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Complete Street Concept, and Ensuring Safety of Vulnerable Road Users

Adekunle Mofolasayo[a]

117-1757 Cunningham Way SW, Edmonton, T6W 3B5, Alberta, Canada. Email: mofoladek@live.com

Abstract

Provision of sustainable and environmental friendly transportation systems that creates adequate travel alternatives for end users is desirable in transportation industry. Complete streets, a system that is oriented towards designing streets to safely accommodate users of all modes and abilities has been seen as a potential solution to satisfy the need for variability in transportation mode choices. While complete street concept has great advantages, there is still concern about the safety of vulnerable road users sharing roads with high speed vehicles. Among other things, factors such as vehicle speed and lateral separation of vehicles from pedestrians and bicyclist has been found to affect the pedestrian level of service (LOS), as well as LOS for bicyclists. While there is interest in increasing the use of active transportation modes, there is also a great need to ensure that infrastructures for active transportation modes are not only safe, but also gives the end users a reasonable feeling of safety. Using basic principle of kinetic energy, this study evaluates some factors to consider when making policy decisions on sharing of limited road spaces. This study also presents pertinent research areas, and recommendations on how to achieve improvement in road, and vehicle designs, as well as driver behavior to result in overall improvement in transportation safety for vulnerable road users.

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Keywords: Complete street; Vulnerable road users; Transportation safety; Transportation policy; Kinetic Energy

1. Introduction

Complete street is a great concept in transportation engineering that seeks to ensure safe provision of alternative transportation modes for users of all abilities in all-weather condition. In complete streets, transportation professionals are guided to ensure that design, construction, operation, and maintenance of the transportation network of a community supports travel by various modal choices: bicycles, assisted device, foot, truck, public transport, and car (Geoff et al, 2015). Advocates of public health in various countries are in support of transportation policies, and a built environment that supports physical activities (Brown et al, 2015). There has also been interest in achieving 'green', and sustainable urban areas. Some of the ways by which green and sustainable urban area can be encouraged includes development of green travel modes like walking, and cycling. Walking has been found to have various advantages including improved health, increased personal independence, and reduced environmental impacts (Asadi-Shekari,

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Moeinaddini, & Shah, 2015). At the same time, both route safety, and feeling of safety are major factors that can help someone choose green travel mode option. The fact that road users like bicyclists, pedestrians, those on assisted mobility devices (wheelchairs), motorcyclists and moped riders, etc. are not in an enclosed medium that may serve as a form of shield from external impacts, makes them more vulnerable when compared to road users in various motor vehicles.

Various cities in North America has committed to the complete street strategies. In the United States, implementation of complete street principles in Main street-Grandview MO, Route 62- Hamburg NY, Grant Avenue-Novato CA, Edgewater Drive Orlando Florida, etc. has been found to result in fewer collisions (Geoff et al, 2015). In Canada, the city of Ottawa in the new transportation master plan has shown a commitment to apply complete street concept; the town of Ajax in her transportation master plan has also incorporated complete street as a future vision of the community (TAC, 2015). The city of Edmonton has identified the need to apply complete street strategy to reflect the city's aspirations in its strategic plans. The goal is to ensure varieties in the way people move and live within the city. The hope is that complete street strategy will help transform the urban form, improve livability within the city, preserve, and sustain the environment, promote active and healthy lifestyle, and address the security and safety of road users. The need for flexibility in complete street design has been identified to ensure that the streets reflects the characteristics of individual environments. A guideline was developed to guide new road design, and rehabilitation works, ensure accommodation of the need of all users, be efficient with the use of space, improve the aesthetics of the environment, and ensure a shift from a rigid road design to a flexible approach that reflects the content of the environment (The City of Edmonton, 2013).

1.1. Complete Street Process

The City of Edmonton in her complete street guidelines (2013) identified a six-step process for complete street as indicated below:

(1) Definition of project scope and goals
(2) Identification of modal priorities
(3) Identification of types of streets
(4) Choosing the elements
(5) Making trade-offs.
(6) Confirming the recommended design.

In the first stage, defining project scope and goals involves identification of the current issue of concern, and identification of how the street design may encourage appropriate driver behavior. In the 2nd stage, various modes of transportation that may use the facility are identified. In the 3rd stage streets are identified based on orientation, land use context, and functional form. The 4th stage involves selecting design elements like lane width, speed limit, etc. that are suitable for each street. The 5th stage involves opportunity cost evaluations, prioritization, and balancing of competing demands for available street space. The 6th stage involves re-examination of the design to ensure that it meets the established goals and objectives. The complete street guideline by the city of Edmonton noted that the six-step process mentioned may or may not be applicable for every design in the city for which it was designed.

During this project, a 7th step (periodic project review) was added to the complete street process to promote a culture that will ensure a continuous safety evaluation of road infrastructures, develop lessons learnt, identify what was well done, and what needs to be improved upon, and incorporate the findings in future developments, and upgrades to road infrastructures.

2. Road Traffic Safety Issue

Road traffic safety has been a serious problem in the world for a while now. Global report indicated that road traffic crashes result in more than 1.2 million fatalities, and over 50 million severe injuries every year (Moeinaddini, Asadi-Shekari, & Shah, 2014). The safety of vulnerable road users has also been of great concern. A report by the world health organization (WHO, 2013), indicated that 27% of global road fatalities are among cyclists, and pedestrians. Walljasper (2015), noted that in the US, every year, more than 4,500 pedestrians are killed by motor vehicles, while more than 700 bicyclists die in traffic crashes. In 2012, 17.9% of 1823 fatal collisions that occurred in Canada involved pedestrians and bicyclists; at the same time, 18.7% out of 122,140 injury collisions involved pedestrians and bicyclists (Transport Canada, 2012). These traffic fatalities necessitate that more efforts be made in traffic safety to consistently improve the systems to ensure better safety for all road users. If we all want to see significant improvement in transportation safety globally, we need to be open to innovative ways to improve road traffic safety, and ensure continuous review of all transportation practices, to eliminate systems that do not guaranty safety for all.

Previous study has noted that accident occur because of one, or a combination of some highway components including: the driver, the road, and the vehicle (Sayed, & Abdelwahab, 1997). Roess, Prassas, & McShane (2011) also categorized critical components that interact in a traffic system as vehicles, traffic control devices, street and highways, road users, and the general environment. Optimization of transportation system to prevent traffic crashes calls for a deep study of both the individual characteristics of the properties that interact in the traffic systems, as well as the inter-reaction of these components.

Various studies have shown that collisions in which front end of a light vehicle collides with a pedestrian or cyclist is the most frequent accident configuration (Serre et al, 2006). Does this mean that every driver that collides with a vulnerable road user did it intentionally? Certainly not! At the same time, it may be somewhat challenging for law enforcement officers to know (without a doubt) the intent of a driver that is involved in a crash with a vulnerable road user. As a result, with a goal to achieve zero fatalities on the road, there is need to ensure an all-round evaluation of how to improve on all the factors that interact during traffic crashes. The following needs a careful attention:

2.1.1. The road

- Ensure continuous improvement in road-side design, and maintenance to better protect vulnerable road users; ensuring that adequate engineering controls are put in place (where applicable).
- Ensure continuous improvement in pavement design, to not only guaranty the required strength, and rigidity for safe movement of vehicles, but also guaranty a soft landing for vulnerable road users during collisions.
- Ensure continuous monitoring of frictional qualities of road surfaces to ensure that portion of the roads that have frictional properties that are less than the acceptable standards receive adequate corrections.
- Ensure adequate policies are in place to monitor road surface friction, (and overall quality of the road) to acceptable standards, in every community. Note that, when there is an accident in which the vehicle is not able to stop on time, there is need to also investigate the quality of the friction properties of the road at the point of crash, and make necessary corrections, where applicable.

With a good policy in place to ensure routine check of the roadway properties, areas with friction properties that are below acceptable standards could be identify earlier, and due corrections could be made on time. No municipality need to wait till an accident investigation reveals that inadequate quality of the road friction properties contributed significantly to accident on a section of the road before appropriate actions for correction is taken.

2.1.2. The driver

- Increased enforcement to deter bad driving behaviors: Better compliance to traffic regulations may be seen if more law enforcements officers are on the roads.

- Provide more out of vehicle warning systems in more places, then ensure adequate use of monitoring systems like photo radar (and the subsequent fines) after a vehicle may have seen the out-of-vehicle warning system, and still did not comply with the traffic regulation.
- Ensure adequate driver education and increase requirement for driver re-training after a certain number of demerits is observed in the driving history within a specified period; It will not be a bad idea to have drivers who have had a lot of demerits go through the driver licensing education, and testing (both theory and practical) again after a period of driving suspension.
- Tighten rules for period where a reckless driver may lose driving privileges for a predefined length of time.

