334	3.6	1.9
Copenhagen	10	**30**	36	26	565	7.0	1.4
Antwerp	20	**24**	17	40	510	2.5	2.7
Auto-oriented cities							
Phoenix	2	1	3	**88**	1512	1.1	8.5
San Diego	3	1	4	**85**	1322	1.5	5.3
Melbourne	4	2	14	**80**	4318	0.4	2.7
Sydney	5	1	21	**74**	4738	0.4	1.8
Dutch new towns					502	1.9	1.0
Almere		**31**			194		
Houten		**37**			48		
Lelystad		**25**			76		
Nieuwegein		**27**			61		
Zoetermeer		**27**			123		
Netherlands	19	**27**	5	49	16,779	0.4	3.0

19.2.1 Cycling Versus Driving

Elvik (2009) was one of the first to study the road safety effects of shifts from driving to cycling and walking using CPMs, in which a non-linear relationship between crashes and volumes is modelled. His results revealed that cycling, walking, and driving tend to become safer as volumes increase, which is known in the literature as Smeed's law on motor vehicle safety, and as the 'safety in numbers' effect in the literature on cyclist and pedestrian safety (Smeed 1949; Jacobsen 2003; Elvik and Bjørnskau 2017). Other benefits of increased cycling volumes may include driver-related factors. That is, as these same individuals who now cycle more drive a car past other cyclists, they likely become more sensitive to, and aware of the needs for, safe passing speed and separation distance, which would reinforce the 'safety in numbers' effect (Schepers et al. 2017b).

Elvik also observed that as the non-linearity of risk ('safety in numbers') applies to volumes of both cyclists and drivers, more cycling does, without changes to circumstances such as infrastructure, not automatically reducing the total number of

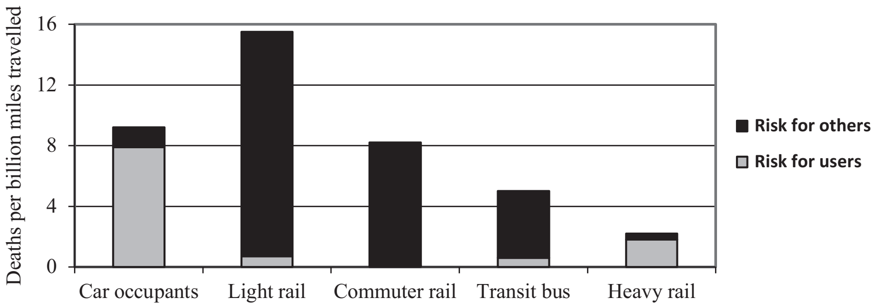

Fig. 19.2 Crash fatality rates per billion passenger miles travelled Litman (2012)

traffic casualties, (Elvik 2013). The CPMs account for the fact that after shifting from car driving to cycling (or walking), road users are less hazardous to other cyclists and pedestrians because of, among other things, the lower speeds and hence lower amounts of kinetic energy released in the event of a crash leading to less severe injuries. Other studies found similar results and also distinguished between age groups (Stipdonk and Reurings 2012). For instance, Schepers and Heinen (2013) expected the number of fatalities above the age of 65 to increase, while the number in the 18–64 age group was expected to decrease.

Therefore, the research suggests that more than just a mode shift is required, since a higher cycling volumes appear to have only a modest impact on the total number of traffic deaths.

19.2.2 Public Transport Versus Driving

While public transport is much safer than driving for transit passengers, it can be relatively risky for other road users without proper system design, as shown in Fig. 19.2 (SWOV 2011b). CPMs can integrate such risks but have not yet been widely applied to estimate the road safety impact of a shift from using private autos to using public transport. Lovegrove et al. (2010) predicted significant 2% safety benefits of transit investment versus 'business-as-usual' (BAU) autocentric approaches using an application of community-level, macro-level CPMs, as part of an evaluation of both urban and rural areas of the Greater Vancouver Regional District's 3-Year Regional Transportation Strategy. Using similar methodology and macro-level CPMs, Alam (2010) predicted an 8% decrease in collision severity due to improving transit in Kelowna, BC, Canada, versus a BAU approach.

It bears repeating that the aforementioned CPMs used autocentric exposure and road safety measures, which by definition are biased and ignore active transport oriented measures, thus discounting overall levels of safety. For example, fatal pedestrian falls are not included in international traffic crash statistics (Methorst et al. 2017). Elvik et al. (2009) studied the modal shift from driving to public

Table 19.2 Road classification and speed limits in the Netherlands in urban areas

Road classes	Speed limits in urban areas, km/h	Location of cyclists
Access roads	30	Mixed with other traffic
Distributor roads	50 or 70	Separated from motorized traffic by bicycle paths or bicycle lanes[a]
Through roads	100 or 120	Cycling not allowed

[a]Bike paths are physically separated from the carriageway; bike lanes are a delineated space on the carriageway

transport on existing infrastructure (i.e. no changes to circumstances), including the potential impact on the number of injuries due to pedestrian falls and concluded 'the unrecorded injuries from falls will, however, increase so much that no overall gain in safety can be expected if car users start using buses or trains.' As the elderly are particularly at risk of severe pedestrian falls (Schepers et al. 2017a), it can be expected that the benefits of a modal shift to transit found by Alam (2010) also apply to the overall level of transport safety for younger age groups. However, more than improved public transit service alone is needed to improve transport safety for all age groups; a system-based approach to transport safety is needed.

