An Investigation of Municipal Truck Size and Safety Guards on Vulnerable Road Users

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Executive Summary

Vision Zero programs have been implemented all over the world with the goal of reducing fatalities and injuries in the transportation system. Vision Zero is designed to be a holistic, systems approach where designers, engineers, operators, and users of the transportation system work to improve safety, particularly for Vulnerable Road Users (VRUs). Although Vision Zero aims to eliminate all road collisions, there is an acknowledgement that these collisions can still occur. Thus, Vision Zero programs look to support the design of the transportation system to reduce severity, change frequency, and mitigate injuries when collisions occur.

Commercial and municipal trucks have a large role to play in the safety of VRUs. These vehicles are disproportionately involved in collisions resulting in fatalities and serious injuries in comparison to other types of vehicles. Between 2007 and 2017 in Toronto, there were a total of 1,950 vehicle collisions with pedestrians and 576 collisions with cyclists. Ninety three (93) of the pedestrian collisions were with trucks, while 32 of the cyclist collisions were with trucks. Results of the analysis of the collisions presented in this report show that both pedestrians and cyclists are more likely to be killed in collisions with trucks than in collisions with non-truck vehicles. Thus, VRUs were more likely to receive fatal injuries in collisions with trucks, or alternatively, VRUs are less likely to receive fatal injuries with smaller vehicles when collisions occur.

Truck size is one factor that can reduce the impacts of collisions with VRUs. Smaller vehicles are less likely to lead to fatalities and serious injuries than trucks. The visibility in smaller vehicles is generally better than with larger trucks. Specific design features, such as seat location, the design of windows and mirrors, and the use of cameras and sensors can all help to improve driver visibility and reduce driver “blind spots”.

Safety guards are another feature that has been implemented to help VRUs. Rear underride guards are mandatory in Canada since these are intended to prevent vehicles from driving under the truck in a collision and these specific guards are not designed to help VRUs. Likewise, front bumpers are designed to protect the vehicle and not VRUs. Side impact guards have become more popular in recent years, as many cities adopt them to support greater safety for VRUs. Studies have shown that these side impact guards can be effective in reducing cyclist fatalities and serious injuries in side swipe collisions where the cyclist and truck are headed in the same direction. They have also been shown to reduce pedestrian fatalities in the same types of collisions.

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Introduction

Vision Zero is a traffic safety program that began in Sweden in 1997 with the goal of ensuring that fatalities and serious injuries of vulnerable road users (i.e., pedestrians, bicyclists, and motorcyclists) are minimized and mitigated (Belin, Tillgren et al., 2012). The program is designed to look at pedestrian and cyclist safety using a systems approach (Penden, Scurfield et al., 2004; May, Tranter et al., 2010). Rather than simply accepting the traditional paradigm that safety is an individual responsibility, the Vision Zero program advocates that responsibility for traffic safety is a mutual responsibility of transportation system designers and users (Belin, Tillgren et al., 2012). Since its introduction in 1997, the Vision Zero program goals and techniques have been adopted in cities all over the world.

Vision Zero does not assume that all collisions can be eliminated, but rather that the system can be designed in a way so as to mitigate against mistakes that would otherwise lead to serious injury or death (Fink, 2016). Vision Zero assumes that the transportation system will be designed so that if a collision does occurs, the limits and tolerances of human physiology will not be exceeded (Tingvall and Haworth, 2000). That is, any collisions should not result in serious injuries or death.

Vision Zero requires that transportation system designers and engineers address the root causes of problems or poor road safety (Fink, 2016). Canada was an early adopter of a national road safety strategy with its first strategy proposed in 1996 (Canadian Association of Chiefs of Police, 2018). Between 1996 and 2011, there was a 30% reduction in fatalities and serious injuries, with an additional 21% decrease by 2013, despite the increase in vehicular traffic (Canadian Association of Chiefs of Police, 2018). Thus, Canadian roads are getting safer even as the number of vehicle kilometres travelled increases. Nonetheless, there are aspects of the transportation system that need improvement.

This report focuses on the physical characteristics of municipal trucks, specifically the visibility and size of the trucks, as well as safety guards (also known as under-ride protection and physical guards) that can be installed on the front, sides, and rear of commercial and municipal trucks. The scope is limited to fire trucks, emergency services vehicles (particularly ambulances), solid waste vehicles, and snow plows.

Trucks and Vulnerable Road Users' Safety

Pedestrians and cyclists are collectively known as Vulnerable Road Users (VRUs) because of the higher likelihood of injuries and fatalities. VRUs have significantly less protection than persons traveling in vehicles. From a truck operator's perspective, VRUs can be difficult to see. As the illustrations in Figure 1 show, pedestrians and cyclists can easily be invisible to drivers of commercial vehicles.

Figure 1: Examples of Truck Visibility Difficulties

[1]

[2]

Although municipal and commercial trucks (hereafter simply referred to as "trucks") are only a small portion of vehicles on the road,[3] collisions involving these commercial trucks are far more likely to result in a serious injury or a fatality for pedestrians and cyclists (Eluru, Bhat et al., 2008). In a study from North Carolina from 1997 to 2002, police reports showed that there was a 15.1% likelihood of a fatal injury if a commercial truck was involved, even though these trucks were involved in only 1.8% of all collisions (Kim, Kim et al., 2007). In the United States overall, trucks are 11% more likely to be involved in fatal collisions than other vehicles, even though they only comprise 8% of the vehicle fleet (Dong, Richards et al., 2015). In a study of London,

[1] From https://lcc.org.uk/articles/transport-for-london-lorry-safety-poster-misinforms-cyclists-and-drivers

[2]From http://www.concreteproducts.com/news/news-scope/9760-pedestrian-cyclist-safety-focus-of-awareness-campaign-innocon-side-guards.html#.XBnEm2sUmpo

[3] The data does not distinguish types of truck.

UK, Transport for London found that trucks were 10 times as likely as cars to be involved in a fatal collision (Transport for London, 2016).

In Toronto between 2007 and 2017, there were a total of 1,950 vehicle collisions with pedestrians that resulted in the fatality of the pedestrian or a serious injury. Of these collisions, 904 (17.0% of the total collisions) resulted in fatalities and 1,619 (83.0% of the total collisions) resulted in serious injuries (see Table 1).

Table 1: Pedestrian Fatalities and Injuries in Toronto, 2007-2017[4]

Year	Total Collisions	Fatality resulting from collision	Serious Injury resulting from collision	Collision with Truck	Fatality resulting from collision with truck	Serious Injury resulting from collision with truck	Truck Collisions as percentage of all Collisions	Fatalities in collisions with trucks as percentage of all Fatalities	Serious Injuries caused in collisions with trucks as percentage of all serious injuries
2007	184	22	162	9	3	6	4.9	13.6	3.7
2008	184	27	157	9	2	7	4.9	7.4	4.5
2009	197	31	166	10	7	3	5.1	22.6	1.8
2010	187	20	167	7	3	4	3.7	15.0	2.4
2011	185	18	167	4	1	3	2.2	5.6	1.8
2012	197	24	173	11	2	9	5.6	8.3	5.2
2013	202	40	162	12	7	5	5.9	17.5	3.1
2014	143	31	112	10	4	6	7.0	12.9	5.4
2015	151	39	112	8	3	5	5.3	7.7	4.5
2016	171	43	128	8	2	6	4.7	4.7	4.7
2017	149	36	113	5	1	4	3.4	2.8	3.5
Avg	177.3	30.1	147.2	8.5	3.2	5.3	4.8	10.7	3.7
Total	1950	331	1619	93	35	58			
Percent of Total	100.0%	17.0	83.0	4.8	1.8	3.0			

The vehicles in the collisions were identified as trucks in 93 of pedestrian collisions, or 4.8% of the collisions.[5] Of the 331 pedestrian fatalities, 35 of them (10.6%) resulted from collisions with trucks and 296 (89.4%) resulted from collisions with non-trucks. Pedestrian fatalities involving trucks are disproportionate to the number of collisions with trucks. While trucks are involved in only 4.8% of all collisions, these collisions resulted in 10.6% of all pedestrian fatalities. In

[4] Data from Toronto Police Service (2018)
[5] The data does not distinguish the type of truck involved, whether it is a heavy duty truck, medium duty, or light duty truck, nor whether the truck is commercial or municipal.

pedestrian collisions with trucks, 37.6% of the collisions resulted in the death of the pedestrian (35 fatalities in 93 truck collisions), whereas only 15.9% of the pedestrian collisions involving non-trucks were fatal (296 fatalities in 1857 non-truck collisions).

Of the 1,619 collisions with pedestrians that resulted in serious injuries, 58 (3.6%) involved trucks and 1,561 (96.4%) involved vehicles that were not trucks. For pedestrian collisions with trucks, serious injuries occurred 62.4% of the time (58 serious injuries from 93 pedestrian collisions with trucks). This is compared to a rate of 84.1% of the pedestrian collisions with non-trucks (1,561 serious injuries from 1,857 non-truck pedestrian collisions). Thus, a pedestrian involved in a collision with a truck is more likely to be killed, and correspondingly less likely to receive a serious injury, than pedestrians involved in collisions with vehicles other than trucks.

Table 2: Cyclist Fatalities and Injuries in Toronto, 2007-2017[6]

Year	Total Collisions	Fatality resulting from collision	Serious Injury resulting from collision	Collision with Truck	Fatality resulting from collision with truck	Serious Injury resulting from collision with truck	Truck Collisions as percentage of all Collisions	Fatalities in collisions with trucks as percentage of all Fatalities	Serious Injuries caused in collisions with trucks as percentage of all serious injuries
2007	47	3	44	2	2	0	4.3%	66.7%	0.0%
2008	41	2	39	1	0	1	2.4	0.0	2.6
2009	48	1	47	1	0	1	2.1	0.0	2.1
2010	47	2	45	0	0	0	0.0	0.0	0.0
2011	55	2	53	5	1	4	9.1	50.0	7.5
2012	75	3	72	4	0	4	5.3	0.0	5.6
2013	72	4	68	3	1	2	4.2	25.0	2.9
2014	47	3	44	1	0	1	2.1	0.0	2.3
2015	53	4	49	5	0	5	9.4	0.0	10.2
2016	42	1	41	6	0	6	14.3	0.0	14.6
2017	49	4	45	4	0	4	8.2	0.0	8.9
Average	52.4	2.6	49.7	2.9	0.4	2.5	5.6%	12.9%	5.2%
Total	576	29	547	32	4	28			
Percent of Total	100.0%	5.0%	95.0%	5.6%	0.7%	4.9%			

Cyclists were involved in a total of 576 collisions between 2007 and 2017 in Toronto (see Table 2), resulting in 29 fatalities and 547 serious injuries. Trucks were identified as being involved in

[6] Data from Toronto Police Service (2018)

32 of the cyclist collisions (5.6% of the total collisions), resulting in 4 fatalities and 28 serious injuries.