2.1.3. The vehicles

- Ensure improvement in vehicles standards to ensure that all vehicles on the road have reliable collision avoidance systems.
- Ensure reliable systems exists in all vehicles that can efficiently monitor the driving environment and detect the presence of vulnerable road users on time to avoid collision; Supplementing the driver efforts with reliable autonomous systems to monitor and react to real life situation to prevent traffic crash will be a clever idea.
- Ensure improvement in vehicle design to ensure that vehicles can both communicate the health of every critical component of the vehicles to both the owners, and the law enforcement officers, and ensure that vehicles that do not meet the minimum safety standards, are taken off the roads. For example, a vehicle that the brake system is faulty, and is likely to fail should not be on the road. Reliable systems should exist in every municipality that will mandate what date a vehicle cannot be on the road if critical safety components are not efficiently repaired.
- Full autonomous vehicles should be designed to have the capability to adjust operating capabilities to prevailing environmental conditions. These vehicles should never be operated at speeds where safety of vulnerable road users cannot be guaranteed. No occupant of the autonomous vehicles should have the operational capability to increase the speed of the vehicle beyond any such reduced speed that is automatically adjusted for prevailing weather conditions.

It will be good to have a system that ensures all vehicles on the road in every jurisdiction undergo a pre-license renewal vehicle inspection testing to ensure that vehicles that are allowed on the roads meets the minimum requirement for traffic safety.

2.1.4. Traffic control devices

- Ensure periodic evaluation of signal timing to ascertain that the timings are reasonable, and can still efficiently serve the present traffic volume, ensuring that wait time during red phase is not too long for both vulnerable road users, and other drivers.
- Ensure traffic control devices are placed at appropriate locations. Pedestrian signals can be very helpful to warn drivers of presence of vulnerable road users.
- Explore wide scale use of vehicle to infrastructure communication system.
- Explore efficient use of actuated traffic control signal over pre-timed signals, especially during off peak hours. A driver that waits (for a long time) at a red light in an intersection where there are no vehicles that require a green light in the other direction may think the traffic control signal is not working and may find it somewhat difficult to respect the signal.

2.1.5. The environment

- Ensure adequate preparedness for inclement weather conditions, like snow plowing, etc.

Various factors including speeding, distraction, fatigue / sleeping, driving under influence of alcohol etc. may impair or reduce a driver’s reaction time. Roadway conditions (e.g. slippery roads) may also make the driver lose control of the vehicle. Previous research has reported that there is a strong relationship between road friction and the risk of accidents (Wallman & Åström, 2001). In addition to having standard routine infrastructure evaluation, and maintenance systems that will check the quality of road, including the adequacy of the surface frictional properties (as mentioned above), transportation policy improvement to include advanced technologies like auto brake system for all vehicles on the road has been recommended (Mofolasayo, 2018). This will help ensure that a reliable system exist that can help initiate the braking system when the driver is impaired, fatigued or distracted.

The distance that the vehicle travels between the time that the driver perceives a vulnerable road user, and the time the car stops depends on the initial speed of the vehicle, the reaction time of the driver (the time taken before the driver engage the braking system), the slope of the road, and the coefficient of forward rolling or skidding friction.

$$Total\ Stopping\ Distance\ (ft) = (1.47 * V_{in} * t) + \left(\frac{{V_{in}}^2 - {V_{fn}}^2}{30(F \pm 0.01G)}\right) \quad (1)$$

The total stopping distance for vehicles is calculated using the above equation. Where V_{in} and V_{fn} are the initial and final velocities of the vehicles respectively (mi/h). F is the coefficient of forward rolling friction, G is the grade of the road, and t is the standard reaction time. The standard reaction time used in design is 2.5s (for some sections of the road). Note that the coefficient of forward rolling friction is expressed as a ratio of the deceleration rate of the vehicle and the acceleration due to gravity (Roess, Prassas, & McShane, 2011). For a vehicle to come to complete stop, i.e. final velocity of zero, the distance must be large enough to satisfy the above equation. If the available distance is less than the total stopping distance required to ensure that the vehicle is brought to a stop, there will be a crash. Meanwhile, it is important to note that it takes a while for human drivers to detect, process, and react to a hazard that could result in collision. This reaction time is critical in collision avoidance. Figure 1 below shows an illustration of how reduction in reaction times at various speeds affect the safe stopping distance. From figure 1 below, it is obvious that as the reaction time reduces, the safe stopping distances also reduces.

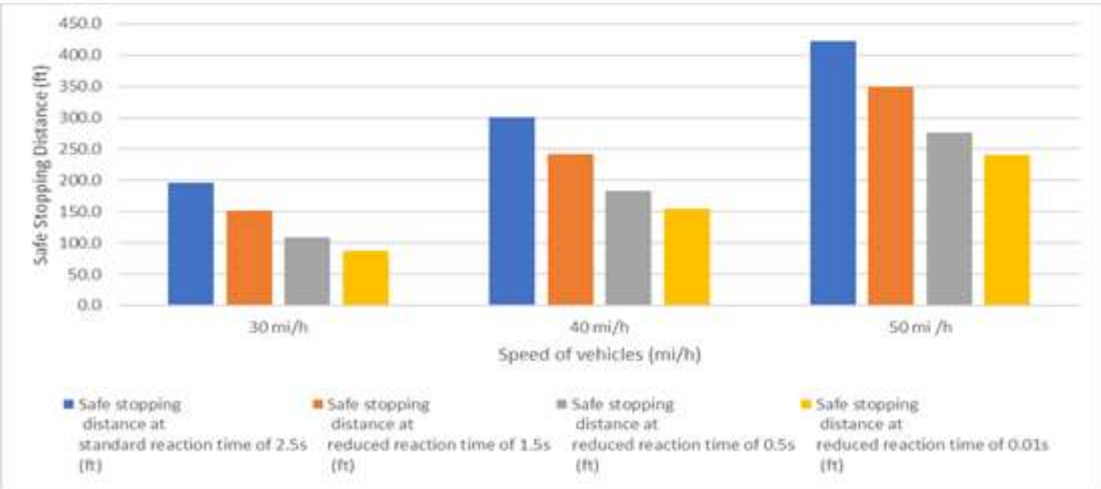

Fig. 1. Comparison of safe stopping distances with varied reaction times, and varied speed

Safe stopping distance also reduces with a reduction in speed of vehicles. These reductions in safe stopping distances for vehicles, are critical in ensuring that vehicles can come to a stop in good time to avoid collision with vulnerable road users. Various obstructions that limit the view angle of the driver, including obstruction of view created by a vehicle in another lane may also result in an accident. For example, a driver that does not see that a vehicle in another lane stopped because a pedestrian is crossing, may not stop on time to avoid collision. More research is recommended into the use of advanced technologies like light detection and ranging data (LiDAR) to detect objects, or movement of people (that might present collision hazard) in proximity to moving vehicles, and automatically trigger appropriate response in the vehicle to help the driver in avoiding a traffic crash (when using a driver-operated vehicle), and ensure adequate maneuver, or completely bringing the vehicle to a stop in good time to avoid collisions (when using driverless vehicles). More research is also recommended in the use of connected vehicle technology that may be able to inform other vehicles about the reason for a stop in another lane, to ensure that other vehicles on the road can slow down on time to avoid collision. Note that LiDAR sensors, with a 360º view angle, obstacle detection, and navigation has already been designed for autonomous ground vehicles, and marine vehicles (VelodyneLiDAR). Giving that the total distance that a vehicle travels after perception of a hazard that warrants an evasive action is dependent on both the reaction distance, and the braking distance, in addition to making efforts to implement systems that can help reduce the reaction distance, improving on factors that can help reduce the braking distance will also help ensure a reduction in the safe stopping distance for vehicles on the road.

2.2. The speed, and mass (kinetic energy) factor

Among the factors that are responsible for traffic crashes, speed is a high determinant factor in the severity of crashes. The gravity of crash increases exponentially with speed (Consumer Reports, 2013). Reduction in speed limits have been found to result in reduction of crashes (De Pauw, Daniels, Thierie, & Brijs 2014). Kahane (2012) noted that the relationship between fatality risk, vehicle mass, and size is complex, and varies with crash type. The Insurance Institute for Highway Safety (IIHS) and Highway Loss Data Institute (HLDI) noted that occupants in bigger, vehicles are more protected than those in smaller vehicles, as size and weight affect forces that occupants of a vehicle experiences during a crash. During collision of 2 vehicles, it was noted that the smaller vehicle will be pushed backwards during the impact. While there will be more forces on the occupants of the smaller vehicle, there will be less forces on the occupant of the bigger vehicle. Note that this is supported by the basic principles of kinetic energy, for 2 objects [with different mass] that are moving at the same speed. Similarly, pedestrians, and other vulnerable road users are susceptible to high impact energy when involved in collision with vehicles on the road. Kahane (2012) gave point estimates for percent fatality increase per 100-pound mass reduction (in cars < 3,106 pounds, cars ⩾ 3,106 pounds, CUVs and Minivans, Truck based LTVs < 4594 pounds, and Truck based LTVs ⩾ 4594) while footprint (size) is held constant. Kahane found that societal fatality increase of 1.56 percent when mass is reduced by 100 pounds in lighter cars is the only statistical significant result from the evaluations made. The societal fatality increase of 1.56 percent that was reported when mass is reduced by 100 pounds in lighter cars may seem to contradict the reasoning that reduction in weight of vehicles should result in reduction in impact energy that a vulnerable road user may experience. However, Kahane, noted that the societal fatality rates include both the pedestrians and the occupants of all vehicles that are involved in the crash. An important question to further study will be, when considering a reduction in the weight of lighter cars (as regards to overall societal fatality rate), what will be the result if the reduction in the weight of lighter cars comes together with an equivalent reduction in the weight of all other vehicles on the road. If reduction in weight is considered only for lighter cars, and if lighter cars continue to be in the same traffic stream with heavier cars, the occupants of the lighter cars may continue to be more susceptible to experiencing a harsher impact of traffic collision than the occupants of heavier cars. However, if the weight factor is considered in reference to vulnerable road users only, the lighter the weight, and the speed with which the car is moving, the lesser the potential impact energy that a vulnerable road user may experience during a crash.