19.3 Network Design and Distribution of Traffic Along Infrastructure Networks

19.3.1 Network Design and the Safe System Approach

Organizations such as OECD and the World Road Association endorse the Safe System approach for road safety policies (World Road Association 2014). It recognizes that the network must eventually be forgiving of routine human (road user) errors and must maintain navigation tasks of all components of a system design at a level that will not exceed the user's mental and physical capacity. Examples of Safe System approaches are the Swedish Vision Zero and Dutch Sustainable Safety Vision (Koornstra et al. 2002). Two key principles of the Safe System approach for network design are homogeneity and functionality (World Road Association 2014). Homogeneity implies that differences in speed, direction, and mass should not be too large, for instance, a safe speed to mix cyclists with motorized traffic is no higher than 30 km/h (Tingvall and Haworth 1999). Functionality refers to classification of roads in a hierarchical road network and aims for roads to have only one function, i.e. a flow function or access function. The Netherlands has adopted a hierarchical road classification by which roads are classified as either access, distributor, or through roads.

Table 19.2 lists the recommended maximum speed limits and cyclist location on these three classes of road. Access roads are within 30 km/h zones only meant for direct access to homes and local destinations. Through traffic should avoid 30 km/h zones. Weijermars and Wegman (2011) indicate that categorization of the road

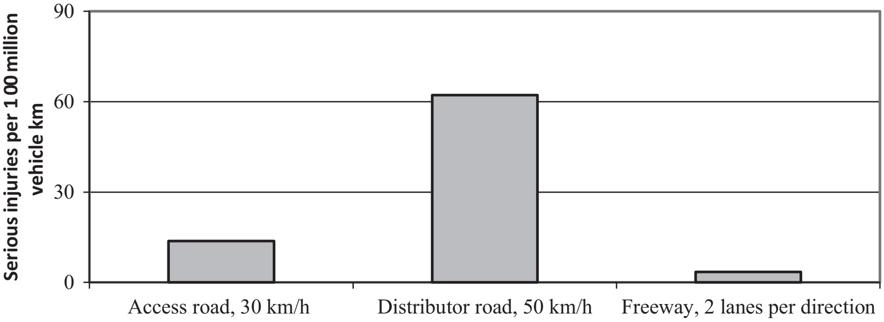

Fig. 19.3 Serious injuries per 100 million motor vehicle kilometres in 2007–2009 in urban areas (Witteveen+Bos 2015)

network and traffic calming measures such as the construction of 30-km/h zones was the most important measure to implement the Dutch sustainable safety approach, accounting for a significant share of the 60% drop in fatalities since the 1990s.

Due to their mixed function character, distributor roads have higher risks than through and access roads; hence, the Dutch safe system approach recommends that the portion of a trip on distributor roads be as low as possible (Dijkstra 2013). Figure 19.3 depicts risk observed on urban roads and freeways in the Netherlands. Other researchers have also found negative road safety effects for an increased length of distributor roads, number of lanes of major roads, and lane-kilometres (Dumbaugh and Rae 2009; Marshall and Garrick 2011). More recently, other researchers have sought to assess the risk of these distributor roads on active transport and found that they are indeed more hazardous for pedestrians and cyclists, and that the likelihood of collisions increases with the number of lanes and road width (Miranda-Moreno et al. 2011; Schepers et al. 2011; Ukkusuri et al. 2012).

19.3.2 Lower Levels of the Hierarchy

Elvik (2001) describes area-wide urban traffic calming as the implementation of a hierarchical road system comprised of physical restrictions to reduce non-local, through-traffic volumes and speeds on residential (access) streets. While this is done in response to resident complaints, a truly effective system solution also requires improvement of distributor and through roads to carry a larger traffic volume without additional delays or more accidents. In a meta-analysis, Elvik (2001) found a collision reduction of 25% for traffic-calmed residential access roads and a 10% reduction for distributor roads, consistent with later research by Lovegrove and Sayed (2006) that found closer to a 30% or 50% safety benefit when done as part of a neighbourhood-wide, systematic road network redesign (Lovegrove and Sayed 2006).