In collisions with cyclists involving trucks, 12.5% of them resulted in fatalities (4 fatalities from 32 cyclist collisions with trucks), as compared to 4.6% of fatalities in collisions with non-truck vehicles (25 fatalities out of 544 non-truck collisions). Thus, even though cyclist collisions with trucks are only 5.6% of total collisions, cyclists involved in collisions with trucks are considerably more likely to receive fatal injuries (12.5%) than if they are involved in collisions with non-truck vehicles (4.6%).

Of the 576 collisions with cyclists that resulted in a fatality or serious injury, 547 resulted in serious injuries (95.0%). Trucks were identified as being involved in 28 of the cyclists collisions that resulted in serious injuries, whereas non-truck vehicles were involved in the other 519 collisions. Cyclist collisions with trucks resulted in serious injuries 87.5% of the time that a collision occurred (28 occurrences in 32 collisions), whereas serious injuries resulted in 95.4% of the collisions with non-truck vehicles (519 serious injuries in 544 non-truck vehicles collisions with cyclists). Thus, a cyclist involved in a collision with a truck is less likely to receive a serious injury (and more likely to be killed) than in collisions with non-trucks.

Though the police investigate every fatality and collision with serious injury, it can sometimes be difficult to determine the cause. According to a study in the City of Hamilton, collisions with pedestrians most frequently occur at intersections where a pedestrian has the right-of-way (City of Hamilton, 2017). A study in Vancouver, British Columbia, found that approximately 75% of collisions occurred at intersections (Sayed, 2012). The Canadian Association of Chiefs of Police found that 30% of fatalities and 40% of serious injuries occur at intersections (Canadian Association of Chiefs of Police, 2018).

Data from Toronto (Toronto Police Service, 2018) also shows that the majority of collisions occur at intersections. Analyzing the collision data, it is possible to isolate those collisions involving trucks and emergency medical services (EMS) vehicles and to examine the details of the collisions. The results of this analysis are shown in Table 3 for pedestrians and Table 4 for cyclists.

For the 35 collisions with trucks that resulted in a pedestrian fatality, 9 (25.7%) occurred at an intersection where the truck was turning left, 7 (20.0%) when the truck was turning right, and 4 (11.4%) where the truck was moving straight ahead. An additional 8 (22.9%) occurred mid-block. The results for serious injuries of pedestrians in collisions with trucks shows similar results.

Table 3: Pedestrian Collision with Trucks with Identifiable Cause[7,8]

Fatalities	Left	Right	Straight	Mid-block
35	9	7	4	8
	25.7%	20.0%	11.4%	22.9%
Serious Injuries				
58	13	8	6	12
	22.4%	13.8%	10.3%	20.7%

Cyclist experience a different dynamic in open traffic. Left turns by trucks are less frequently identified as the reason for a collision. Right hand turns and straight trajectories are more common in collisions. Serious injuries and fatalities often occur when a vehicle overtakes the cyclist and the cyclist is side swiped by the truck. This happened in two of the four cyclist fatalities resulting from a collision with a truck with identifiable cause (50%) and 13 of the 26 serious injuries (50.0%).

Table 4: Cyclist Collision with Trucks with Identifiable Cause[9]

Fatalities	Left	Right	Straight	Mid-block
4	0	0	2	0
	0.0%	0.0%	50.0%	0.0%
Serious Injuries				
26	2	11	13	0
	7.7%	42.3%	50.0%	0.0%

Though the numbers are relatively small in the aggregate, the effects of a collision can be devastating and lead to public calls for greater safety for VRUs . Trucks are undeniably more dangerous to VRUs in a collision when compared to other vehicle types. In addition to the actual collision, there is a significant amount of public and media focus on collisions with VRUs that result in fatalities and deaths (see for example, Goffin, 2018; O'Neil, 2018; Rieti, 2018; Smith and Levin, 2018; Spurr and Bensadoun, 2018). Investigating the root causes of these collisions and looking at what can be done to prevent and mitigate them is an important component of Vision Zero programs.

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[7] There are additional miscellaneous other causes in the data as well, which are not broken down for the table. This explains why the data does not sum to 100%.

[8] Data from Toronto Police Services (2018) KSI database, http://data.torontopolice.on.ca/datasets/9f05c21dea4c40458264cb3f1e2362b8_0

[9] Data from Toronto Police Services (2018) KSI database, http://data.torontopolice.on.ca/datasets/9f05c21dea4c40458264cb3f1e2362b8_0

Vision Zero and Safety in Municipal Trucks

As explained in the introduction, Vision Zero is both a goal and a philosophy. The goal is to eliminate fatalities and serious injuries in the transportation system. The philosophy is that the transportation system should be designed with a holistic view and the safety of humans in the system is of paramount importance (Johansson, 2009). If collisions cannot be eliminated, then the effects should be reduced or mitigated through system design. Vision Zero espouses that "no foreseeable accident should be more severe than the tolerance of the human in order not to receive an injury that causes long term health loss." (Tingvall and Haworth, 2000, p. 2) There is no one prescribed way to do Vision Zero. Vision Zero programs are broad with many different elements and techniques, including, but not limited to: reducing speed limits on roads, geometric improvements at intersections, and installing electronic warnings and sensors.

The main causes of collisions resulting in fatalities and serious injuries are well-known (Canadian Association of Chiefs of Police, 2018). Drivers that are impaired, either through alcohol, drug-use, fatigue, or distraction are a major problem. In their report, Canada Road Safety Week - The Facts and Stats, May 15-21, 2018, the Canadian Association of Chiefs of Police outlined the extent of the problem. Sixty percent (60%) of collisions involve a single vehicle being driven by an alcohol-impaired driver. For fatally-injured drivers between the ages of 26-35, 47.7% tested positive for drugs in their system at the time of the collision. Eighty percent (80%) of collisions are the results of some form of driver distraction or inattention. Driver fatigue is a factor in 20% of fatal collisions. The Report also identified other factors, such as: aggressive driving (i.e., speeding and aggressive maneuvering) as a factor in 27% of fatalities and 19% of serious injuries; and not wearing a seat-belt as a factor in 30% of driver fatalities and 26% of passenger fatalities. The report shows that human factors play a major role in collisions that result in fatalities and serious injuries (Canadian Association of Chiefs of Police, 2018).

Vision Zero programs have been developed and implemented in cities globally. Table 5 outlines the major features of Vision Zero programs in numerous cities.

<u>Table 5: Vision Zero Programs</u>

City	Country	Population	Vision Zero	Main Features of Program	Source
Toronto	Ontario, Canada	4,263,000	Active	Improved design of roads and infrastructure for safety; Increased enforcement for violation; Enhanced education of all transportation system users; Increased use of Safety Zones and Bicycle Lanes	https://www.toronto.ca/services-payments/streets-parking-transportation/road-safety/vision-zero/vision-zero-plan-overview/
Montreal	Quebec, Canada	3,327,000	Considering	Reduce speeding and impaired driving; Enhanced education of all transportation system users; increased use of data and analytics to understand conditions and root causes of accidents	https://ville.montreal.qc.ca/visionzero/en/
Vancouver	British Columbia, Canada	1,832,000	Considering	British Columbia has a Road Safety Strategy; separation of pedestrians, cyclists, and vehicular traffic; reduce speeding and impaired driving; improved traffic control and transportation infrastructure; increased inspection of commercial vehicles	https://www2.gov.bc.ca/assets/gov/driving-and-transportation/driving/publications/road-safety-strategy-update-vision-zero.pdf
Ottawa	Ontario, Canada	1,010,000	Considering	Discussions of Vision Zero benefits	https://visionzero.ca/category/ottawa/
Edmonton	Alberta, Canada	863,000	Active	Five principles: Engineering (Building in Safety; Redesign); Education (Changing Behaviour); Enforcement; Engagement (Get Involved); Evaluation	https://www.edmonton.ca/transportation/traffic_safety/vision-zero.aspx
Calgary	Alberta, Canada	822,000	Active	Reduce speeding and impaired driving; Better biking and pedestrian infrastructure; Better use of data and analytics to improve programs and policies for safety	http://visionzeroyyc.ca/city-of-calgary-traffic/
Hamilton	Ontario, Canada	624,000	Active	Reduce speeding and impaired driving; restricted access for vehicular traffic; red light cameras; safety zones; designated truck roads; improved education for all transportation system users	https://www.hamilton.ca/streets-transportation/driving-traffic/vision-zero
London	Ontario, Canada	399,000	Active	Reduce speeding and impaired driving; red light cameras; improved intersection safety	https://www.london.ca/residents/Roads-Transportation/Road-Safety/Pages/London-Road-Safety-Strategy.aspx