Applying the basic principle of kinetic energy of an object to moving vehicles, as illustrated in figure 2 below, it is obvious that the kinetic energy is expected to increase with the mass of the object. The risk of fatality for a vulnerable road user is also expected to increase with increase in mass and velocity of the object that is in collision with the vulnerable road user. Note that from fundamentals of physics, when velocity, v of a particle of mass m is well below the speed of light, the kinetic energy (K.E) of a particle can be represented as $K.E = \frac{1}{2} mv^2$ (Walker, Halliday, & Resnick, 2014). This also confirm that both the mass as well as the speed of vehicle is a factor in the resulting impact energy during collisions.

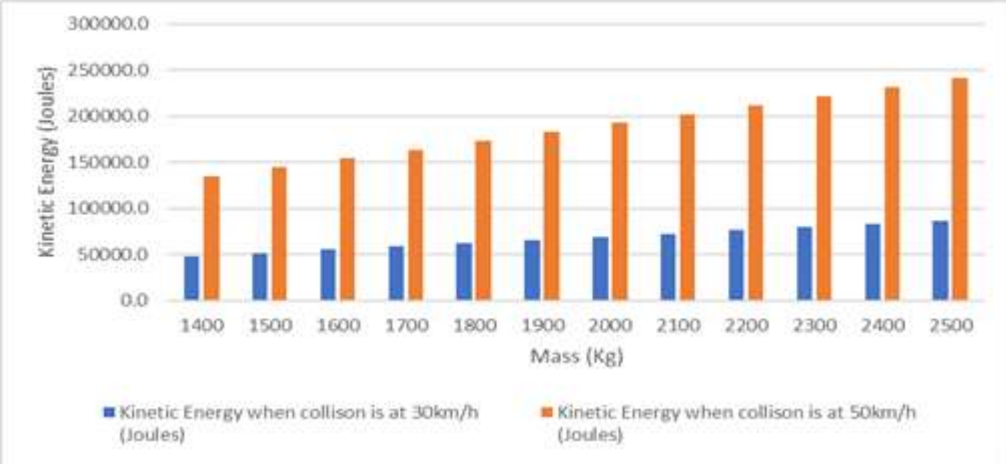

Fig. 2. kinetic (impact) energy of moving object with varying mass at speed of 30Km/h and 50Km/h

It is obvious that both mass and velocity with which the vehicles move affect the kinetic energy that goes along with the vehicles on the road, to minimize the impact on vulnerable road users, it appears a reduction in not only the speed of vehicles (where possibility of contact with vulnerable road users may exist), but also an equivalent reduction in the overall mass of vehicles in the traffic stream will be desirable. But, it is good to note that the safety of vulnerable road users cannot be treated in isolation without considering the safety of people in automobiles too. While the Insurance Institute of Highway Safety, and Highway Loss Data Institute [IIHS & HLDI] (2018) noted that people are less likely to be injured or killed in a bigger, heavier vehicle, IIHS & HLDI further noted that fuel economy can be improved without sacrificing size, and weight, using technologies like that of electric vehicles, hybrids, etc. The fact that increased vehicle mass is more dangerous for vulnerable road users during collision, but bigger, and heavier vehicles are preferable for safety of occupants of automobiles puts humanity at a conflicting point about where to draw the line. The questions that exists here includes, should weights of all vehicles on the road be reduced in favour of safety of vulnerable road users, or should automobile manufacturers be encouraged to manufacture bigger, and heavier vehicles (instead of smaller, and lightweight vehicles) to better protect occupants of automobiles?

Given that the traffic stream is a mixture of both heavier and lighter vehicles, and a collision between a lighter and a heavy vehicle puts the occupants of the lighter vehicle at more risks than the heavier vehicle, in the effort to ensure good protection for both the occupants of automobiles, and the vulnerable road users, it will be a good idea to see more research on the optimum weight, and size which a vehicle can be to prevent traffic fatality for occupants of the vehicles, at the same time, it will be good to give proper attention to adequate systems for automobiles to avoid collisions, not only with vulnerable road users, but also with other automobiles on the road. It is certain that not all road vehicles have the same weight. If light weight vehicles could be at a disadvantage to bigger, heavier vehicles during collision, how much more will vulnerable road users be at more disadvantage to bigger and heavier vehicles.

To reduce potential energy impact on vulnerable road users, more research is recommended into how reasonable reduction in the weight of all vehicles on the road may be achieved, and still be able to transport people, and goods efficiently, and safely from various origins to destination. It will be desirable to see more research on how vehicles may be manufactured with light weight, but strong (durable) materials that are able to withstand high impact energy without significant deformation. To ensure safety for car occupants, this research may also involve how more cushioning effect may be incorporated in the vehicles to minimize the impact on vehicle occupants during any traffic crash. If humanity at large can achieve a breakthrough in this research, it should be a win-win situation in terms of traffic safety for both the occupants of cars, and for vulnerable road users. Given that it takes more energy to stop a heavier object that is in motion, than a lighter object, more research is also recommended on how reduction in weight of vehicles on the road may transmit to a reduction in the effort to bring the vehicle to a stop within the shortest (breaking) distance.

Although reduction in vehicle weights is desirable for a number of reasons, it is good to remember that all vehicles should have sufficient weight to be able to withstand turbulent wind conditions, and also have enough capacity to fulfil the intended purpose for which they were designed. However, unnecessary additions to vehicle weight should be avoided. If a car can attain a minimum weight to ensure safe travel on the road (in all weather conditions) while at the same time, the engine is made with light weight materials, such technologies should be welcomed for all vehicles. It is known that the human body is not strong enough to withstand high impact energy that occurs during many traffic collisions. There is need to pay adequate attention to how the streets are designed and shared to minimize possible contact of vulnerable road users with vehicles that go about with higher energy in motion (kinetic energy).

3. Sharing of Street Elements

Using the basic principle of kinetic energy, figure 3 below shows graphs of kinetic energy of a car and a bicycle, with a hypothetical gross car mass of 2100 kg, bicycle and rider mass of 100 kg. Note that the gross vehicle weight varies for different vehicles, likewise, the gross weight of bicycles with the cyclists may vary. The energy with which an object will be impacted as illustrated in figure 3 is meant to illustrate the potential risk that both a bicycle and a car may bring during collision, at various speeds.

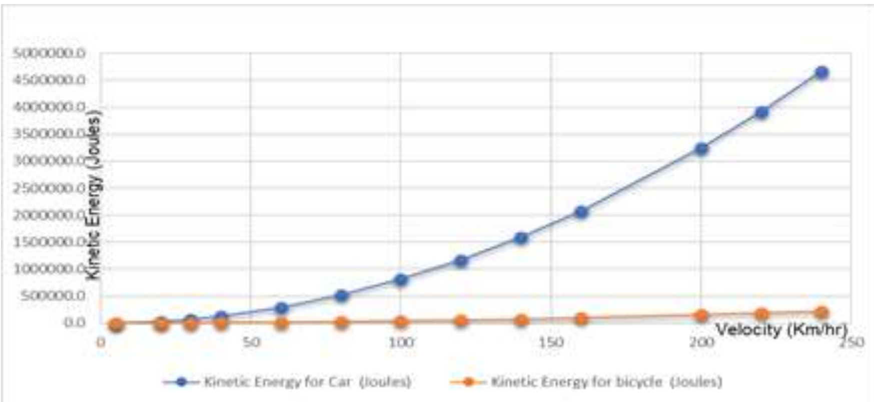

Fig. 3. Comparison of kinetic energy of a car and a bicycle unit in relation to speed

Note that the illustration for kinetic energy given in this report is based on the assumption that apart from the effect of mass and velocity of the traveling unit, in relation to the kinetic energy, pull, and push back forces, as well as any other propelling force, have no additional effect.

In this context, since the energy of impact of a moving object is dependent on both the weight and the speed of the object, knowing that the weight of a car far exceeds that of a bicycle, even when a car is driving at the same speed as the bicycle, a car will exert more energy during impact, or collision with another object, or person, than a bicycle. The degree of energy impact during collision could also be related to the degree of property damage, injury, or fatality. Knowledge about the impact energy of various transportation modes, as well as the level of exposure of vulnerable road users to various transportation modes with potentially high impact energy is important in planning and making decisions about sharing of street elements, and the level of protection that is needed for vulnerable road users.