Several studies have analysed the neighbourhood road network patterns depicted in Fig. 19.4a, b using community-based, macro-level CPMs (Lovegrove and Sayed 2006;

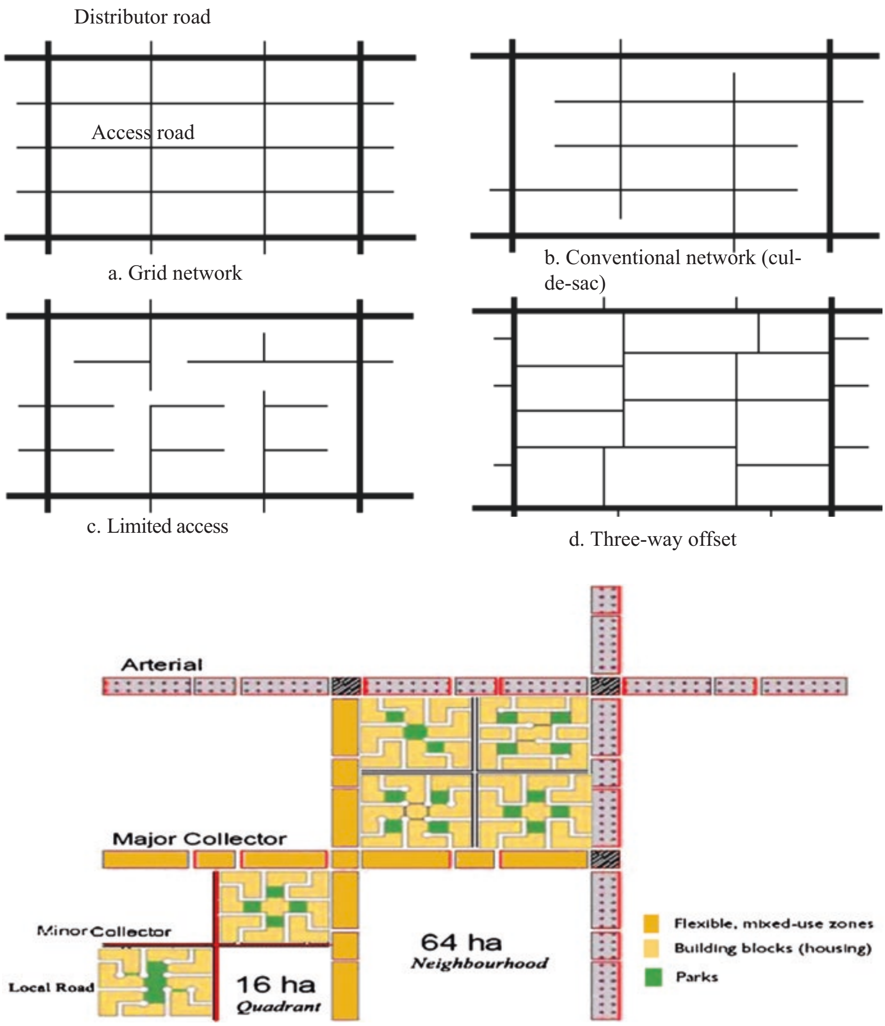

Fig. 19.4 (**a**) Neighbourhood road network patterns (Wei and Lovegrove 2012). (**b**) Neighbourhood road network patterns (Wei and Lovegrove 2012)

Wei and Lovegrove 2012; Sun and Lovegrove 2013; Masoud et al. 2015). The benefits of convenient vehicular connectivity of traditional grid network have been offset by the cost of shortcutting problems. The benefits of the contemporary response, cul-de-sac network designs that prelude shortcutting, have been offset by the cost of severed vehicular connectivity that results in increased VKT (and collisions) and, if not carefully designed for, loss of active transport network connectivity. A three-way offset network combines vehicular connectivity and safety benefits using offset 3-way intersections to calm traffic and thereby prevent shortcutting. When a safely designed vehicle network is 'fused' or integrated with a coordinated, connected, and compacte

Fig. 19.5 Cauliflower network pattern with winding roads and limited access (left); example of a winding road in a cauliflower neighbourhood (right)

land use design, results appear promising, as suggested by recent North American research on a design known as the Fused Grid (FG) sustainable neighbourhood, or SMARTer Growth Grid (SGG) neighbourhood as it has come to be known.

The SGG concept springs from a study of many historic, human-scale communities worldwide, including many in Europe, to identify common patterns that contribute to a sustained higher than average quality of life for its residents and businesses. With its ubiquitous off-road active transport paths conveniently connected to nearby corner parks and a protected core green space, the SGG neighbourhood can be expected to experience up to 60% fewer collisions than conventional grid and cul-de-sac road network patterns, as shown in Fig. 19.4b (Grammenos and Lovegrove 2015; Masoud et al. 2015).