Victoria	British Columbia, Canada	304,000	Considering	British Columbia has a Road Safety Strategy; separation of pedestrians, cyclists, and vehicular traffic; reduce speeding and impaired driving; improved traffic control and transportation infrastructure; increased inspection of commercial vehicles	https://www2.gov.bc.ca/assets/gov/driving-and-transportation/driving/publications/road-safety-strategy-update-vision-zero.pdf
Windsor	Ontario, Canada	279,000	Considering	Discussing; Developing the concept of the "Complete Street" accessible and safe for all road users	https://www.citywindsor.ca/cityhall/committeesofcouncil/Advisory-Committees/Windsor-Bicycling-Committee/Documents/ATTACHMENT%20AUG%2017%202017.pdf
Kingston	Ontario, Canada	143,000	Considering	Developing Road Safety Plan based on collision data and consultation for improved safety measures	https://www.cityofkingston.ca/city-hall/projects-construction/vision-zero
Alexandria	Virginia, USA	146,000	Active	Better enforcement of traffic laws; improved data collection and evaluation; enhanced education; safer transportation infrastructure; reduce speeding and impaired driving	https://www.alexandriava.gov/VisionZero; https://www.alexandriava.gov/uploadedFiles/tes/info/Vision%20Zero%20Action%20Plan%20Final_12012017.pdf
Anchorage	Alaska, USA	299,000	Active	Five principles: Engineering (Building in Safety; Redesign); Education (Changing Behaviour); Enforcement; Engagement (Get Involved); Evaluation; reduce speeding and impaired driving; enhanced education of bike laws	http://www.muni.org/Departments/OCPD/Planning/AMATS/Pages/visionzero.aspx; https://www.muni.org/Departments/OCPD/Planning/AMATS/Documents/Vision_Zero/2018/1%20Anchorage_VZ_Report_EXECUTIVE_SUMMARY_122618.pdf
Austin	Texas, USA	843,000	Active	Five principles: Education (Changing Behaviour); Engineering (Building in Safety; Redesign); Enforcement; Evaluation; Policy; reduce speeding and impaired driving; Improved use of data and analytics to improve safety of transportation system	https://austintexas.gov/visionzero; https://www.austintexas.gov/sites/default/files/Vision_Zero_Annual_Report_2016-2017_Cover_Thumb.jpg
Bellevue	Washington, USA	8,000	Active	Enhanced education; improved pedestrian and bicycle safety	https://transportation.bellevuewa.gov/safety-and-maintenance/traffic-safety/vision-zero
Bethlehem	Pennsylvania, USA	76,000	Active	Maximize safety procedures and activities; more traffic citations for violations; Better signs for cyclists and pedestrians; additional crosswalks at busy	https://www.mcall.com/news/local/bethlehem/mc-bethlehem-vision-zero-crashes-20161011-story.html

				intersections; No funding allocated;	
Harrisburg	Pennsylvania, USA	571,903	Active	Announced in 2018; Developing Road Safety and Vision Zero Plan; No tangible targets or goals	http://harrisburgpa.gov/visionzeroprogram/
Boston	Massachusetts, USA	637,000	Active	Reduce speeding and impaired driving; Improved transportation infrastructure; increased use of data and analytics to understand conditions and root causes of accidents	https://www.boston.gov/transportation/vision-zero
Boulder	Colorado, USA	107,000	Active	Four key principles: Education (Changing Behaviour); Engineering (Building in Safety; Redesign); Enforcement; Evaluation; reduce speeding and impaired driving	https://bouldercolorado.gov/transportation/vision-zero
Charlotte	North Carolina, USA	859,095	Active	Reduce speeding and impaired driving; Improve seatbelt use; increased use of data and analytics to understand conditions and root causes of accidents	https://charlottenc.gov/VisionZero/Pages/VisionZero.aspx; https://ncvisionzero.org/
Chicago	Illinois, USA	2,714,000	Active	Goal to eliminate all traffic fatalities and serious injuries by 2026	visionzerochicago.org/
Columbia	Missouri, USA	121,717	Active	Three key principles: Engineering (Building in Safety; Redesign); Education (Changing Behaviour); Enforcement; reduce speeding and impaired driving; Safety audits and road safety assessments	https://www.como.gov/city-manager/city-columbia-vision-zero/; https://www.como.gov/wp-content/uploads/City-of-Columbia-Vision-Zero-Action-Plan-2017-2020.pdf
Denver	Colorado, USA	634,000	Active	Enhance Processes and Collaboration; Build Safe Streets for Everyone; Create Safe Speeds; Promote a Culture of Safety; Improve use of Data and Analytics	https://www.denvergov.org/content/denvergov/en/vision-zero/what-is-vision-zero.html
Durham	North Carolina, USA	239,000	Active	Reduce speeding and impaired driving; Improve seatbelt use; increased use of data and analytics to understand conditions and root causes of accidents	https://durhamnc.gov/2995/Vision-Zero
Eugene	Oregon, USA	158,000	Active	Resolution to adopt Vision Zero in 2015; Improved use of data and analytics for safety	https://www.eugene-or.gov/3239/Vision-Zero
Fort Lauderdale	Florida, USA	171,000	Active	Five principles: Engineering (Building in Safety; Redesign); Education (Changing Behaviour); Enforcement; Engagement (Get Involved); Evaluation; Reduce collisions at targeted locations;	https://www.fortlauderdale.gov/departments/transportation-and-mobility/transportation-division/vision-zero-fort-lauderdale; https://www.fortlauderdale.

				encourage safety culture and attitudes	gov/home/showimage?id=32313&t=636810036585980182
Fremont	California, USA	222,000	Active	Rigorous Evaluation of Safety Data; Engineering for Safety; Proactive Engagement; Public Communication; Encourage Community Participation	https://fremont.gov/2594/Fremont-Vision-Zero-2020; https://mtc.ca.gov/sites/default/files/Fremont_Vision_Zero.pdf
Los Angeles	California, USA	3,858,000	Active	Curb Extension; Intersection redesign; pedestrian islands; new traffic signals; pedestrian-activated flashing beacon; protected left turn	visionzero.lacity.org
Macon	Georgia, USA	92,000	Active	Pedestrian Safety Review Board; Create Safer Streets	http://psrb.maconbibb.us/
Minneapolis	Minnesota, USA	393,000	Active	Part of the overall Minneapolis Vision 2040; Pedestrian-oriented building and site design; Restore and maintain the traditional street and sidewalk grid; equity-oriented transportation; Improved use of data and analytics to support transportation system safety and accountability	http://www.minneapolismn.gov/publicworks/TransportationPlanning/visionzero
Monterey	California, USA	29,000	Active	Reduce speeding and impaired driving; Improved transportation infrastructure	https://monterey.org/Services/Public-Works/Traffic-Engineering/Vision-Zero-Monterey
Montgomery County	Maryland, USA	1,058,810	Active	No traffic deaths by 2030; Key principles: Engineering; Education; Enforcement; Traffic Incident Management; Policy; Improved bike lanes and pedestrian safety; Vison Zero Youth Ambassadors;	https://montgomerycountymd.gov/visionzero/
New York City	New York, USA	8,337,000	Active	Enhanced education; improved pedestrian and bicycle safety; improved use of data and analytics for safety	https://www1.nyc.gov/site/visionzero/index.page
Orlando	Florida, USA	250,000	Active	Key principles: Education; Enforcement; Engineering; Evaluation; safer pedestrian crosswalks; strong yield requirements	http://www.iyield4peds.org/orlando-commits-to-vision-zero/
Philadelphia	Pennsylvania, USA	1,527,000	Active	Reduce speeding and impaired driving; increase numbers of pedestrians and cyclists	visionzerophl.com/
Portland	Oregon, USA	603,000	Active	Reduce speeding and impaired driving; Fixed speeding cameras; improved street design	https://www.portlandoregon.gov/transportation/66612; https://www.portlandoregon.gov/transportation/40390
Richmond	Virginia, USA	210,000	Active	Reduce speeding and impaired driving; improve seatbelt use	www.richmondgov.com/PublicWorks/VisionZero.aspx

Sacramento	California, USA	475,000	Active	Improve road safety; red light cameras and monitoring; traffic studies; improved safety zones	http://www.cityofsacramento.org/public-works/transportation/programs-and-services/vision-zero
San Antonio	Texas, USA	1,383,000	Active	Five principles: Engineering; Education; Enforcement; Engagement; Evaluation; Reduce speeding and impaired driving; improve cyclist education and visibility; improve obedience to laws by all transportation system users	https://www.sanantonio.gov/TCI/Vision-Zero
San Diego	California, USA	1,338,000	Active	Three key principles: Engineering (Building in Safety; Redesign); Education (Changing Behaviour); Enforcement; reduce speeding and impaired driving	https://www.sandiego.gov/vision-zero
San Francisco	California, USA	826,000	Active	Four key principles: Education (Changing Behaviour); Engineering (Building in Safety; Redesign); Enforcement; Evaluation; reduce speeding and impaired driving	https://visionzerosf.org/
San Jose	California, USA	983,000	Active	Five key principles: Education; Engineering; Enforcement; Evaluation; Technology; Upgrade street lights to improve lighting; Upgrade signage to increase reflectivity; improve bicycle and pedestrian facilities; improve use of data and analytics	www.sanjoseca.gov/VisionZero
San Luis Obispo	California, USA	48,000	Active	Targeted improvements at collision sites	https://www.slocity.org/Home/Components/News/News/4795/
Santa Barbara	California, USA	92,000	Active	Improved street design; Improved enforcement and education to reduce violations and impaired driving; Improved street design	coast-santabarbara.org/vision-zero/
Seattle	Washington, USA	635,000	Active	Four key principles: Education; Engineering; Enforcement; Evaluation; reduce speeding and impaired driving; improved infrastructure design	https://www.seattle.gov/visionzero
Somerville	Massachusetts USA	13,000	Active	Reduce speeding and impaired driving; improved street design; safety zones and routes for schools; improved pedestrian and cycling routes	https://www.somervillema.gov/departments/ospcd/transportation-and-infrastructure