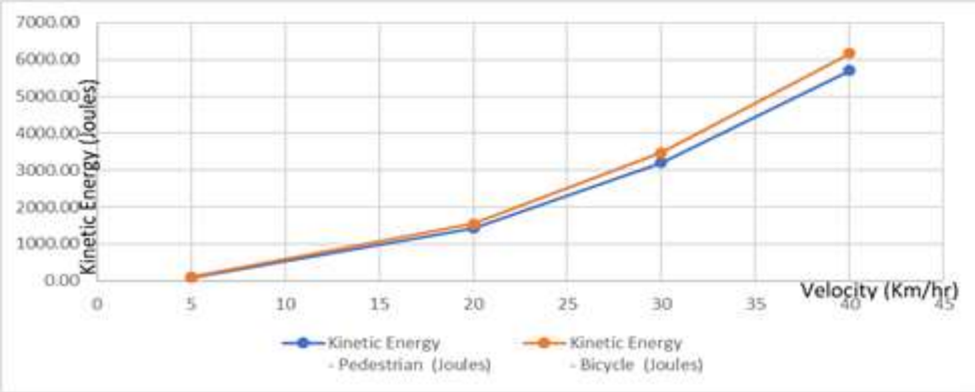

Fig. 4. Comparison of Kinetic energy of Pedestrian, and Bicyclist

Figure 4 above shows an illustration of kinetic energy that can be associated with two vulnerable road users, using a hypothetical pedestrian weight of 92.3 Kg, bicycle weight of 7.7 kg, and rider weight of 92.3 Kg. Using the basic principles of kinetic energy, the graph of kinetic energy of pedestrians and bicyclist is as represented above. The energy of impact to be expected from both the bicyclist, and the pedestrians is both dependent on the mass, and the speed of the traveling unit. A pedestrian that is running with a high speed on the walk way may cause a fall, and injury to other vulnerable road users on the road, if collision occurs with another vulnerable road user. Similarly, a bicyclist that is moving with a high speed on the walkway, or shared use path may cause a fall, or an injury to a vulnerable road user on the shared use path. It is widely accepted that pedestrians should walk on walkways, and not on the road, except when there is need to cross the road. It will be unsafe to ask pedestrians to walk or run on relative high-speed roads together with cars, without provision of adequate engineering controls to shield the pedestrians from being accidentally hit by a car. Similarly, it may be unsafe to ask skateboard users, or hoverboard users to share the road with high speed cars without provision of adequate engineering controls to shield them from high speed traffic. It is known that both pedestrians and bicyclists are vulnerable road users. From the previous illustration in figures 3, it is obvious that a car can carry higher kinetic energy than a bicycle. Meanwhile in figure 4, if moving at the same speed, the kinetic energy output from a bicyclist, and a pedestrian is not too far apart. It is known that bicyclists move faster than the normal walking speed of a pedestrian. However, in sharing of street space, in limited space situation, considering the volume and speed of traffic, it is good for every municipality to truthfully answer these questions, “will a bicyclist create as much injury or fatality to a pedestrian, or other vulnerable road users like a car may cause for a bicyclist”? Also, is there any documentation of bicyclists causing fatal injury on other vulnerable road users in the community? If there is any of such cases, how frequent is it? At the same time, it is good to examine the traffic safety records of automobiles on bicyclists. This information will help to give a rational decision of whether it is better to make allowance for bicyclists to share the path with other vulnerable road users or to send all bicycles on the road with high speed cars. From common knowledge during traffic crashes, it cannot be disputed that the high potential impact energy that moving cars carry, especially at higher speeds is unsafe for both pedestrians, and all other vulnerable road users. Given that vehicles carry higher weights, and moving cars have higher kinetic energy than bicycles, the severity of injury that a car may cause on a vulnerable road user, while moving at the same speed with the bicycle, is likely to outweigh the level of injury that a bicyclist may inflict on another vulnerable road user like pedestrian. As it is unsafe for pedestrians to walk on highspeed roadways without adequate engineering controls to shield them, likewise, it is unsafe to allow bicycles on high-speed roads without provision of proper engineering controls to provide some form of shield from moving vehicles. Note: Figure 4 showed the comparison of kinetic energy to be expected from both bicyclist, and pedestrian if they are moving at the same speed. A comparison of the kinetic energy of the two modes of transport at their average moving speed may be of more interest.

In designing elements and making trade-offs for street planning, it is important to consider the severity of injury that a travel mode may inflict on another travel mode that share the road elements. It is also good to consider the amount of exposure that various travel modes have to each other. If the probability that collision of a bicyclist with a pedestrian will result in a fatality is very low, while the probability that the collision of motor vehicles and bicyclist will result in a fatality, or severe injury is high, in a situation where a reduction in travel speed of vehicles on the road cannot be guaranteed to ensure safety of vulnerable road users, (such as bicyclists, etc.) and where available resources for installation of adequate engineering controls to protect those vulnerable road users is limited, it will be a wise idea to have a preference for bicyclists to share the walkway with pedestrians, than for bicyclists to share the road with high speed cars without provision of appropriate engineering controls as shield against accidental collisions from motorists.

The concern that collision of bicyclists with pedestrians may also result in injury brings about the need to ensure that in planning and design of future roads, adequate space be reserved as shared use path for vulnerable road users, to allow for safe commute. Designs that provides adequate separation (engineering controls serving as shield) from high speed cars is also a factor that warrants adequate consideration.

Sharing of road space by vulnerable road users may involve:

(1) Having lanes for pedestrians, and for bicyclists, distinctly marked out on the pavement
(2) Having a multi-use path that is wide enough to accommodate all vulnerable road users, with or without distinct pavement markings to divide the multi-modal paths.

In the situations mentioned above, it will be a good idea to ensure continuous education and enforcements to encourage all vulnerable road users to share the path in a respectful, and responsible manner to avoid injury to others. Enforcement actions against reckless cycling and reckless use of shared use paths is recommended in all municipalities. To encourage a good use of the shared use path, it will not be a bad idea to have systems to create awareness about how the shared use path connects various places in the community (ensuring that vulnerable road users are very familiar with these paths from various origins to destinations). Figure 5 shows an example of how public education for users of a multi-use path is conveyed in a community.

Fig. 5. Multi-use path with guidelines for users

In some situation, a separate space may even be created for bicyclists, pedestrians, and automobiles on the road. An example is given in figure 6 below.

Fig. 6. Separate lanes for bicycles, pedestrians and automobiles

4. The plight of motorcyclists

Motorcyclists, and moped users are also more vulnerable on the roads than car occupants. Because motorcycles can go at considerably higher speeds than bicyclist, and the average weight of motorcycles are also considerably higher than that of bicycles, motorcycles will carry higher kinetic energy, and impact force than bicycles, even at the same speed. For this reason, it is not recommended that motorcycles should share bike paths and walk ways with bicyclist and pedestrians. However, motorcyclists should ensure adherence to good cycling practices. When sharing roads with high speed cars, as much as possible, it may be more advisable for motorcyclists to keep to the slower moving lane, except when trying to pass another vehicle on the road. Use of motorcycle helmets has been found to reduce the risk of severe injury by more than 70%, and risk of death by almost 40% (WHO 2015). Strong enforcement of the use of helmets by motorcyclist in all jurisdictions globally is recommended. The plight of motorcyclists in road traffic safety is one that requires more research, to find more reliable means to adequately ensure the safety of all those who chose this mode of transport. Some of the potential areas for research improvement for motorcyclists includes:

(1) Design of safety wears / enclosures that is geared towards preventing serious injuries or fatalities if there is a crash. Airbag vests are now available for cyclists (e.g www.helitemoto.com, www.bikebone.com). For example, the "Hit Air" jacket (Bike bone) uses CE certified armor to give protection to the spine, shoulders, and elbows. During an accident in which the rider is thrown off the motorcycle, the air cushion inflates within 0.25 seconds or less to protect the rider's body. More research and testing of various safety systems for motorcyclists, at all the speed range for the motorcycles/moped is recommended (it will be nice to see innovative designs for research systems in which a robotic system with stress measuring sensors can be used in place of motorcycle riders to evaluate the stress impacts on the riders for all the speed of the motorcycles). The goal of the suggested testing of the safety systems is to ensure that the safety systems are able to accommodate the worst situation a motorcyclist may face, to prevent fatality, and greatly reduce the risk of injury. The manufacturer for the best design in safety for motorcyclists may be adequately compensated. Subsequently, the design from the manufacturer with the best safety performance for motorcyclists may be made as the minimum standard for all manufacturers of such products. Such improved safety wears may be mandated for all motorcyclists in every municipality.

(2) Incorporating some collision avoidance features in the motorcycle system: Since motorcyclists are at risks when they collide with an object, collision avoidance systems for motorcyclists will not be a bad idea. This system may ensure an automatic reduction in speed of the motorcycle/moped when an object is detected within a reasonable distance in the trajectory of the moving motorcycle.

(3) Ensuring adequate training for motorist not only to maintain appropriate following distances to motorcyclist/moped riders but also to maintain appropriate distance before moving over to the front of the motor cyclist, when passing a motorcyclist on the road. Some enforcement, and establishment of fines for motorists who move too close to a motorcyclist/moped rider may help raise more awareness about the need to give some space to these vulnerable road users.