Unlike the recent SGG 'rediscovery' by North American community planners and designers and their struggles to apply it and retrofit urban and suburban sprawl in the face of physical sprawl realities, European community planners have for decades understood and successfully applied safer transport networks and healthier community designs as living models of the SGG design principles. There are many road network patterns in practice, including many so-called cauliflower neighbourhoods built to provide for population growth in the 1970s and 1980s in the Dutch new towns and even earlier, as shown in Fig. 19.5 (Wegman 2014). The 'cauliflower' structure is characterized by winding roads and a maze-like grouping of little courtyards or 'woonerfs' (literally, 'residential-premises' or 'home zones') intended to preclude through traffic, provide a social play zone, and keep speeds at a walking pace. This would be similar to what is only now being recommended as a 'residential shared street' by the North American Association of City Transportation Officials (NACTO) in their recently released Urban Street Design Guide (NACTO 2013). Separated and stand-alone paths built for cyclists and pedestrians conveniently connect between woonerfs and other activity destinations, more directly and shorter than those offered to car drivers, thus making walking and cycling the most convenient mode choices for local trips (Wagenaar et al. 2008).

There are many design measures to achieve the lowered design speed set at the network level for access roads. According to PIARC's Human Factors Guidelines for Safer Road Infrastructure (Birth et al. 2009), drivers tend to accelerate on straight, smooth, wide roads with long sight distances and a monotonous environment. Some of their recommended measures to disrupt drivers and reduce speeding include (Bach et al. 2006; Birth et al. 2009):

1. Surface treatments, such as colour and brick pavers instead of asphalt pavement
2. Physically narrowed roads, such as less road right way, and/or planting flower boxes
3. Visually narrowed roads, such as staggered parking

19.3.3 Higher Levels of the Hierarchy

An example helps to explain the potential safety advantage of the highest ranked mobility or through-road category in the hierarchy, freeways. Similar to Fig. 19.3 for the Netherlands, Bayliss (2009) reports much lower risk of fatal and severe collisions on freeways compared to lower ranked roads (less than 25% of the number of fatalities per VKT observed on distributors). Of course, the external costs of building more lane-kilometres of freeways include induced traffic (and associated energy consumption and pollution emissions) as in the longer term when people relocate or change jobs to travel more kilometres within their travel time budget (Goodwin 1996). If a freeway allows a person to travel twice as far in the same amount of time, simple math suggests that fewer kilometres travelled formerly on the lower category road (e.g. distributor) may be replaced by twice as many kilometres on the new freeway. If this were true, for example, a doubling would halve the expected road safety benefits noted above, suggesting that a shift from urban distributor road to a freeway would reduce the number of deaths by much less than a factor of 4 (e.g. $1/4 \times 2 = 1/2$). However, if a 50% reduction could be realized, this would still be a large safety improvement and illustrates the reasoning behind designing for the highest share of the trip distance to take place on relatively safer mobility-oriented, through-roads (Dijkstra 2011). Schepers et al. (2017b) mention the dense Dutch freeway network, covering about half of the country's motor vehicle kilometres, as one of the success factors for the country's high level of cycling safety. In North American parlance, many Dutch freeways resemble higher speed, restricted access arterial highways, of usually not more than one or two lanes in each direction (see Fig. 19.6).

Cyclists are not allowed on these roads and therefore not exposed to freeway traffic. However, for lower population densities, such as in sprawling communities in North America, it becomes difficult to provide a limited access, safe freeway network dense enough to cover a high share of the distance travelled by motor vehicles. For example, the two hypothetical villages in Fig. 19.7 have similar populations and network design, but the left village has a much higher population density. Obviously, the residents in the village with the highest population density need to travel less kilometres to enter the freeway. A similar line of reasoning would apply to the exposure to risk while accessing public transport, as per Fig. 19.7. If we

Fig. 19.6 Bicycle bride over a freeway (the A50 near Arnhem)

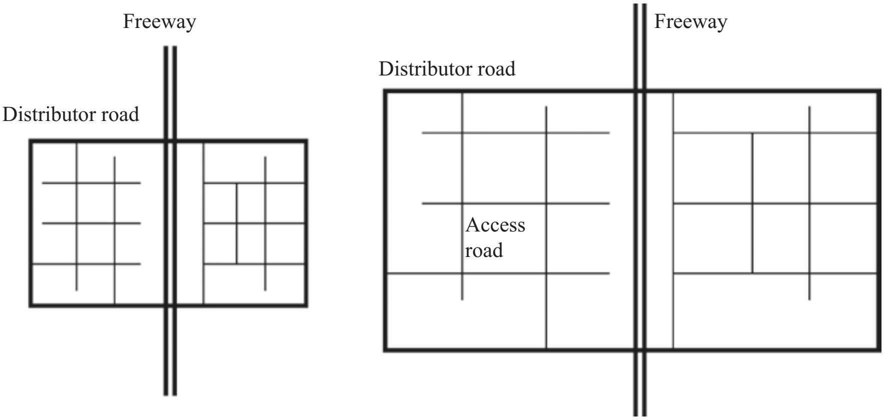

Fig. 19.7 Two hypothetical villages along a freeway with similar populations and road networks but different population densities, i.e. high in the left village and low in the right village

replace the freeway in Fig. 19.7 by heavy rails, we can conclude that less relatively unsafe kilometres using light rail or transit buses would be needed to travel to a railway station to take a relatively safe train.