Tempe	Arizona, USA	185,038	Active	Improved cyclist education; Strategies and Tools still being developed	https://www.tempe.gov/VisionZero
Washington D.C.	USA	632,000	Active	Greater enforcement and education for vulnerable road users; Increased use of data and analytics; Reduce speeding and impaired driving	https://ddot.dc.gov/page/vision-zero-initiative; https://www.dcvisionzero.com/
London	United Kingdom	7,074,000	Active	Reduce speeding and impaired driving; Improve visibility at junctions; Improve vehicle design for improved safety;	https://tfl.gov.uk/corporate/safety-and-security/road-safety/vision-zero-for-london
Berlin	Germany	3,387,000	Active	Enshrined Vision Zero in legislation; Design of traffic system; Reduce impaired driving	https://visionzeronetwork.org/tag/berlin/; https://www.dvr.de/presse/informationen/berlin-fuehrt-vision-zero-per-gesetz-ein_id-5019.html; https://www.dvr.de/dvr/vision-zero/
Rome	Italy	2,649,000	Active	Four key principles: Road Safety Management; Enforcement; Road Safety Rules awareness; traffic implementation and measures	www.eltis.org/sites/default/files/c1_iacorossi.pdf
Kiev	Ukraine	2,590,000	Active	Reduce speeding and impaired driving; Improve seatbelt usage; Controlled intersection turning (no turning on red); Improving the accuracy of collision and fatality data	visionzero.org.ua
Paris	France	2,152,000	Active	Restrict vehicles from some roadways, particularly in downtown core; Road Safety Plan, but without specific goals (i.e., number of fatalities and serious injuries) and no target dates	https://visionzeronetwork.org/european-cities-lead-the-way-toward-vision-zero/
Hamburg	Germany	1,705,000	Active	Reduce speeding, red light violations, impaired driving, illegal parking; increase pedestrian and cyclist safety	https://www.gruene-hamburg.de/presse/vision-zero-mehr-verkehrssicherheit-hat-oberste-prioritaet/
Warsaw	Poland	1,615,000	Active	Pedestrian safety; Reduce speeding; Improve the design and construction of road infrastructure for increased safety	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5446843/
Munich	Germany	1,195,000	Active	Reduce speeding, impaired driving; increase pedestrian and cyclist safety; increased digital monitoring	https://www.muenchen.de/rathaus/Stadtverwaltung/Kreisverwaltungsreferat/Wir-ueber-uns/Pressemitteilungen/04-2018/Verkehrssicherheit-.html

Melbourne	Victoria, Australia	4,800,000	Active	Safety Barriers; Improved vehicle and road design; reduce speeding and impaired driving	https://www.towardszero.vic.gov.au/

In some cities, the Vision Zero program also includes specific provisions and initiatives to improve the safety of trucks and VRUs interactions with trucks. One of the most common measures for protecting VRUs is to provide a physical separation between the VRUs and the vehicular traffic, in Figure 2. London, United Kingdom, has launched an initiative to try to isolate construction trucks from pedestrians, cyclists, and other vehicles, reducing the amount of time that that these vehicles need to be on the roads and limiting the use of trucks with low and limited visibility (Mayor of London, 2018).

Figure 2: Example of Physical Separation between Cyclists and Trucks


[10]

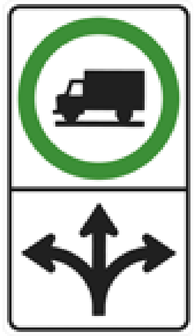

[11]

In addition to separating trucks from pedestrians and cyclists on the roads, some cities designate specific roads for trucks. Toronto has classified roads for appropriate traffic (City of Toronto, 2018a), restricting truck schedules and access under Municipal Code Chapter 950 (City of Toronto, 2018b). Many other cities have restrictions and truck schedules too. For instance, Hamilton, Ontario has also adopted a hybrid road system, with some roads restricted from truck traffic, with sample signage shown in Figure 3. Trucks are allowed off the permissible route to reach their final designation, but they must go by the shortest route possible (City of Hamilton, 2018).

[10] From http://ontruck.org/ota-submits-comments-on-improving-safety-between-trucks-cyclists-and-pedestrians/
[11] From www2.gov.bc.ca

Figure 3: Hybrid Road System Signage

[12]



[13]

[14]

[15]

In addition to physically separating and isolating trucks, there are some efforts to improve the engineering and design of vehicles. The Safer Lorry Scheme was initiated in 2015, to improve the safety of heavy goods vehicles through improved vehicle sensors and engineering, including: improved mirrors, blind-spot cameras, close-proximity sensors, side under-run protection (on both sides), an audible alert for vehicle turning left, and prominent pictorial warning signage (Mayor of London, 2018). In 2016, the Mayor of London, Sadiq Khan, announced a rating system for trucks (Lydall, 2016). Transport London will rate trucks on a five star scale for driver visibility (Robinson, Knight et al., 2014). Zero star trucks will be banned from 2020; one- and two-star trucks will be banned starting in 2024 (Sullivan, 2016).

Boston, San Francisco, and New York City have been on the forefront of implementing truck side guards as part of their Vision Zero programs. Each worked with the Volpe Center for the U.S. Department of Transportation to investigate the effectiveness of side guards on trucks, which resulted in technical assessments and recommendations for safety guard dimensions (Volpe Center, 2016, 2019). Boston passed an ordinance in October 2014 requiring all city contracted trucks over 10,000 pounds to install side guards for pedestrian and cyclist protection, becoming the first city in North America to require the side guards (City of Boston, 2017). New York City followed and began installing side guards on their municipal trucks in 2015 (Vision Zero Network, 2016). San Francisco began a pilot project in 2016 to determine the effectiveness of side guards on trucks (Vision Zero Network, 2016).

The colour of trucks is another important safety factor. Lime yellow and white trucks are much more visible, and thus safer, than traditional red trucks because those colours are easier to see in dimming light or at night (American Psychological Association, 2014). There are some

[12] Sign image from https://www.roadtrafficsigns.com/signs/all-trucks-with-right-arrow-sign/sku-k-8878-r.aspx
[13] Sign image from https://www.hamilton.ca/streets-transportation/driving-traffic/hamiltons-truck-route-network
[14] Sign image from https://www.hamilton.ca/streets-transportation/driving-traffic/hamiltons-truck-route-network
[15] Sign image from https://www.frpsigns.com/products/signs/traffic-signs/truck-signs/

additional safety measures that have been introduced to help with visibility and safety. Retro-reflective tape along the sides and rear of trucks have been shown to improve the visibility of these vehicles to other road users, particularly at night and during inclement weather (Bloch and Schmutzler, 1998). Vehicle technologies and safety apparatus, such as 360 degree cameras and scans, proximity sensors for detection of Vulnerable Road Users and objects, blind spot warnings, and other advanced driver assistance systems (ADAS) can help drivers with their visibility. In addition to electronic and computer assisted technologies, simple mechanical design fixes, such as greater window area, see-through passenger doors, and better mirrors, can also be used to help drivers.

Codes and Standards

The design and use of municipal and commercial trucks are governed by codes and standards. Depending on the use and purpose, different codes and standards apply. In this report, several different types of municipal vehicles are discussed, specifically, Fire Trucks, Emergency Medical Services vehicles, Solid Waste vehicles, and Snow Plows.

Fire Trucks

Fire trucks in Ontario are subject to multiple regulations by different ministries and agencies. All fire apparatus are regulated under the Occupational Health and Safety Act (OSHA), general duty clause 25(2)(h), Sections 7 and 7.1 (Firefighters – Protective Equipment). Transport Canada regulates all vehicles under the *Motor Vehicle Safety Act* (Transport Canada, 2018a). Fire Departments are expected to meet the codes and standards for Automobile Fire Fighting Apparatus (CAN/ULC S515), and the applicable National Fire Protection Association (NFPA)[16] (Ontario Ministry of Labour, 2015).

Vehicles in Ontario require insurance. Thus, the insurance and finance industries can provide recommendations, constraints, and guidance on fire vehicles and apparatus. The length of the aerial ladder or an elevating platform is generally determined by the physical requirements of the buildings in a community. However, there are guidelines based on the normal height of one storey of a building and expected physical grading, and ladders are typically expected to be between 50 feet to 100 feet in length (Fire Underwriters Survey, 2018b).

The Fire Underwriters recommend that in high-hazard situations (e.g., schools, hospitals, nursing homes, large fire potential situations, etc.), at least four pumpers, two ladder trucks, two chief officers, other specified apparatus, and not less than 24 firefighters are to be present. In medium-hazard situations, at least three pumpers, one ladder truck, other specialized equipment as required, one chief officer, and at least 16 firefighters are required (Fire Underwriters Survey, 2018b).

The Underwriters Laboratories of Canada (UL) is accredited by the International Accreditation Services to provide inspection services and standards for manufacturers of firefighting

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[16] The NFPA has numerous standards and recommendations for firefighting apparatus, which may or may not be applicable for particular vehicles, including: NFPA 1901 (Standard for Automotive Fire Apparatus), NFPA 1906 (Standards for Wildland Fire Apparatus), NFPA 404 (Standard for Aircraft rescue and Firefighting Vehicles). A full list of the NFPA codes and standards is available at: https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards?mode=code&code=1901.

apparatus to ensure that they comply with NFPA 1901 (Standard for Automotive Fire Apparatus) (Underwriters Laboratories of Canada, 2018).

These codes, standards, guidance, and recommendations determine many of the requirements, constraints, and usage of firefighting apparatus. For instance, fire vehicles and apparatus are expected to operate without failure at least 95% of the time for the first 15 years of service and be retired after 20 years of service, though this can be extended under specific circumstances (Fire Underwriters Survey, 2018a). This stringent set of standards makes certifying a new make of truck onerous, difficult, and sometimes impossible, for vehicle manufacturers to meet, thereby, limiting the market availability.

There are many different types of fire trucks, designed for different purposes and responses. The requirements are dependent on the needs for which the truck is used. There are, of course, trade-offs in the capabilities and configurations of the vehicles with these different sizes and configurations. Thus, there is no generic or universal preference for the size of vehicle.

Aerial or ladder trucks are fire apparatus that are equipped with an aerial ladder, evaluating platform, or water tower (CFA, 2018) (See Figure 4).

Figure 4: Example of Aerial Ladder Truck used in the City of Toronto[17]

These ladders are capable of reaching several stories and allow firefighting personnel to position themselves in a raised position (Jon's Mid America, 2017). Ladder Trucks have the ladder fixed to the truck. Ladder sizes vary, with 75 foot and 105 foot ladders being common lengths.[18] The NFPA Standard 1901 requires that aerial ladders have a minimum vertical height of 50 feet (15m) (NFPA, 2016, Chapter 19, Section 19.2.2). Trucks with water towers must

[17] Photo from http://www.firetrucks.ca/ProductDetails.asp?ProductCode=NEW%2D2015TorontoAerials
[18] http://www.e-one.com/product_category/aerial-ladders/

provide a minimum water spray of 1000 gallons per minute (gpm) or 4000 litres per minute (L/min) at 100 pounds per square inch (psi) or 700 kPa (NFPA, 2016, Chapter 19, Section 19.4.1). Aerial trucks must have a minimum of 115 feet (35 metres) of ground ladders and a minimum of one folding ladder, two straight ladders, and two extension ladders. In addition, they must have storage space for hoses and required equipment (NFPA, 2016, Chapter 8). A hook and ladder truck, or tractor-drawn aerial truck (TDA), is essentially a tractor-trailer, where the trailer is equipped with a fixed ladder and other firefighting apparatus (Miller, 2015).