(4) Ensuring good visibility for riders: This may include having regulations in all municipalities to mandate all motorcycles to come with some reasonable retro reflective materials to improve visibility. Riders also should be admonished to wear retro-reflective, or bright colored clothing (most especially in the dark) to improve visibility. Note various high visibility clothing already exists. (e.g. http://www.urban-glow.com/motorcycling.html, https://www.revzilla.com/hi-viz-neon-motorcycle-gear etc.). High visibility clothing alone should not be a substitute for technologies that can help prevent injury or fatality in case of a traffic crash.

Although it may be somewhat expensive, it will not be a bad idea to see a system in which road users that use a mode of transport with similar energy impact share a section of the road space together. This will help ensure that some modes of transport are not at a disadvantage to others during a traffic crash (if everyone abides by the same traffic regulations).

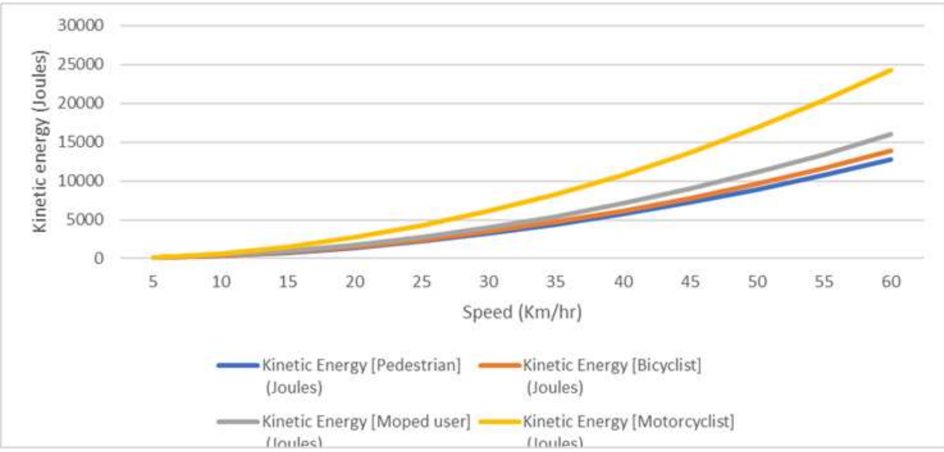

Fig. 7. Comparison of Kinetic energy of vulnerable road users in their mode of transport

Figure 7 shows an illustration of kinetic energy that is expected from a motorcycle (with rider), with a gross weight of 175kg (assuming the rider weighs 92.3Kg and the motorcycle weighs 82.7kg) , a moped (with rider), with a gross weight of 115 Kg (assuming the rider weighs 92.3Kg and the moped weighs 22.7Kg), a bicycle (with rider), with a gross weight of 100Kg (assuming the rider weighs 92.3Kg and the bicycle weighs 7.7Kg), and a pedestrian with a hypothetical mass of 92.3 Kg. It is obvious that motorcycles carry higher kinetic energy in comparison with other vulnerable road users, moped users also carry a higher kinetic energy than bicyclist, and pedestrians.

Establishment of systems in which the speed of vehicles is recorded by a device in the vehicle and included in the accident records for every municipality may help traffic safety researchers be able to make a good association of the correlation of the effect of speed, and weight of the vehicle to the severity of injury of vulnerable road users. This correlation could be made, if all accident records include detail information to facilitate research, and development to prevent future re-occurrence.

5. Sample field evaluation

During this project, site visits was done to evaluate the traffic conditions for a certain a street in a municipality. Figure 8 below shows a sample mode choice data obtained within a 20 minutes interval during the morning peak hours, on 2 separate days, using manual field count.

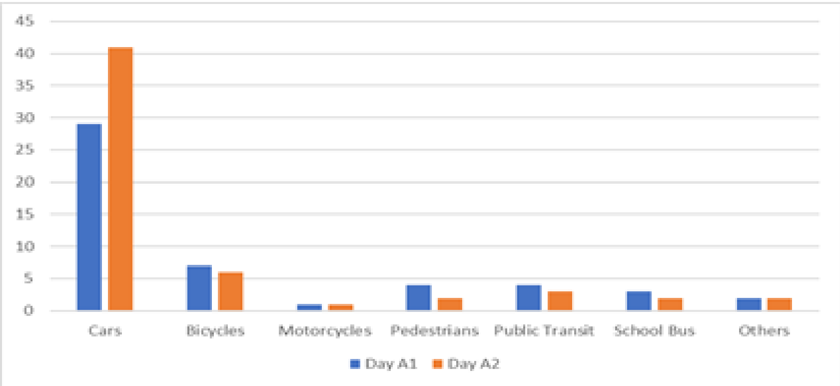

Fig. 8. Sample mode choice evaluation of a street

Result from filed visit, as in figure 8, will give a good knowledge of how the street is being used. During such field visits, documentations of potential safety hazards to vulnerable road users may also be made to help in choosing of adequate street elements that will better guaranty safety. Note that manual field counts such as presented in figure 8, may not be completely free from limitations due to human error in counting. Alternative mode of traffic evaluation, such as real-life video recording of traffic conditions is recommended, when evaluating mode choice, modal priorities, choosing of street elements, and making trade-offs. This will allow for a re-visit of the traffic condition on various route for detail evaluation at future times. It should also allow for a more convenient avenue for data analysis. For example, analysis of traffic data behind the computer in the office, using video recordings of traffic data will both ensure that traffic analysts are not subjected to safety hazards from moving traffic, and ensure availability of a proper record of safety practices of road users, that will enable transportation officials a good opportunity to improve on education, enforcement, or engineering countermeasures for safety improvements. After a good knowledge of the transportation mode choices, focusing on the safety of vulnerable road users, the next step will be to evaluate potential safety issues that these transportation mode choices may be subjected to (while interacting with each other on the roadway), and how these safety issues may be best addressed to ensure safety for all.

6. Establishing safe travel speed

A report by world health organization (WHO) and the world bank that compiles findings from various researchers around the globe noted that pedestrians have less than 50% chance of surviving impacts at 45km/h or above but have more than 90% chance of surviving car crashes at 30km/h or below. Also, as the impact speed of a car increases from 30 km/h to 50 km/h, the probability of death of pedestrian increases by a factor of 8. Kröyer (2015) noted that although fatal accidents (not including run-over accidents) are not common where the mean travel speed is below 40km/h, and severe injuries are also not common below 25 km/h, more than 30% of severe injury accidents happen in areas where the speed is below 35km/h, raising a concern that even 30km/h may not be as safe as previously thought. BC (2013) also noted that the average risk that a struck pedestrian will have an injury on an Abbreviated Injury Scale 4 or greater, is up to 10% when the impact speed is 17.1 miles per hour (mph), 25% at 24.9mph, 50% at 33.0mph, 75% at 40.8mph, and 90% at 48.1mph, while the average risk of death is up to 10% when the impact speed is 24.1mph, and 25%, 50%, 75%, and 90% at impact speeds of 32.5mph, 40.6mph, 48.0mph, and 54.5mph respectively. BC further noted that the risks were said to vary by age.

To prevent road traffic fatalities, there is need for more research on the limit of impact energy that the human body can safely accommodate and ensure that traffic systems are designed not to exceed this limit. However, in the meantime, it is known that the higher the speed of motor vehicles, the higher the chance of fatality, this information should be taken into consideration when deciding the speed limit, in any municipality that is considering a mixture of traffic and unprotected road users through the complete street system. Establishing safe travel speed depends on a range of factors such as, volume of motor vehicles on the street, volume of pedestrians, and other vulnerable road users that use the street, land use type (the characteristics of the area), etc. Factors that influence how drivers perceive the safe operating speed in which vehicles are operated has been identified as; design and physical factors of the road, the vehicle, the driver, weather and visibility, etc. The design and physical factors includes: horizontal and vertical curves, high driveway density, hidden driveways and other developments at the roadside, developed or rural residential areas, lack of striped, improved shoulders. The ability of average driver (in relation to perception-reaction time, in determination of postings distances for signs, critical approaches speed to locations with limited sight distances, and intersection crosswalks) is a factor in speed selection (TxDOT).

Areas close to playgrounds or schools where children may be crossing the road often have reduce speed. The higher the number of vulnerable road users, the slower the speed of traffic should be. Accident reconstruction speed limits are used as a temporary measure during investigation of an accident. Other factors that affects speed of drivers, but their effects are not so easily measured has been identified as lane width, width and type of shoulders, surface condition, roadside developments, and frequency of intersections (TX DOT). It is important that all factors in the driving environment are reasonably considered in the determination of the speed limit, ensuring that potential impact on vulnerable road users in the community is given higher priority. With human drivers, increased presence of law enforcement officers helps to ensure better compliance with speed limit. Considerable presence of speed enforcement cameras (although may not be very popular with drivers) is also a good way to ensure that motorists do not engage in excessive speed within the municipality.