19.3.4 Alignment of Network, Land Use, and Different Modes

There are different design practices regarding how to position land uses relative to the road network. Slop and Van Minnen (1994) describe conflicts between crossing pedestrians and cyclists and high-speed motor vehicles on distributor roads as a key road safety problem. They suggest the frequency of such conflicts is minimized if traffic-calmed areas enclose neighbourhood-oriented land uses. In the core of residential neighbourhoods, for example, the designers should locate walking and cycling opportunities for primary school, child care, grocery, social meeting spaces, parks, churches, fitness, seniors, library, and so on. Lovegrove and Sayed (2006) were able to quantify this safety benefit of area-wide traffic calming in North American neighbourhoods, including the need to protect the core of each neighbourhood from shortcutting and higher class roads and traffic, a finding consistent with the research on Dutch neighbourhoods that found traffic-calmed areas can be as large as possible, up to some 2 km^2 (SWOV 2010c).

Despite these findings, Dumbaugh and Rae (2009) found that the more common practice in North America is to restrict land uses in residential areas to only parks, schools, and churches. Any other uses placed inside communities would create too much traffic in the auto-oriented North American culture, and thus they get relocated onto perimeter distributors that bound residential areas. This planning approach is intended to divert traffic from invading residential areas while still allowing residents to conveniently access retail stores on their trips to and from work. The problem with this autocentric approach is that it also increases the frequency of conflicts between two distinct streams of traffic: (1) higher-speed, through-vehicles on perimeter distributor roads and (2) lower-speed, access-vehicles, and crossing pedestrians and cyclists going to and from the retail stores (Lovegrove and Sayed 2006; Dumbaugh and Rae 2009). Moreover, it violates the Safe System principle of functionality because the flow (through) and access functions are mixed (SWOV 2010a). The impressive safety results achieved in Dutch new towns (i.e. 1.0 fatal crash per 100,000 residents) seem to confirm that the design approach formulated by Slop and Van Minnen (1994) works, while North American communities does not (i.e. 6.8 fatalities per 100,000 residents in auto-oriented cities).

Finding ways to retrofit and address these safety concerns towards Vision Zero are underway within these auto-oriented North American communities, and pockets of hope do exist as beacons of a vision of what could be; for example, transit-oriented New York experiences only 3.7 fatalities per resident. Others are researching retrofits with safer intersection designs (e.g. roundabouts, three-way offsets) and reinvented, calmed 1-way couplet hybrid land use schemes (Masoud et al. 2015). In these hybrid, calmed 1-way couplet schemes, each carriageway is narrower and controlled by roundabouts to improve visibility and reduce vehicle speeds and task demands (i.e. only one-way vehicle flows) for drivers, cyclists, and pedestrians at crossing conflict points. Moreover, each couplet's carriageway is moved away from the other by an 80-m wide boulevard on which local retail and service land uses occur. While clearly not ideal, this hybrid design recognizes and tries to adapt the pre-existing North American built form of communities that mix access and flow traffic streams. Emerging research findings appear promising that lower vehicle speeds, improved visibility, and reduced driver task demands can reduce risk (and associated consequences) of vulnerable road users that must cross these pre-existing perimeter roads to access commercial areas (Masoud et al. 2017).

A significant barrier to retrofits remains, however, in the fundamental land use planning that encourages 'big box' urban and suburban destination retail developments in North America, which is a foreign concept to planning community-friendly smaller retail establishments in most European communities. For instance, the Netherlands established rules at the national level to curb the growth of (peripheral) hypermarkets and shopping malls (Evers 2002). Box developments are the norm in North America and will remain for at least a generation as artefacts of historic car-centric BAU sprawl. Some evidence suggests (as shopping malls decline in popularity

Fig. 19.8 The city of Houten with a population nearing 50,000; southern railway station (bottom left) and stand-alone bicycle paths near the northern railway station (bottom right)

in favour of more community-oriented shops and activity hubs within local communities) that they will be reabsorbed and transformed as part of community retrofits and SMARTer Growth Grid (SGG) neighbourhood redesigns. However, wherever and whenever SGG retrofits occur, there is significant evidence that employing more sustainability-oriented community design principles in a systematic approach can be successful, as witnessed by Dutch new town successes over the decades even before SMART Growth, FG, and, most recently, SGG labels became 'in vogue'!

For over 30 years since their development, the Dutch new towns included in Table 19.1 have experienced low death rates, even though these cities have a much smaller population and density (greater and denser populated cities tend to be safer) than the larger bicycle and public transport-oriented cities listed in the same table. Interestingly, the modal share of cycling in new towns is similar to that in larger bicycle-oriented cities. To explore why this might be, we point to Fig. 19.8 which shows the perimeter distributor road network of the smallest Dutch new town, Houten, with only 50,000 inhabitants. Houten consists of two traffic-calmed neighbourhoods roughly 5 km^2 in area, in which all facilities including railway stations can be reached by foot or by bicycle in less than 10 min and without having to cross a distributor road. Where access across perimeter roads is needed, for example, when residents in one neighbourhood travel to reach the city centre in the other, they do so using shallow bicycle tunnels and 2% slopes to pass under it. In this way, Houten designers have provided a central, tree-shaped, car-free pedestrian and cycle network, a ‘green backbone’ that is heavily used by businesses and residents of all ages (Bach et al. 2006).