Rescue vehicles are designed to support the rescue of people in emergency situations, such as rescuing people from car collisions or from elevated positions, where the primary concern is not fighting or suppressing fire (CFA, 2018) (See Figure 5). Rescue vehicles can be either for Walk-in or Non-Walk-in rescues. Non Walk-in Rescues are for situations and locations where personnel cannot go easily, including: situations with confined spaces, high-angle rescues, wet rescues, and hazardous material (Haz-Mat) (E-One, 2018b).

Figure 5: Example of Rescue Truck used in the City of Toronto[19]

Pumpers are used for pumping large quantities of water through a permanently mounted pump (Jon's Mid America, 2017) (See Figure 6). Pumpers are mostly used in urban and suburban locations where water is present (CFA, 2018). Pumpers usually carry additional gear, such as hoses, nozzles, ladders, breathing and other firefighting gear (CFA, 2018). Pumpers can use either city water or water from tankers. Pumpers must have a minimum certified capacity of 300 gallons (1100 Litres), a minimum hose storage of 40 cubic feet (1.1 cubic metres), a

[19] Photo from https://www.flickr.com/photos/109984443@N07/27743825036

minimum of one straight ladder with roof hooks, one extension ladder, and one folding ladder (NFPA, 2016, Chapter 5).

Figure 6: Example of Pumper Truck used in the City of Toronto[20]

Tankers, Tanker Trucks, Foam Tenders, and Water Tenders are designed to transport or pump large amounts of water wherever it is needed. Tankers come in many different sizes. They are generally used in rural locations where pressurized water is rarely readily accessible (Heavy Duty Direct, 2017a). Like other fire trucks, tankers carry firefighting equipment, such as hoses, nozzles, safety and rescue equipment, and hand tools (CFA, 2018).

Ambulances, Emergency Medical Service (EMS), and Paramedic Service Vehicles

In addition to being regulated by Transport Canada under the Motor Vehicle Safety Act (Transport Canada, 2018a), vehicles that provide transport and emergency response services are governed under the Ontario Provincial Land Ambulance & Emergency Response Vehicle Standard Version 5.0 – September 28, 2012, Emergency Health Services Branch, Ministry of Health and Long-Term Care, Government of Ontario (Ontario Ministry of Health and Long-Term Care, 2012).

A Type 1 Ambulance is classified as a "conventional truck cab and chassis with a remountable modular body that contains the patient compartment" (Ontario Ministry of Health and Long-Term Care, 2012, p. 1). A Type 2 Ambulance is classified as a "standard van with integral cab and body, [with] the patient compartment contained within the body and a raised roof over the patient compartment" (Ontario Ministry of Health and Long-Term Care, 2012, p. 2). A Type 3 Ambulance is classified as a "cutaway van cab and chassis with a remountable modular body that contains the patient compartment" (Ontario Ministry of Health and Long-Term Care, 2012, p. 2). Figure 7 shows examples of Type 2 and Type 3 Ambulances. There are other EMS vehicles, such as transport buses and support vehicles, but the vehicles are covered by the appropriate regulations for the type and usage of vehicle.

[20] Photo from https://www.spartanerv.com/delivery.aspx?id=65369

Figure 7: Examples of Type 2 and Type 3 Ambulances used in the City of Toronto

 Type 3 Ambulance[21]	 Type 2 Ambulance[22]	 Type 3 Ambulance [23]

Solid Waste Vehicles (SWV) and Garbage Trucks

Within Ontario, there are regulations regarding the weight and dimensions of trucks that are allowed on public roads under the Highway Traffic Act. These regulations are Ontario Regulation 413/05 (Vehicle Weights and Dimensions – For Safe, Productive, and Infrastructure-Friendly Vehicles) (Government of Ontario, 2017). Trucks on Ontario can be a maximum of 2.6 metres wide and 4.15 metres high. Tractor trailers are longer than either solid waste vehicles or snow plows. Gross weight limits are dependent on the many factors, including the length of the vehicle, tire size, chassis length, etc. (Government of Ontario, 2017).

Municipal solid waste trucks come in several configurations, commonly front loaders, rear loaders, roll-off trucks, and grapple trucks (Heavy Duty Direct, 2017b) (see Figure 8). Front loaders have automated prongs on the front of the vehicle that pick up commercial and industrial garbage bins, lift them, and dump the into the collection bin of the truck. Rear loaders are loaded from the back, often by manual garbage collectors. Once the back container is full, a mechanical compactor is used to compress the garbage. Roll-off garbage trucks or dumpster trucks are typically used at construction or demolition sites where the waste is from a single location. Dumpsters are generally left at the site and are loaded and unloaded off the transporting truck. Grapple trucks pick up big and bulky items with a large claw or gripper (Heavy Duty Direct, 2017b).

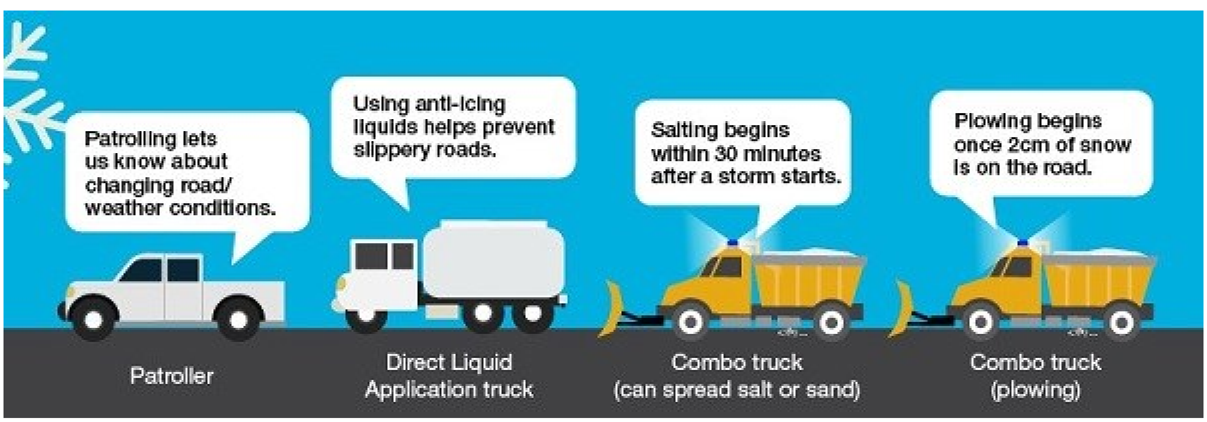
[21] Photo from https://www.hobbydb.com/catalog_items/ford-e-350-ambulance-74aec8bc-a810-45a9-b3b2-4e589ca0a48e
[22] Photo from https://www.hobbydb.com/catalog_items/ford-e-350-ambulance-74aec8bc-a810-45a9-b3b2-4e589ca0a48e
[23] Photo from https://en.wikipedia.org/wiki/Toronto_Paramedic_Services#/media/File:TorontoAmbulanceParamedics.JPG

Figure 8: Example of Municipal Solid Waste Vehicle used in the City of Toronto [24]

Snow Plows

The City of Toronto is required to meet or exceed the minimum standards set by the Province of Ontario for winter road maintenance (Ontario Ministry of Transportation, 2019). The Province of Ontario sets the standards for road maintenance, including the requirements for clearing snow and ice for municipal highways (Government of Ontario, 2018). As a part of this maintenance, the Ontario Ministry of Transportation dictates the different operations of maintenance (shown in Figure 9), which necessarily govern the types of trucks that can be used for road maintenance and snow plowing.

Figure 9: Steps in Winter Maintenance of Roads[25]



Snow Plows are under the same regulations and restrictions as other commercial trucks. That is, Ontario Regulation 413/05 (Vehicle Weights and Dimensions – For Safe, Productive, and Infrastructure-Friendly Vehicles) (Government of Ontario, 2017) and the Motor Vehicle Safety

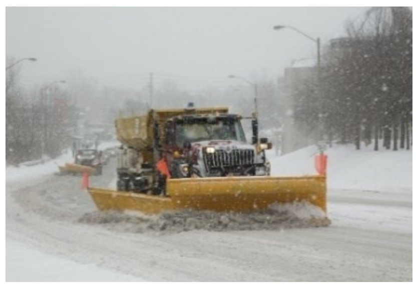
[24] Photos provided by City of Toronto staff

[25] Photo from http://www.mto.gov.on.ca/graphics/english/ontario-511/winter-highway-process.jpg

Act (Transport Canada, 2018a). Much of the snow plowing in the province of Ontario is done by contractors, who have a wide variety of trucks (see Figure 10 for examples). Some of the snow plows are commercial vehicles (either medium duty or heavy duty trucks) with the additional dimensions of a mounted snow plow on the front of the vehicle. Some of the snow plows are combination trucks, that is capable of plowing snow and spreading salt or sand. A tow-plow is a commercial truck that pulls a tow-plow, which is offset in the adjacent right hand lane, making these trucks more like tractor trailers. All snow plows in Ontario are required to be identified with black and yellow checkered signage on their rear to improve visibility of the snow plows to other road users (Ontario Ministry of Transportation, 2015).