It is obvious that a lot of concern is raised about speed of vehicles, but not about the overall mass of the vehicles on the road. Recall, that the impact energy that will be exerted by a moving object is not only dependent on the speed of that object, but also on the mass of the object. In the effort to improve safety for vulnerable road users, the issue about maximum allowable speed in relation to the mass of the vehicle needs to be given a closer attention. If vehicles that are beyond a certain weight are to be allowed in places where vulnerable road users are present, it is reasonable to allocate a slower speed limit to all vehicles in such categories. Figure 2 shows an illustration of how the energy of impact that may be experienced from a vehicle is dependent on both the speed and the weight of vehicles.

6.1. Multimodal concept for roadways

In the past few years, focus on planning and design of urban streets has shifted from a car-centered approach to a multimodal approach. Arterial planning is now expected to lead an integrated urban environment that encourages multimodal and balanced use of street in a way that ensures safety for everyone (and not only convenience for motorists). Automobiles, transit, bicycle, and pedestrian are the usual modes that are recognized on an arterial (Roess, Prassas, & McShane, 2011). As transportation system evolves, there will be need for consistent policy review to ensure adequate accommodation of every road user, in a way that ensures safety for all. Analysis of the level of service (LOS) as presented by NCHRP report 616 (Dowling et al, 2008) indicated that increase in speed of vehicles on the road result in improvement in LOS for automobiles but increase in speed of vehicles on the road result in decrease in LOS for both pedestrians and bicyclists. Increase in directional volume worsens the LOS for both pedestrians, and bicyclists. Increase in lateral distance between the edge of pavement and the sidewalk results in improvement in the LOS for pedestrians, while decrease in the lateral distance between the edge of pavement, and the sidewalk results in decrease in the level of service for pedestrians. For bicyclists, increasing the width of paving between the edge of pavement, and the stripes for the outside lane shows an improvement in the level of service. Reduction in the quality of the road also shows a decrease in the level of service for bicyclists. To ensure a balanced road user experience in a multi-modal way, there is need to ensure a good balance of the interrelated factors in sharing the road space. More research is recommended on how other factors like engineering controls (guardrails, concrete barrier, etc.) to separate pedestrians, bicyclists, and other vulnerable road users can both increase the level of service for vulnerable road users, and also increase the feeling of safety on the road. Improvement in road design to properly incorporate the goal of multimodal concept for roadways in a way that gives adequate priority to all road users may not only improve the feeling of safety for vulnerable road users, it may also help encourage the choice of active means of transportation.

7. Evaluation of ways to improve traffic safety from some of the factors that interact during traffic crash

Remembering that in the effort to reduce traffic fatalities for vulnerable road users, there is need to have adequate evaluation of all the factors that interact during the traffic crash, the remaining sections of this paper will evaluate potential ways to improve traffic safety from the point of view of some of the factors that interact during traffic crashes.

7.1. Ways to improve traffic safety for automobiles.

Possible ways to ensure that vehicles on the road do not operate in ways that are dangerous for vulnerable road users includes:

(1) Improve on in-vehicle alert systems for driver operated vehicles.
(2) Improve use of innovative out-of-vehicle systems that can warn drivers that are going beyond the speed limit.
(3) Increase enforcement systems to encourage safe driving behavior
(4) Consider using autonomous vehicle systems that can limit the maximum speed with which the vehicle can operate to the speed limit that is appropriate for the driving environment.
(5) Increase vehicle standards globally to incorporate technologies that can identify vulnerable road users on the road, and automatically initiate actions to avoid collisions.
(6) Set a timeline in which all vehicles on the road in all municipalities will have the minimum safety standards (e.g. collision avoidance systems)
(7) Increase monitoring systems to ensure that manufacturers, globally comply with the standards
(8) Develop systems to ensure that all vehicles either upgrade to the minimum safety standards or be off the roads.

Survival of unprotected road users depends on either separation of the unprotected road users from high speed vehicles or ensuring that vehicle speeds at collision point is low enough to prevent severe injury when impacted with crash-protective safer car fronts (WHO & World Bank, 2004). The best way to ensure adequate protection for vulnerable road users is to provide adequate separation from high speed vehicles. The mass and possible travel velocity of various transportation modes, the principle of kinetic energy, the potential severity of impact of various transportation modes, and the expected level of exposure between various transportation modes can be used as a guiding principle in design of engineering controls, separation of street elements for various modes of transportation, and in policy decisions to determine what modes of transport should be allowed to share the street elements.

The remaining part of this paper will be mainly focused on analysis of safety issues that bicyclists, pedestrians, and road users with assisted mobility devices may face. A discussion about how to develop new guidelines for impact energy and research opportunities for improvement in pavement properties to minimize injury or risk of fatality for vulnerable road users is also discussed.

7.2. Bicyclists.

Bicycling is an environmental friendly, and active mode of transportation. There have been various efforts to ensure that bicyclists have a fair share of the road. Promoting active means of transportation is a great idea, but there is need to implement, and properly enforce measures that will promote good safety habits for vulnerable road users. Traffic collisions with bicyclists may come in different forms which includes error caused by the bicyclist, error caused by the motorist (driver), errors that resulted from the circumstances in the environment (road conditions), and vehicle or bicycle errors.

7.2.1. Potential Safety errors that a bicyclist may cause.

(1) Distracted Cycling: This may occur if a cyclist has a divided attention and is not able to properly focus on the cycling.
(2) Not dismounting from bicycle at intersections: Dismounting from bicycle at intersections is a safety procedure that is fairly common, but still not all bicyclist obeys that safety precaution. A bicyclist that carry on with the same speed that was used to approach an intersection, without stopping the bike, and checking to make sure that the road is safe, before proceeding may be more at risk than a bicyclist that stopped at intersections, dismount, and ensure that it is safe to proceed before moving on.
(3) Cycling under the influence of alcohol or drugs: A bicyclist that rides while intoxicated may be at higher risk of being involved in a crash.
(4) Not using helmets: If a crash occurs, a cyclist that is not using a proper head protection may be at higher risk.
(5) Not wearing high visibility clothing: High visibility clothing and bicycle lights / reflectors should enable other motorist to easily notice a vulnerable road user in dark hours of the day. Cycling in dark hours without high visibility clothing, or other systems to detect the bike in the dark may subject the cyclist to higher danger. Although it may be said that using high visibility clothing, or reflective material for vulnerable road users is a fairly common safety knowledge, more public education on ways to improve visibility for vulnerable road users in dark hour of the day will not be a bad idea.
(6) Reckless cycling: A cyclist that cycle recklessly may be in more danger.
(7) Novice cyclist: New, and inexperienced cyclists may be at higher risk on the road. Any municipality that wants to encourage safe cycling should consider having facilities where people may learn how to cycle. Learning to cycle on the roads with high speed car may be risky.
(8) Unintentional swerving: This may happen more frequently with new or inexperienced cyclist that cycle on the road. Unintentional swerving could be a challenge to motorist, as inexperienced bicyclist does not necessarily go on the road with sign to show that they are inexperienced in cycling.

7.2.2. Ways to improve traffic safety for bicyclists.

Safety review of streets: Periodic safety review of roadways with documentation of items to be improved, and concrete actions to implement the recommended improvements will be a great idea for every municipality. These reviews may include study of visibility of vulnerable road users on the streets in the dark hours, presence of various obstruction that may limit the sight distance of driver to notice the presence of vulnerable road users, road conditions, and the need for engineering controls in various places. Proper lighting is encouraged for any part of the roadway that is accessible for vulnerable road users. To ensure safety of bicyclists, there is need to ensure a greater level of enforcement not only on motorists, but also on bicyclists to make sure that every road user use the roads safely. Efforts to ensure better protection for cyclists from high speed cars should also be consistently improved. Some of the ways that this can be achieved is by provision of barricades to shield the bicyclists away from high speed cars. Meanwhile the national association of city transportation officials (NACTO) identifies bike lanes as a section of the road that has been set aside by pavement markings, striping, and signage for exclusive or preferential use of bicyclists. Buffered bike lanes allow for some space between the bicycle lanes, and the travel lanes for motor vehicles. The presence of physical barriers like raised curbs, bollards, medians, etc., differentiates cycle tracks from bike lanes. The physical barriers in cycle tracks restricts traffic from encroaching into the bicycle paths. In terms of safety for bicyclists, it cannot be disputed that a physical barrier that separates the moving traffic from the bicyclists is better than the use of pavement markers to mark out bicycle paths on roadways. While it may seem expensive to construct cycle paths with physical barrier to separate bicyclists from high speed vehicles, with the present transportation systems in which many vehicles on the road do not have collision avoidance systems, physical separation of bicyclists (cycle tracks) is better on the long run than pavement markers. The use of cycle tracks (physical barriers to separate moving traffic) does not only ensure a reasonable protection for bicyclist, it also provides an added protection for pedestrians. Recall, 27% of global traffic fatalities is among vulnerable road users, and there is need to explore reliable options to eliminate this fatality statistics for vulnerable road users.

Fig. 9. Some separation for bicyclists

It is hoped that having physical barriers that separate vulnerable road users from high speed traffic, as illustrated above should help encourage appropriate driver behavior, and reduce collisions with vulnerable road users. Although the barriers in figure 9 are reasonable, physical barriers that are a little higher than the ones shown in figure 9 may give a vulnerable road user more feeling of safety. High strength chains in connecting the poles may not be a bad idea too. As interest grows in encouragement of active modes of transportations, more research may be needed to evaluate what levels of protection from high speed traffic will encourage more use of active transportation modes.