Designing for people first has been a critical success factor in the Netherlands. In Almere, the largest of the Dutch new towns, the main and direct cycle routes to the city centre were set at an early stage in the design process. Cycle routes run alongside and at the level of waterways, while cars cross via bridges without interrupting cyclist traffic (i.e. grade separated). Almere also has dedicated bus lanes for fast bus travel (Bach et al. 2006). Dutch new towns have large traffic-calmed areas and car-free cores, which are characterized by high ped/bike network connectivity and low auto network connectivity for local access within and high auto connectivity on perimeters. A study by Schepers et al. (2013) shows that cities where cyclists travel more kilometres through traffic-calmed areas (either along access roads or stand-alone bicycle paths), such as in Dutch new towns, are safer for cyclists but also for road users in general.

Bach et al. (2006) describes this people-first, ‘reverse’, or ‘bottom-up’ design process as the way to achieve safe and pedestrian- and bicycle-friendly neighbourhoods, such as in Houten, containing all frequent destinations for these road and non-road user groups. His recommended design process is as follows:

1. Locate quality-of-life sustaining daily activities and amenities as priority locations, not forgetting the need to identify plentiful opportunities for ‘green’ areas of restorative, spiritual, sport, and social space.
2. Layout direct walking and cycling routes between these locations and core residential areas.
3. Identify and protect the cores and main routes for traffic calming priority, crossing safety and pedestrian precincts.
4. Integrate ‘people pumps’ such as public transport stops, rail and metro stations, and the pedestrian entrances to public buildings and parking garages.
5. Develop lines and networks for public transport.
6. Evaluate whether the objectives have been met.
7. Last, superimpose the network for private cars (on the remaining blank space).

This formalized design process epitomizes the Dutch critical success ‘people-first’ factor. It replicates how traditional communities everywhere started (and at least in Europe for the most part have organically evolved and been preserved), as a community focused on and scaled by the human, not the private car. First, it starts by identifying the main daily activities and amenities that sustain quality of life, including schools, playgrounds, parks, markets, homes for the elderly, and starting points for walking routes. After this, routes for pedestrians, cyclists, and elderly are to be laid out from home address clusters (neighbourhoods) to important pedestrian and bicycle destinations. Zones such as traffic-calmed areas and pedestrian precincts can be marked off around frequent routes. Public transport stops and networks are planned in the next step. Routes for private car access are designed as the last step with a perimeter distributor road around the residential area and short-looped local access roads serving each residential cluster that minimize crossings and speeds.

Using a similar line of reasoning, several researchers have suggested to map frequent pedestrian and cyclists routes relative to distributor roads to identify potential safety problems (Bach et al. 2006). Researchers should give specific account of the needs and abilities of children and the elderly who may have specific problems with complex traffic situations such as crossing a busy road with high-speed motor traffic (Räsänen and Summala 1998; Van Beek and Schreuders 2002). Multimodal traffic models will support such analyses as pedestrian and cycle traffic is modelled at a microsimulation level of detail (Masoud et al. 2017).

19.4 Discussion

19.4.1 Road Safety

To summarize, we have found that the number of fatalities per 100,000 population is significantly lower in large cities of denser populations, more diverse land uses, greater use of public transport, and more cyclists and pedestrians. However, we cannot confirm that this is a causal relationship, as neither high-density nor more active transport use can directly explain improved road safety (Elvik 2009; Schepers and Heinen 2013). Despite many studies to date, the link between road safety and dense, mixed development oriented towards active transport is complex and difficult to reliably model in a predictive approach (Wei and Lovegrove 2012). We can say that increased volumes of cycling and walking are associated with reduced traffic speeds, increased awareness of cyclists, and increased travel times for all road users, especially at intersections. Intuitively, one would expect public demand for dedicated infrastructure for cyclists and pedestrians to increase with increasing levels of cycling and walking. We see this happening in North America as community governments must respond to climate change, energy conservation, and other sustainability-oriented challenges, whether handed down as legislated mandates or inherited as fiscal realities. Whether or not road authorities concur and take action, community retrofits will take time, during which casualties continue to occur. Unfortunately, what we are seeing to date in North America are very few governments that seem able to find ways out of their traditional patterns of political behaviour and unaffordable BAU cycles that expend precious tax dollars to increase TLKM and maintain travel time budgets between origins and destinations (see Fig. 19.7).