Figure 10: Examples of Snow Plows used in Toronto, Ontario


Motor Grader Plow[26]


Truck Snow Plow[27]


Sidewalk Plow[28]

Implications and limitations for the Size of Vehicles

Typically the size of the vehicle is constrained by its function and usage. A fire truck that is expected to carry multiple firefighters, a 105 foot aerial ladder, and the supporting equipment, is necessarily going to be relatively large. Regulations are designed to ensure that vehicles are manufactured and operated safely and can perform their intended function. However, there is a great deal of momentum in regulations as well and change can be fiercely resisted. For instance, when Transport Canada instituted more stringent rear underride guards for Canada in 2007 than existed in the United States, there was a backlash and fears that the regulations would economically harm Canadian Trucking companies. However, by 2015, the U.S. National Highway Traffic Safety Administration (NHTSA) was proposing that the Canadian standards be adopted in the United States as well (Safety Research Net, 2015). In December 2015, the NHTSA submitted a proposed regulation to the Federal Register for public comment (United States Federal Register, 2015). However, the proposed regulation has not yet been approved.

[26] Photo from https://www.toronto.ca/services-payments/streets-parking-transportation/road-maintenance/winter-maintenance/levels-of-snow-clearing-service/
[27] Photo from https://www.thestar.com/news/gta/2016/02/16/city-of-torontos-new-snow-plow-tracking-app-put-to-the-test.html
[28] Photo from https://www.blogto.com/city/2014/12/snow_removal_in_toronto/

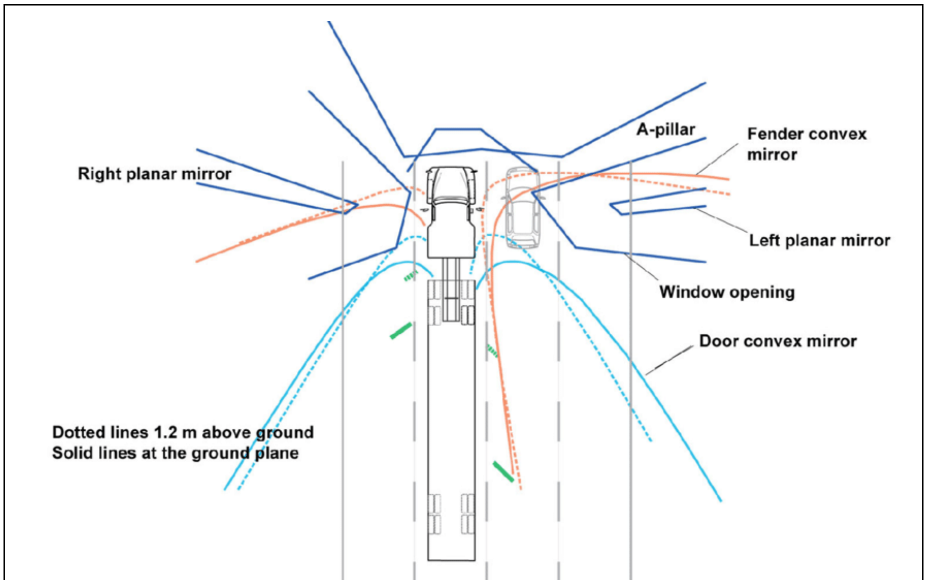
Large Vehicle Safety

The versatility and flexibility of trucks are dependent on their size and configuration. Larger fire trucks are often more versatile than smaller trucks because they carry more equipment and are able to reach more locations and structures and are able to better deal with the unexpected and ever changing circumstances and needs in the field. However, larger trucks are not as nimble due to their size.

As discussed above, collisions involving trucks are typically more serious than those involving smaller passenger vehicles. The design of commercial trucks has inherent challenges for safety (Vision Zero Network, 2016). Commercial trucks are typically higher than smaller vehicles and they weigh significantly more than smaller vehicles, even unloaded. They have significantly greater momentum when they are moving, and thus they have longer stopping distances than smaller vehicle (Arrive Alive, 2009). The height of commercial trucks can also make visibility challenging for truck drivers, with blind spots common (Vision Zero Network, 2016).

A study conducted by Daniel Blower at the University of Michigan Transportation Research Institute shows that a driver's visibility in a truck is significantly more impaired than in other types of vehicles. The design of the truck results in many blind spots and can make it difficult for drivers to see pedestrians, cyclists, and other vehicles, as shown in Figure 11 and 12.

Figure 11: Top Views of Truck Blind Spots

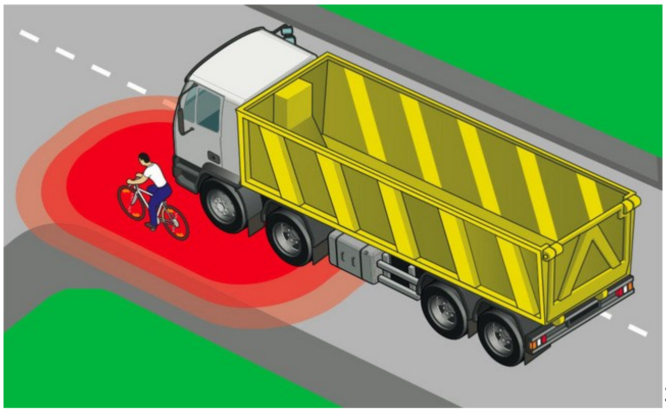


[29]

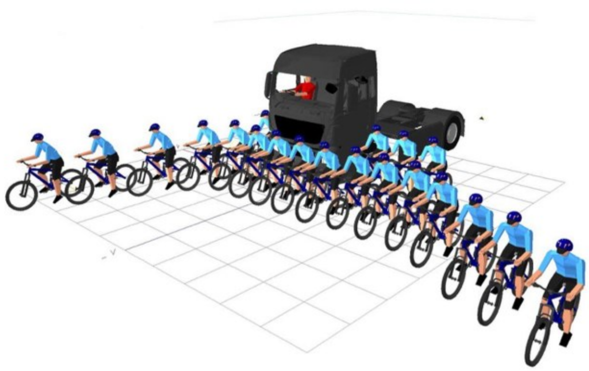
[29] Image from Daniel Blower (2007)

Twenty percent of collisions were during maneuvers in which the truck driver had to use mirrors to maneuver (known as mirror-relevant crashes). However, mirrors on trucks do not always provide the visibility that would be desired. The results of Blower's study suggest that trucks are more likely to be involved in collisions when the driver is relying only on the mirrors for visibility and maneuvering (Blower, 2007).

Figure 12: Truck Visibility and Blind Spots


[30]


[31]



[33]

[32]

In an investigation of truck design and visibility for Transport for London, Steve Summerskill and Russell Marshall found that visibility of truck drivers was significantly impaired, but that the degree of visual impairment varied by the height and design of the truck (Summerskill and Marshall, 2015). Trucks with greater driver heights generally had larger direct visual blind spots, as shown in Figures 11 and 12. The authors found that specific design features, such as the driver seat location, the design of the windows and mirrors, could all impact the severity of

[30] Image from https://lcc.org.uk/pages/lorries
[31] Photo from https://imgur.com/gallery/PUfmP
[32] Image from Steve Summerskill and Russell Marshall
[33] Image from https://lcc.org.uk/articles/transport-for-london-lorry-safety-poster-misinforms-cyclists-and-drivers

the blind spot (Summerskill and Marshall, 2015). That is, the design of the vehicle could improve the visibility of the driver and reduce the likelihood of collisions.

In addition to visibility concerns, trucks all pose the danger of vehicle under-run, in which a smaller vehicle, pedestrian, or cyclist will get run over or trapped under a large truck during a collision. The next section will look at Truck Size and Visibility. The section following that will look at Truck Safety Guards. Both will examine what is being done in Toronto and compare it to alternatives in other Vision Zero municipalities.

Large Vehicle Size and Visibility

Fire Trucks

The City of Toronto uses a variety of vehicles from several manufacturers. As explained above, there are different types of fire trucks for different purposes. A listing of truck manufacturers is available in Appendix A. The composition of the fire truck fleet for the City of Toronto is presented in Table 6, with the fleet of the City of Hamilton used as a comparison. Smaller light trucks (i.e., pickup trucks) are excluded.

Table 6: Fire Truck Fleet Composition for the Cities of Toronto and Hamilton

Body Manufacturer	Cab and Chassis	Specs	Toronto	Hamilton
Aerials & Quints				
Smeal	Spartan Gladiator Classic	105' ladder	31	
Smeal	Spartan Gladiator Classic	100' ladder	3	
Smeal	Spartan Gladiator Classic	75' ladder	8	1
Smeal	Spartan Gladiator Classic	Bronto	2	
Smeal	Spartan Gladiator		3	
E-One	Cyclone II	100' Metro Ladder	5	
KME	Severe Service LFD	103' ladder		3
KME	Severe Service LFD	100' ladder		1
Pierce	Dash 2000	75' ladder		1
		Total.....	52	6
Fire Engines				
KME	Predator Severe Service	1050/500/30F		2
KME	Predator Severe Service	1050/500/25F		4
KME	Predator Severe Service	1050/500/20F		4
KME	Excel	1050/500/15A		5
Spartan	Spartan Gladiator Classic MFD / Almonte	1050/500/180F		1
		Total.....		16
Pumper				
Crimson	Spartan Metro Star Classic	5000 L 1250/500	9	
E-One	Cyclone II	1250/500/2x15F/50' Teleboom	1	
E-One	Typhoon	1250/500	3	
ERV	Spartan Metro Star Classic	1250/465/35B	1	
ERV	Spartan Metro Star Classic	1750/500/25A	19	
Dependable	Ford	3000 L	1	
Seagrave	Spartan Advantage	6000L 1250/420/20A	1	