7.3. Pedestrians.

Walking is another active form of transportation. Traffic crashes involving pedestrians has also been alarming. As a result, there is need to pay attention to improve on issues that may result in pedestrian's getting involved in traffic crashes. To reduce traffic crashes involving pedestrians, the following things may be implemented:

(1) Provision of overhead bridges on busy roads having high pedestrian volumes.
(2) Provision of pedestrian crossing traffic signals.
(3) Provision of crosswalks and high visibility pedestrian crossing signs at all intersections.

(4) Ensuring adequate awareness at various levels of education to ensure that people are reminded of the need to use high visibility cloths in dark hours.
(5) Ensuring proper lighting of streets to enhance visibility in dark hours.
(6) Making policies that ensure that cloth manufacturers incorporate some reasonable reflective material components for winter jackets that are likely to be used during periods of longer nights. It is hoped that this will help motorists, to easily see a vulnerable road user on time, to avoid potential collision.
(7) Ensuring consistent enforcement of laws that discourage jaywalking around various municipalities.
(8) Making and enforcing laws that prohibit people from walking on the streets while drunk. A drunk pedestrian may be at higher risk than a normal pedestrian.
(9) Ensuring appropriate speed limits, and adequate enforcement of speed limits within various communities.
(10) Ensuring equity in traffic signal timing for both motorists and pedestrians: Pedestrians should not be made to wait for too long after the pedestrian crossing system has been activated at a signalized intersection.
(11) Ensuring appropriate buffers, and or engineering controls (barricades, like guardrails) between walkways and the roads.

Some of the items above may be identified in a road safety audit. A municipality that maintains a culture of periodic road safety audit (not only when a traffic crash occurs) may easily identify any significant change in roadway condition or usage of a facility that warrants a special road safety improvement action. Figure 10 below shows an example of a place where guardrail is provided that may further shield vulnerable road users. The second image is a case where a considerable distance between the walkway and the road is an additional advantage.

Fig. 10. Engineering controls (guardrail) as shield, and considerable buffer for vulnerable road users

Some of the potential countermeasures mentioned above to prevent traffic collisions with pedestrians may be regarded as common knowledge, but continuous public education, and enforcement of good safety practices for pedestrians may also be of help in reducing traffic crashes with pedestrians. Pedestrians should be taught to take more responsibility for their safety. Although, it is a common knowledge for multi-modal road use, where there is no traffic signal that pedestrians have the right of way, there is need for pedestrians to also be watchful. A driver that hits a pedestrian may not see the pedestrian on time to avoid the collision. If a pedestrian goes about with a mentality of having the right of way, and expects that all motorists will stop, in a situation where a motorist did not see the pedestrian on time to avoid collision, such a pedestrian may be added to the statistics for the road traffic crashes, injuries, or fatalities. Noting that the world is gradually moving into the era of driverless vehicles, and giving that in addition to the reaction distance, the total stopping distance also includes the breaking distance, pedestrians need to still be cautious with autonomous vehicles. If a pedestrian gets in the way of an autonomous vehicle in a distance that is less than the safe stopping distance for the vehicle, such a pedestrian may get hit by the autonomous vehicle. Figure 11 shows an example of how road users in a community are being admonished to share the responsibility.

Fig. 11. Sharing the responsibility for safety on the road

7.4. Road users with assisted mobilities

Ensuring safety of road users with assisted mobility, is equally as important as ensuring safety of other road users. For streets to be regarded as a complete street in every municipality, there is need to ensure that the design allows for good accessibility for users with assisted mobility devices like wheel chairs. This may include provision of adequate ramps to walkways, ensuring adequate space on walkways to safely accommodate road users with assisted mobility devices, and other vulnerable road users, provision of good walkway pavement design and maintenance to ensure reasonable slope, and adequate friction level. Ensuring appropriate barricades or engineering controls to protect vulnerable road users on assisted mobility devices from high speed traffic, depending on the speed, road geometry, and other environmental conditions.

Engineering controls, and not administrative controls is surely the better means of ensuring user conformity with safety standards. For example, with proper gates in place, it is common that pedestrians, as well as motorists may wait for a train to pass before proceeding. However, without the engineering control (the gate), it is not impossible that some road users even after seeing the sign that a train is approaching may try to cross the track with the hope of making it to the other end before the train approaches. Applying the same logic, administrative controls like pavement markings may not always be as effective in ensuring proper driver behavior to vulnerable road users, as much as engineering controls will do.

8. How can new guideline for impact energy be developed?

Impact energy (the amount of energy with which an object collide with another object) is crucial in the severity of damage to the objects and the chance of survival (if an animal or human is involved in the collision). It is no doubt that the goal to achieve a design of transportation system that will see zero fatalities on the road need to include a design that will adequately take account of the maximum impact energy that humans can sustain without severe injury or fatality. This will also include a good attention on both the hardness of the impacting surface, and the hardness of the surface to which the fall occurs. This area is one that still need a great deal of research. As regards driving in accordance with the speed limits, UK's highway code, road safety and vehicle rules indicate that driving must not be faster than the speed limit for the type of road and type of vehicle. It was noted that most vans have a lower speed limit than cars, and most vans must follow the speed limits for goods vehicle of the same weight. UK's highway code, road safety and vehicle rules also indicated that Speed limiters (designed to limit the speed of vehicles by restricting fuel supply to the engine) must be fitted on goods vehicle that has a maximum laden weight of more than 3.5 tonnes, and on vehicles that has more than 8 passenger seats, e.g. stretch limousines, minibuses, etc.

On a more general sense, as described in figure 2, seeing that the impact energy of an object increases with the weight of the object, it is good to have a bench mark for establishing maximum impact energy that motor vehicle may have at any section of the road. In Swedish's vision zero strategy, the amount of biomechanical energy that people can be exposed to without sustaining serious injury is now being promoted as the basic parameter for road and vehicle design (European commission road safety, mobility and transport). Previous study has also mentioned that the forces that can be tolerated by the human body varies with different things. In a study about human tolerance and crash survivability Shanahan (2004) noted that in developing crash worthiness or protective system design standards for any vehicle, it is important to have an understanding of human tolerance to abrupt acceleration. Regarding tolerance to acceleration, in addition to some extrinsic factors, Shanahan identified age, health, sex, physical condition, etc., as important intrinsic factors that need to be considered in examining human tolerance to abrupt acceleration.

Table 1. Illustration of kinetic energy of objects with varied mass and speed.

Velocity (Km/h)	Kinetic energy (Joules) of an object with mass 1400kg	Kinetic energy (Joules) of an object with mass 2000kg	Kinetic energy (Joules) of an object with mass 2600kg	Kinetic energy (Joules) of an object with mass 3200kg	Kinetic energy (Joules) of an object with mass 3800kg	Kinetic energy (Joules) of an object with mass 4400kg
0	0	0	0	0	0	0
10	5401	7716	10031	12346	14660	16975
20	21605	30864	40123	49383	58642	67901
25	33758	48225	62693	77160	91628	106096
30	48611	69444	90278	111111	131944	152778
40	86420	123457	160494	197531	234568	271605
50	135031	192901	250772	308642	366512	424383
60	194444	277778	361111	444444	527778	611111
70	264660	378086	491512	604938	718364	831790

To achieve a design that will better ensure the safety of vulnerable road users, it is important to know the maximum impact energy that human body can tolerate without severe injury or fatality. Roadway parameters need to be designed to ensure that the impact force that a vulnerable road user may be subjected to on the roadways does not reach a level that can result in death of any road user. If the design indicates that safety of vulnerable road users can be best guaranteed by having a maximum weight limit of vehicles not to exceed a certain limit, at a certain speed, a good safety culture will ensure that any other vehicle that must exceed the weight limit is equipped with systems that will automatically limit the speed of those vehicles to the maximum speed limit that is applicable to that specific vehicle, at that section of the road. For example, assuming that it has been established that within a built up area, the maximum impact energy from a motor vehicle must not exceed 30,000 joules (considering the hardness of the pavement and the hardness of the bumper of the vehicle), a what if analysis (goal seek), or even a simple mathematical calculation may be used in determining the maximum velocity that a vehicle that has a weight beyond the given limit can be allowed to have. Using the above illustration, with a what if analysis, table 2 shows the maximum velocity that moving objects at different mass may have, to achieve the maximum kinetic energy of 30,000 joules (note that this is just an illustration). There is need for more research on the maximum amount of impact energy that human body can tolerate without injury or fatality. It will be desirable to have vehicles traveling at an impact energy level that is lower than the maximum impact energy that humans can bear without chance of severe injury or death.

Table 2. Illustration of speed of moving objects at various mass to achieve equal kinetic energy.

Mass of object (Kg)	Speed (Km/h) to achieve Kinetic energy of 30,000 Joules
1400	23.6
3400	15.1
5400	12.0
7400	10.3
9400	9.1
11400	8.3

It is recommended that more research be done on the above concept, to evaluate possible effects of size of the moving object in relation to potential point of impact on the chance of survival.