On the other hand, Dutch governments and designers have been able to create new towns, but not without overcoming many of these same traditional patterns. Dutch designers also planned for car traffic after World War II, but the post-war reconstruction took decades to complete, and levels of cycling were still high when the 1971 oil crisis hit (Schepers et al. 2017b), high enough to be recognized by policymakers as a solution for issues associated with motorization such as congestion, air pollution, and noise (De la Bruhèze and Veraart 1999). This may explain why only the first of the five Dutch new towns planned post-war in the 1960s, Lelystad, has a grid network of mostly 70 km/h distributor roads. It was planned first for cars, and separated cyclist path networks were not planned nor built until after the road network was built; hence, Lelystad has a less convenient bicycle network, and often cyclists get lost due to its nondirect networks and longer distances to local destinations. The city has the lowest bicycle modal share of the Dutch new towns in Table 19.1. The lesson to be learned for North American town planners is that despite the fact that dedicated infrastructure did not get priority treatment, and is only now being thought about given existing auto networks, safety levels can still be improved significantly when dedicated cycling and walking infrastructure is retrofitted into existing communities.

Most Dutch cities were built before World War II with higher densities and mixed land use. In cities such as Amsterdam, where most of the built environment survived the war, heavy roads were planned such as a four-lane arterial (Lastageweg) though the Nieuwmarkt neighbourhood. While most of the buildings were demolished in the 1960s, a broad coalition of squatters, residents, and conservation advocates were able to stop the demolition of the monumental Pinto house. On January 5, 1972, the Amsterdam city council decided by a narrow one vote majority to abandon the plan in favour of more dense and diverse human-first, cycling-oriented planning. Summarizing, key factors that may have contributed to this human-first urban planning approach in some European countries are the relatively late, post-war motorization, strong pre-war walking and cycling cultures, awareness of emerging problems in American 'auto-oriented cities', and opposition to demolition of existing neighbourhoods (De la Bruhèze and Veraart 1999; Ebert 2004).

In both Europe and North America, governments and planners are no doubt aware of these studies, yet North American leaders appear afraid to take economic and/or political risks. The research shows conclusive evidence of the economic benefits that with higher densities and mixed land uses (not high rises, just modestly higher densities), more money becomes available to invest in (sustainably) safer transport systems, both between communities (heavy rail, metro systems, and freeways having only grade-separated intersections) and within each community (lower speed limits, roundabouts, separated paths). Moreover, in denser communities, all of these safer transport systems (i.e. safe public transport and freeway systems) are closer to origins and destinations, which contribute to a higher share of kilometres travelled as safely as possible. This is a significant result when one recalls that in low-density, sprawling communities, higher shares of kilometres travelled will need to occur along distributor roads where risks are higher due to the multifunction, multi-purpose nature of the traffic on these distributor roads. To add more ammunition with which designers can help change leaders, we suggest that there is a second avenue beyond economic benefits to be considered, that being the significant health benefits of SGG (aka Dutch new town) community design. For comparison, the annual health benefits of cycling in the Netherlands are estimated at €19 billion (approximately 3% of the Dutch GDP), while annual capital investments by all levels of Dutch government in road and parking infrastructure for cycling amount to only €0.5 billion (Fishman et al. (2015). The estimated health benefits are controlled for negative side-effects due to cyclists' increased exposure to road safety and air pollution risks.

19.4.2 Public Health

In response to the adverse health impacts of urban transport that are the result of accelerated and auto-oriented urbanization and motorization (Khreis et al. 2016), many cities are beginning to shift their mobility strategies. Official community plans and growth management strategies are shifting away from auto-oriented and towards more human-focused, active transport-oriented means to reduce greenhouse gas emissions and improve public health (Nieuwenhuijsen and Khreis 2016). Road safety also benefits from urban designs oriented towards active transport (and vice versa). Moreover, it is no coincidence that the sustainably safer North American SMARTer Growth Grid and the Dutch new town community designs have in common the same traits found in traditionally sustainable communities, which also parallel human-first design principles by Bach et al. (2006).

Due to arguments surrounding these health benefits, the SMARTer Growth Grid design may be starting to catch hold across North America in new developments (e.g. Calgary, Alberta, Canada) and in retrofits of existing areas (e.g. Kelowna, BC, Canada). Robust, science-based public-health research is lending voice to the need to retrofit existing and design new urban form (Handy et al. 2002; Frank et al. 2005; Levine and Frank 2007) These built form and public health linkage experts have concluded that the following urban design principles paralleling Bach et al. (2006) will result in addressing public health problems, for example, related to obesity that in NA is commonly referred to now as 'the new nicotine'.