Seagrave	Spartan Advantage	6000L 1250/500/20A	19	
Smeal	Spartan Advantage	6000L 1250/500/25A	6	
Smeal	Spartan Metro Star	6000L 1050/500	6	
Smeal	Spartan Metro Star	6000L 1250/465/35B	11	
Smeal	Spartan Metro Star	6000L 1250/500/20A	5	
Almonte	Spartan Advantage	1050/900		1
Freightliner	FL80 / C-Max	1050/1000		2
Freightliner	FL80	1050/650		2
KME	Excel	1050/500		1
KME	Predator Severe Service	1050/1600/20F		1
KME	Renegade Pumper	1050/600/30F		1
Pierce	Saber	1050/600/2x12F		2
Spartan	Gladiator Classic	1050/500/180A/40B		1
		Total.....	82	11
Rescue				
Almonte	Spartan Metro Star MFD	1050/500	5	
Crimson Fire	Spartan Metro Star Classic MFD	2000/500	3	
E-One	Typhoon	1250/500	6	
ERV	Spartan Metro Star Classic	6000L 1250/500	12	
Smeal	Spartan Metro Star MFD	6000L 1250/500	8	
Smeal	Spartan Metro Star MFD	5000L 1050/500	3	
KME	Severe Service LFD	Walk-around rescue		4
KME	Renegade MFD			1
		Total.....	37	5
Squad and Air/Light				
Almonte	Spartan		1	
Dependable	Freightliner		8	
Dependable	International		1	
Dependable	Spartan		7	
Seagrave	Spartan		4	
Ford	E			3
Ford	F550			4
		Total.....	21	7
HazMat Trucks				
Ford	Del Unicel		1	
Ford	Ford F450		1	
Spartan	Spartan Metro Star LFD		2	
KME	Predator XLFD	Walk around HazMat		1
Sterling	Commercial Babcock			1
		Total.....	4	2
Tanker Trucks				

Spartan	Metro Star / Almonte	1050/1800/30F		2
KME	Predator Severe Service	1050/500/30F		1
KME	Predator Severe Service	1050/1680/25F		3
KME	Predator Severe Service	1050/1600/20F		1
KME	Predator Severe Service	840/1600		1
Freightliner	FL80 / C-Max	280/2500/20F	1	2
		Total.....	1	10

Hamilton is a significantly smaller city than Toronto. It is also comprised of both an urban core and surrounding suburban/rural areas. In 2001, the borders of the City of Hamilton were expanded under a reorganization plan by the Province of Ontario to include the towns of Ancaster, Dundas, Flamborough, and Stoney Creek. Hamilton now covers a land area of 1,371.9 km^2 and has a population of approximately 748,000, giving Hamilton a population density of approximately 545 people per square kilometre (StatsCan, 2016a). It has 165,055 single detached homes, 45,395 apartments over five stories, and 24,355 apartments under five stories (StatsCan, 2016a). In comparison, Toronto covers only 630.20 km2 and has a population of approximately 2.73 million, giving Toronto a population density of approximately 4,334 people per km2 (StatsCan, 2016b). It has 269,675 single detached homes, 493,275 apartments over five stories, and 165,630 apartments under five stories (StatsCan, 2016b).

This makes it necessary to have a different composition of fire trucks between Toronto and Hamilton, not simply more fire trucks in Toronto. Hamilton, for instance, has 10 tanker trucks, whereas Toronto only has 1.[34] This is because there are many areas in Hamilton where a fire truck does not have access to water onsite and needs to bring water to site. Toronto has 28 rescue trucks, while Hamilton has 5. Toronto also has 5 squads (also referred to as heavy rescue trucks).

Since the vast majority of fire trucks in North America are customized (Petrillo, 2016), there is no published "average" length of a vehicle. Cabs and Chassis are typically built by one manufacturer and the body is supplied by another. Thus, trucks lengths vary by configuration and specifications. Aerial fire trucks can be less than 9 meters to over 15 meters (see for example, E-One, 2018a; KME, 2018; Spartan, 2018; Spartan Metrostar-RT, 2018). Pumpers and Rescue trucks can vary from less than 8 metres to over 10 metres (Brindlee Mountain Fire Apparatus, 2018).

[34] Tanker trucks are used for transporting water to a site, as opposed to using water at the location (i.e., from local fire hydrants).

Some cities have been looking for alternatives to help improve driver visibility. San Francisco recently purchased smaller vehicles (James, 2017). The city purchased eight new fire trucks in 2017 that were 10 inches shorter than other trucks in their firefighting truck fleet. The trucks had smaller turning radii and were more maneuverable. However, in addition to the smaller dimensions, the new fire trucks were equipped with on-board cameras, which provided a 360 degree view of the truck, making it significantly easier for the driver to see pedestrians, cyclists, or other objects that might be near the vehicle (James, 2017). The trucks also have recessed hose fittings and valves (i.e., they don't stick out from the truck) so that they are less likely to snag someone or something if they are moving past it (Rudick, 2017).

There are smaller fire truck options, designed for smaller fires or rescues. However, larger trucks provide greater means for reaching apartment building balconies and elevated structures, as well as bringing more firefighting personnel to large fires. Larger trucks tend to be more flexible in their activities as they generally carry more (and more diverse) equipment and firefighting apparatus.

Thus, there is some flexibility and capability that is diminished with a fleet comprised only of smaller vehicles. European countries tend to use shorter and narrower trucks with smaller turning radii (Petrillo, 2016). At the same time, in North America, 75% to 80% of trucks are custom built, whereas in Europe, approximately 95% percent of their trucks are standard trucks (Petrillo, 2016). However, the trucks in Europe tend to be less versatile. They are designed for single purpose and are not expected to perform multiple functions as they are in North America (Petrillo, 2016); thereby, requiring a larger fleet of more specialized vehicles for a given population and service level. This trend may be the results of the differences in population distribution and density between North America and Europe. In North America, there is a generally a lower population density than in Europe. For instance, Toronto has a population of 2.73 million residents and a population density of approximately 4,334 people per km^2 (StatsCan, 2016b). Paris (France), on the other hand, has a population of 2.2 million residents, but a population density more than four times that of Toronto at 20,909 residents per km^2; Athens (Greece) has a population density of 19,135 residents per km^2; Barcelona (Spain) has a population density of 15,991 residents per km^2, and Naples (Italy) has a population density of 8,183 residents per km^2 (World Atlas, 2018). The lower density in North America means that firefighters have a larger area to service for the same population, which makes it more difficult to deploy multiple specialized vehicles on an "as-needed" basis.

It is difficult to compare the fleets specifically for vehicle size and lengths, since vehicle configurations change with specifications and customization. Manufacturers have also been working to reduce the size of their vehicles and so the age of the trucks is also a factor. The Division Chief, Mechanical Maintenance Division, City of Toronto, Rob Anselmi, analyzed the size of the most recently ordered Fire Trucks. The City of Toronto's orders for the Fire Truck fleet are already decreasing in size and are smaller than those ordered most recently by the City of Hamilton (see Table 7).

Table 7: Apparatus Size Comparison; Toronto Fire Services / Hamilton Fire Services[35]

Pumper Apparatus				
	Toronto Fire Services most recent order	Toronto Fire Services revised design for pending order	Hamilton Fire Services Former Design	Hamilton Fire Services Revised Design
Gross Vehicle Weight	47,000Kg	47,000Kg	21,320kg/47,000lbs	21,320kg/47,000lbs
Front Axle Weight	20,000Kg	20,000Kg	9,072kg/20,000lbs	9,072kg/20,000lbs
Rear Axle Weight	27,000Kg	27,000Kg	12,247kg/27,000lbs	12,247kg/27,000lbs
Over All Length	378"	378" or 366"	393"	371"
Cab Width	94.5"	94.5"	100"	100"
Body Width	100"	96"	100"	100"
Overall Height	118.5"	114"	124"	112"
Wheel Base	187"	187"	206"	188"
Single or tandem axle	S	S	S	S
Aerial Apparatus				
	Toronto Fire Services Quint Aerial	Toronto Fire Services Urban Aerial	Hamilton Fire Services Current Design	Hamilton Fire Services Revised Design
Gross Vehicle Weight	77,000Kg	54,000Kg	36,741kg/81,000lbs	N/A
Front Axle Weight	23,000Kg	21,000Kg	10,432kg/23,000lbs	N/A
Rear Axle Weight	54,000Kg	33,000Kg	26,308/58,000lbs	N/A
Over All Length	504"	466"	472"	N/A
Cab Width	99"	96"	100"	N/A
Body Width	100"	96"	100"	N/A
Overall Height	144"	130"	140"	N/A
Wheel Base	229"	220"	232"	N/A

[35] Analysis and chart from Rob Anselmi, Division Chief, Mechanical Maintenance Division, City of Toronto

Single or tandem axle	T	S	T	N/A
Aerial Device Height	105'	100'	103'	N/A
Heavy Rescue (Squad) Apparatus				
	Toronto Fire Services Rescue Squad	Hamilton Fire Services Rescue Squad		
Gross Vehicle Weight	44,000Kg	19958kg/44,000lbs		
Front Axle Weight	20,000Kg	9071kg/20,000lbs		
Rear Axle Weight	24,000Kg	10886kg/24,000lbs		
Overall Length	396"	362"		
Cab Width	99"	96"		
Body Width	99"	100"		
Over All Height	112"	126"		
Wheel Base	199"	185"		
Single or tandem axle	S	S		

Camera and video imaging systems provide an enhanced visibility system that uses cameras mounted to the exterior of the truck, providing drivers with a view of previously less visible (or completely invisible) areas of the truck. One study of Camera/Video Imaging Systems (C/VISs) found that drivers indicated that C/VISs gave them greater visibility at night, when making lane changes, and facilitated greater awareness of their surroundings (Fitch, Blanco et al., 2011). In a study for Fordonsstrategisk Forskning och Innovation, Habibovic and his colleagues (Habibovic, Andersson et al., 2017) found that camera-based rear-view mirrors in trucks were helpful in improving visibility and that many of the drivers' concerns about the reliability and ease of use were quickly alleviated once they actually used the system.

Several features of a truck can impact the overall driver's visibility, including the overall length and turning radius. Fire Trucks can vary in length from less than 9.1 metres (30 feet) to approximately 50 feet. The length and wheelbase affect the turning radius of the truck. The minimum curb radii for Toronto are specified in guidelines from the City of Toronto Transportation Services (City of Toronto, 2017). Curb radii is determined based on the largest type of vehicle that can be anticipated to use a particular street. Smaller (shorter) vehicles have smaller wheelbases and can maneuver more easily. However, these vehicles cannot carry as many firefighters to the incident site.