To see a drastic reduction in the number of severe injuries and fatalities in the transportation sector, we must be ready to challenge the status quo and open to new approach to designing the transportation systems. With the present rate of traffic collisions, if adequate systems to ensure proper collision avoidance is not in place, and the transportation systems are not designed to be able to safely accommodate the maximum force that human systems can tolerate without injury or fatality, vision zero for traffic fatalities and injuries may not be achieved anywhere. However, with an improved transportation system design, it is possible to achieve a vision zero for traffic collisions, the associated property damages, injuries and traffic fatalities.

The following procedure may be followed to develop a new guideline for impact energy:

1. Identify the maximum weight that must not be exceeded to guarantee safety of vulnerable road users, and give adequate consideration to the established weight of vehicle when designing the speed limit.
2. Ensure that adequate regulations exist to prevent manufacturing of vehicles that will exceed the identified maximum allowable weight for specific class of vehicle.
3. For vehicles other than passenger vehicles that need to have additional weight for specific functions, ensure that the vehicles are equipped with adequate systems to limit the speed of the vehicles, especially when the vehicles are in locations that they are likely to be in contact with vulnerable road users.
4. In an automatic speed control environment, design the vehicle to limit the maximum speed to such as can guarantee safety. In addition to consideration for the weight of vehicles, it will be a good idea to have automatic system in all motor vehicles that can limit the speed of the vehicle in relation to the location of the vehicle. This may mean that the maximum allowable speed for a motor vehicle in built up areas, such as area close to schools, residential or business areas may be automatically limited to a predetermined level, while a different restriction may be given to the maximum allowable speed on highways (an exception may be given to vehicles for law enforcement).

When planning for autonomous systems either to supplement the driver effort or in a full autonomous driving, it is good to recognize the limitations of the system and also ensure that drivers are aware of the limitations of the autonomous system. For example, a computer system that has not been programmed to recognize and solve a certain type of problem may not be able to work on that kind of problem. As it will not be wise to assume that a computer can solve any type of algorithm for which it is not programmed, in the same way, it will not be wise to assume that an autonomous vehicle will work efficiently under any road condition for which it is not designed to work. Continuous testing of full autonomous systems (in all-weather condition) is recommended to ascertain their safe use before they are deployed for large scale use in any community. Note that this does not mean that full autonomous systems should not be used. Full autonomous system may be used under conditions in which they have been tested and their safety has been satisfied by professionals of high integrity. In the meantime, autonomous systems that has been tested and found to have the capability to assist the driver avoid traffic collision should be encouraged on a wide scale. When autonomous systems are being used to support the driver effort, a driver in a vehicle that is supported by such autonomous systems still has the responsibility for safe operation of the vehicle. The autonomous systems may provide additional safety support for collision avoidance. For example, a driver that is operating a vehicle that is equipped with automatic speed reduction and auto brake system is still responsible to manually apply the brake if any situation occurs in which the autonomous system fails to apply the brake when needed. If the driver sees a need to go at a slower pace, due to prevailing road condition, the driver should still be able to make this judgement. However, a good system design to reduce the chance of collision will not give the driver the capability to collide with any object on the road when the vehicle has detected the presence of the object.

9. Research opportunities for improvement in pavement properties to minimize injury or risk of fatality for vulnerable road users (The road)

Energy absorbers are important in injury reduction. In a goal to achieve a zero fatality for vulnerable road users in their daily commute, while effort is being made to improve other systems that interact during a crash, to minimize impact on vulnerable road users, more research is recommended on the use of soft pavement surfaces in areas where vulnerable road users may be in contact with vehicles. It is no doubt that a fall on a concrete or asphalt pavement can result in more injury than a fall on some soft surfaces. Even in playgrounds, it has been noted that more than 70% of all playground injuries comes from fall to the ground (SofSurfaces Inc., Ontario). For example, rubber surfacing materials have been used for various internal and external applications, including running and walking tracks in public places, playgrounds, aged care, recreational and fitness centers (Flexitec Synthetic Surfaces, Australia). According to SofSurfaces, Ontario, it is hard to overestimate the importance of safe surface. Looking inside a helmet, it will be noted that it is made of special materials to minimize injury to the head during a fall. While the use of helmet is encouraged for some road users like cyclists, pedestrians are not required to go about with helmets. But this does not mean that pedestrians, or other vulnerable road users cannot be knocked down to the pavement by vehicles. Even if the exterior (and not only the interior) of vehicles are equipped with energy absorbers to reduce the impact of collisions, (given that a vulnerable road user that is involved in a crash with a motor vehicle may be knocked down on the pavement) there will still be a need to ensure that pavement surfaces are overlaid with durable energy absorbers that can help to reduce potential injury, or fatality to vulnerable road users, in any situation where a vulnerable road user is involved in a traffic collision. As a result, it is recommended that more research, and field testing be done to further investigate the possibility of having overlay of soft surfaces on areas of the road where vulnerable road users may be in close encounter with motor vehicles. More research to ensure that such soft surfaces could adequately carry the expected load of vehicles and stand the test of time is recommended.

In addition to encouraging research into implementation of soft surfacing for the roads, more research is also recommended to ensure that parts of the vehicles on the road, that may collide with a vulnerable road user have adequate cushioning effect to minimize injury. Note that depending on the type of material that a hand gloves is made with, hitting an object with a bare hand will not feel the same as hitting an object while wearing good hand gloves. In the goal to achieve zero fatalities for vulnerable road users, more research is recommended on the impact of the hardness of the pavement, as well as the impact of the hardness of the bumper of vehicles on injury and survival rates for vulnerable road users during road traffic collisions. It will be nice to see innovative systems that can utilize robotics technologies that are enabled with stress measuring sensors to simulate potential stress impact on humans, given various hardness of both the pavement surfaces, as well as the bumper of vehicles. Results from a research like this may be used to establish a new standard for the maximum limit of the surface hardness for the surfaces that a vulnerable road user may be in contact with during traffic collisions.

10. Conclusions and recommendations

Complete street, a system that seeks to allow safe access for road users of all modes and abilities, is a great idea in the transportation sector. However, a range of factors that present hazards to vulnerable road users still exist. This report discussed major factors that can result in safety issues for vulnerable road users. Various areas in which improvements can be made to better ensure the safety of vulnerable road users were also presented. Considering the high number of traffic related injuries and fatalities, to vulnerable road users globally, there is a need for periodic, and consistent road safety audit that will identify diverse ways by which the safety of vulnerable road users may be improved in various municipalities. This report recommends inclusion of periodic project review as a 7th step to the complete street process, to identify, and document lessons learnt, and incorporate the findings into future projects. Consistent education, and enforcement of good road safety practices in every community is recommended to improve the culture of motorists to other vulnerable road users. This may require inclusion of road safety curriculum as a compulsory subject at various levels of education, installation of variable message signs to bring real time safety information to road users, and recruitment of more traffic safety enforcement workers to enforce traffic safety. There is also a need for more public awareness about the need for vulnerable road users to share the responsibility for their safety. A vulnerable road user should not always assume that a vehicle will automatically stop.

Considering the facts that traffic crashes with vulnerable road users may be an unintentional act by a motorist, and having bicycle signs, or pavement markings alone is not sufficient to hold back traffic crashes with cyclists, and other vulnerable road users, there is need to improve on various means to implement appropriate engineering controls that will serve as a shield for vulnerable road users. Provision of some form of barrier to bicycle lanes, to discourage bad driver behavior and serve as an added protection for bicyclists, and other vulnerable road users (in more places) may be a clever way forward. The plight of motorcyclists, and moped riders has been a challenging one. More research is recommended on the reliability of air-vest technology, and other safety related systems for motorcyclists, and the possibility of making the use of air -vest a requirement to better ensure safety of motorcyclists.

More studies on overlaying road surfaces (wherever a vulnerable road user may be in contact with other transport modes with high kinetic energy) with energy absorbing (softer pavement) materials is recommended. Issue analysis presented in this study, as relating to the kinetic energy of ‘a car, and bicyclist’, and the potential impact energy may also be useful for policy makers in making decisions regarding the risks, and preferences that may be given to various road users in sharing various road elements. Global sharing of information on efficient road safety practices (On a consistent basis), setting up of international targets for every nation, on making, and enforcing efficient road safety practices in every community of the world is recommended to ensure that all nations of the world are up to date on how the streets can be made safer for people. Hopefully, this will help in reducing traffic crashes globally.

To see a great turn around in the fatalities for vulnerable road users, the world needs to be open to innovative approach to research, and design of transportation systems. We must be ready to challenge the status quo with an open mind, without bias, using adequate research techniques. It will be good to see a great collaboration between all stakeholders (researchers, policy makers, automakers, and end-users) in not only allocating adequate fund for research in transportation safety, but also be willing to welcome innovative approach to improve transportation systems with an open mind. It will also be good to see a concerted effort in advocating for transportation policies that will greatly bring the trend in traffic fatalities around the globe to a decline, legislating these policies, and ensuring adequate enforcements of the policies until the world reach a stage where nobody in any part of the world will lose their life because of mishaps in the transportation systems. A range of research recommendations that is hoped to bring the world closer to a state of achieving zero fatalities for vulnerable road users has been presented in this report.

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