19.4.3 Study Limitations

In this chapter we mainly focused on the linkages between urban form and road safety in terms of traffic deaths. However, it should be noted that cyclists and pedestrians are frequently injured in falls by themselves, regardless of urban form design (Methorst et al. 2017). For instance, single-bicycle crashes cause almost three-quarters of all serious injuries among hospitalized cyclists, partly due to flaws in associated infrastructure (Schepers et al. 2015a). A shift from driving to cycling may result in increased numbers of serious road injuries until infrastructure design details catch up (Stipdonk and Reurings 2012), but we know that the health benefits of increased physical activity do substantially outweigh morbidity due to these active transport road injuries (Mueller et al. 2015). Moreover, while the net health benefits of cycling in the Netherlands (after adjusting for mortality due to air pollution and traffic fatalities) are estimated at €19 billion per year (and are even higher if the benefits of walking are added), the total road crash costs of all transport modes (including minor injuries and property damage) amount to €13 billion per year (SWOV 2014; Fishman et al. 2015). Increasing the quality and dedicated infrastructure for pedestrians and cyclists would further reduce the likelihood of injurious falls and help to keep elderly people mobile and therefore also need to be a priority in any discussion about urban form design (Fabriek et al. 2012; Methorst et al. 2017; Schepers et al. 2017a).

19.4.4 Recommendations

The Safe System approach (see the Road Safety Manual for more details; World Road Association 2014) is recognized as a solid basis for safe urban road design; however, the results of our exploration suggest that urban form can be better optimized by putting road safety policy in the context of a broader policy focussed also on improved public health. In this chapter, we have acknowledged that integrating urban planning and infrastructure network design for sustainably safer communities is easier said than done; however, we have also cited many examples that demonstrate it can be done, to great economic benefit, especially when linked to public health benefits. Relying on historically successful community designs worldwide, sustainably safer community design starts with a 'bottom-up, humans-first' design process of development patterns that focus on the needs of pedestrians and cyclists first, supported with high-quality public transport, and only consider motor traffic in the last stage. Retrofitting existing, or building new, communities towards a SMARTer Growth Grid and sustainably safer design will be a radical departure for many designers, just as it was for the Dutch new town planners, but it does work when properly done. Therefore, as a critical first step, we urge all urban planners and designers to work in a multidisciplinary team under a strong leadership that demands forward-thinking, evidence-based input from all disciplines (Van Beek and Schreuders 2002). The Safe System approach is based on the ethical premise that preventable loss of human life and long-term disability due to traffic crashes are unacceptable and transport designers ('system designers') are responsible to take preventive measures (Fahlquist 2006). There is strong science-based evidence—economic, safety, and health—that applying this ethical vision to transport and health in general is the proper planning and design approach, both in the immediate and long terms.

19.5 Conclusion

Dense and diverse land use and urban form oriented towards active transport (walking, cycling, and transit) have been demonstrated to be associated with higher levels of road safety (and public health) relative to 'business-as-usual' (BAU) sprawling, lower-density cities. However, we found that this relationship between urban form and road safety is indirect and the aforementioned urban form characteristics are likely to contribute by creating favourable preconditions for road safety (and public health in general). It appears that increased volumes of walking and cycling are associated with reduced traffic speeds, increased awareness of pedestrians and cyclists, and increased public support for large scale traffic calming and dedicated pedestrian and cycling infrastructure. Moreover, with dense and diverse land use, more money becomes available to invest in (sustainably) safer transport systems such as metro and rail, and more origins and destinations can be served by these systems that contribute to a higher share of kilometres travelled as safe as possible. To achieve higher levels of road safety and public health in general, we conclude that the most sustainable community and urban form design will be based on a 'bottom-up, humans-first' design process that focuses on the needs of local residents and pedestrians and cyclists first, supported with high-quality public transport, and that only considers private auto traffic in the last stage.

Appendix: Description of the Data Used for Fig. 19.1 and Table 19.1

Recorded deaths per 100,000 population in 2011–2015 in Fig. 19.1 are either calculated using road death and population statistics from governments such as statistical agencies or taken from OECD (OECD/ITF 2014, 2016) or WHO (WHO 2015). Phoenix or San Diego rates were from Kegler et al. (2012) and adjusted for the reduction in the USA between 2009 and 2011–2015.

Modal share of trips in Table 19.1 data was taken from the Wikipedia (2017) page about modes of transport in large cities (https://en.wikipedia.org/wiki/Modal_share) and supplemented with data for Hong Kong from Sun et al. (2014), Fietsberaad (2010) for cycling in Dutch new towns, and Statistics Netherlands (2017) for the average modal split in the Netherlands. Population densities from the Wikipedia pages of the cities are also added to Table 19.1.

Sources Table 19.1 and Fig. 19.1: Fietsberaad (2010), SWOV (2011a), Kegler et al. (2012), Préfecture de Police (2013), OECD/ITF (2014), Sun et al. (2014), NSW Centre for Road Safety (2015), Office for National Statistics (2015), Transport Accident Commission (2015), Transport Department Hong Kong (2015), WHO (2015), Department for Transport (2016), OECD/ITF (2016), Transport Accident Commission (2016), Statistics Belgium (2017), Statistics Denmark (2017), Statistics Netherlands (2017), Transport Analysis (2017).

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