<u>Emergency Medical Service (EMS) and Paramedic Service Vehicles</u>

There are various ambulance manufacturers across North America. The City of Toronto uses Ambulances produced by Crestline Coach in Canada. Toronto has 121 ambulances, 23 emergency response units, 22 special service units, 4 critical care units, and 2 ambulance buses (City of Toronto, 2018c) Ambulances are approximately 7 meters in length (Crestline, 2018). In Toronto, only Modular Type 3 ambulances are deployed with wheelbases of 139 inches (3.5 metres) and 159 inches (4.0 metres). These vehicles are smaller vehicles in general than tire trucks. Thus, they have a smaller overall length and a smaller turning radius. They also tend to be lower to the ground, as they are frequently built off of a van chassis. Visibility can still be an issue. Table 8 shows several examples of EMS vehicles used in Toronto.

Table 8: Examples of EMS vehicles used in the City of Toronto

	EMS Ambulance [36]	EMS Ambulance[37]	EMS Transport Bus[38]
Picture			
Cab/Chassis	Type III Ambulance Chevrolet Express Cutaway	Type III Ambulance Ford E-Series	Multi Patient Emergency Response Vehicle ElDorado National Axess
Manufacturer	Crestline Coach Ltd. is an ambulance manufacturer located in Saskatoon, Saskatchewan	Crestline Coach Ltd.	Crestline Coach Ltd.

[36] Photo from https://en.wikipedia.org/wiki/Toronto_Paramedic_Services#/media/File:TorontoAmbulanceParamedics.JPG
[37] Photo from https://www.hobbydb.com/catalog_items/ford-e-350-ambulance-74aec8bc-a810-45a9-b3b2-4e589ca0a48e
[38] Photo from https://www.flickr.com/photos/112704828@N03/13227962004

Solid Waste Vehicles (SWV)

Solid Waste vehicles comprise approximately 61% of Toronto's municipal truck fleet (City of Toronto, 2014). Solid waste vehicles (i.e., garbage trucks) in Toronto are typically 12 metres (39.4 feet) in length, 2.4 metres (7.9 feet) wide, with a wheel base of 5.49 metres (18.0 feet), and a turning radius of 14 metres (45.9 feet) (City of Toronto, 2012). Thus, it is approximately the same dimensions of a typical Aerial Ladder fire truck. It generally has the same size and visibility issues discussed in the fire truck section. In 2015, the City of Hamilton announced that it was installing cameras in all its garbage trucks in an effort to improve safety and reduce collisions by garbage trucks and snow plows (Van Dongen, 2015).[39]

Snow Plows

Transportation Services is the division in the City of Toronto responsible for the planning, construction, and maintenance of the transportation infrastructure in Toronto (City of Toronto, 2019b). The City of Toronto uses approximately 600 snowplows, 300 sidewalk plows, 200 salt trucks, 200 larger pickup and dump trucks, and 200 smaller pickup trucks to maintain the roads during the winter (Holyday, 2018). There are also more than 1500 City employees and contracted staff employed for winter road maintenance (Holyday, 2018). Figure 13 shows examples of winter road maintenance vehicles used in Toronto and a list of selected manufacturers is in Appendix A.

Figure 13: Examples of winter maintenance vehicles used in the City of Toronto[40]

[39] Hamilton, Ontario, was responding to a safety violation rate of 90%. In the two years prior to the pilot program, commercial trucks in Hamilton were involved in 118 collisions with 30 convictions, mostly by garbage trucks and snow plows. Warning letters are issued by the Ontario Ministry of Transportation when the violation rate is 35% (Ontario Ministry of Transportation , 2009).

[40] Photo from https://www.toronto.ca/services-payments/streets-parking-transportation/road-maintenance/winter-maintenance/salt-management-plan/

<u>Safety and Size</u>

Trucks can have substantially different features and dimensions, just as they can have different operating parameters, and still meet the regulations and expectations for use. The results of the investigation show that different sizes of vehicles are available for different applications, but that the requirements of the vehicles often constrain and dictate its size. Smaller trucks may require a greater number of trips to accomplish their tasks. Municipal Solid Waste trucks that are smaller may have less load capacity and may require a greater number of trips to complete its route. This would actually increase the kilometres travelled by the vehicle and the more likelihood of an incident occurring.

However, it is not just the dimensions of the truck that matters. For instance, the City of Hamilton uses different trucks (see Table 6 for a comparison of firefighting trucks in Toronto and Hamilton). Municipal truck drivers in Hamilton have been involved in excessive number of collisions with solid waste trucks and snow plows (Van Dongen, 2015). In 2015, the City of Hamilton placed dashboard cameras in all municipal trucks, hoping to lower collisions and convictions of municipal drivers for safety violations. At the time, Hamilton had a safety violation rate of 90%. At 100%, the Ministry of Transportation can suspend a trucking operator's registration (Van Dongen, 2015). A warning letter is sent out by the Ministry of Transportation when an operator’s safety violations reaches 35% (Ontario Ministry of Transportation, 2017). The City of Toronto, in contrast, had an overall rating of 33% in 2018 for all the trucks in its municipal fleet (City of Toronto, 2019a). The City has kept its rate low by implementing a behaviours-based approach to identify and address issues through design, configurations, operations, and training. For example, an automated side loader solid waste collection vehicle was redesigned to increase visibility in a cab-over instead of a conventional truck (Toronto, 2019).

Rather than simply the size of the truck, the driver’s visibility is a key factor. The driver’s visibility is affected by the height of the truck cab, the placement of mirrors and windows, and the lines of the truck (i.e., the design of the truck). Some trucks have significantly larger blind spots and visibility problem, making other road users more vulnerable.

There are also issues of familiarity and experience that need to be considered. The City of Toronto has tended to buy certain types of vehicles. For example, in firefighting, many of the Aerial Ladder Trucks are from Spartan and Ambulances from Crestline Coach. The City of Hamilton, by comparison, has many trucks from KME, but few that are Spartan. Maintenance and operation tend to be smoother when the same type of equipment is used (provided that it works properly and used for its intended purpose).

Safety Guards[41]

Collisions with trucks are dangerous. Their height means that vehicles, pedestrians, and cyclists can be pulled under the truck. Many Vision Zero cities are looking at requiring safety guards on their truck fleets, as well as with municipal contractors (Blocker, 2017).

Rear Guards

Rear impact guards, or rear underride guards, are designed to prevent vehicles from going under the rear of a truck when a rear collision occurs, as shown in Figure 14.

Figure 14: Rear Impact Guard[42]

Rear underride guards are required on every large commercial truck, as per the Transport Canada's Motor Vehicle Safety Regulations CMVSS No. 223 (Transport Canada, 2019). The CMVSS requirements for rear underride guards are more stringent than the Federal Motor Vehicle Standards from the United States (FMVSS) and NHTSA is considering adopting the Canadian standard (Safety Research Net, 2015). Testing under the current FMVSS standard showed that almost half of the passenger vehicles had underride damage during a rear collision (Brumbelow and Blanar, 2010). Rather than preventing underride, many of the underride guards actual buckled or bent during the test (Brumbelow and Blanar, 2010). Effectiveness of rear underride guards are dependent on the correct design and positioning of the guard (Mariolani, de Arruda et al., 1997).

[41] The terms "safety guard" and "bumper" may sometimes be used interchangeably, but they serve different purposes. A bumper is designed to protect the vehicle itself. A safety guard is intended to increase safety during a collision, either for the occupants of the vehicle or external to the vehicle.

[42] Photo from http://safedrivehome.com/nhtsa-proposes-new-rear-impact-guard-standards-for-safer-trailers-safer-roads-department-of-transportation/

On vehicles with lower rear profiles, such as Emergency Medical Service Vehicles and Rescue trucks, rear underride is not a problem as the bumper prevents underride. Instead, guards and bumpers are used to protect the vehicles themselves and to promote visibility for pedestrians and cyclists when proper highlighting is done. Figure 15 shows examples of these bumpers and guards.

Figure 15: Rear Bumpers and Guards

Rear Bumper[43]

Rear Bumper[44]

Rubber Bumper[45]

Front Guards

Currently, there are no requirements for front-end protectors or guards. There are various types of grills and bumpers available for trucks, as shown in Figure 16. These grills and guards are designed to protect the truck during collisions. They are not specifically designed to protect Vulnerable Road Users (Lambert and Rechnitzer, 2002).

Figure 16: Examples of Front Guards and Protections

Front Grill[46]

Metal Bumper[47]

[43] Photo from https://www.fireapparatusmagazine.com/articles/2015/04/ultraguard.html
[44] Photo from https://www.fixmyambulance.com/product-p/rear%20bumper.htm
[45] Photo from https://www.morgancorp.com/options/bumpers/
[46] Photo from https://www.rigguard.com/custom.php
[47] Photo from https://forums.firehouse.com/forum/emergency-vehicles-operation/the-engineer/107495-sireno-model-40010-the-answer-to-the-q-siren

Recently there has been some research into external protections for pedestrians and cyclists (Inhabitat, 2013). One such proposal is an external airbag (see Figure 17), which would act much as an internal airbag operates currently. However, this kind of external safety device is still in development and is not yet available commercially.

Figure 17: Examples of Proposed External Airbag

External Airbag[48]

Side Guards

Side impact collisions comprise a large portion of the collisions with trucks that are fatal for pedestrians and cyclists (Epstein, Breck et al., 2016). A significant number of side impacts are essentially sideways swipes, which occur when the truck is overtaking a pedestrian or cyclist (Langwieder and Danner, 1987). The injury occurs not from the speed or momentum of the truck, but rather from the individual falling under the vehicle and getting run over (Langwieder and Danner, 1987). Side impact guards (also called "lateral underrun protection" and "side underrun protection") are designed to keep pedestrians, cyclists, and other objects from getting pulled under the truck and getting run over by the truck's wheels during a side-impact collision (Epstein, Breck et al., 2016).[49] They cost between $1,000 to $4,000 per vehicle, depending on the truck configuration and the design of the side guard (see for example McIntosh, 2016; Montreal Gazette Editorial Board, 2016; Nesseth, 2016 for Canadian cost estimates).[50]

In 2014, the City of Boston passed an ordinance requiring that all municipal and city-contracted trucks over 10,000 pounds be equipped with side impact guards (City of Boston, 2017). San Francisco initiated a pilot study to determine the effectiveness of side guards. They worked

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[48] Photo from https://inhabitat.com/exterior-automobile-airbags-could-save-the-lives-of-pedestrians-and-bicyclists/

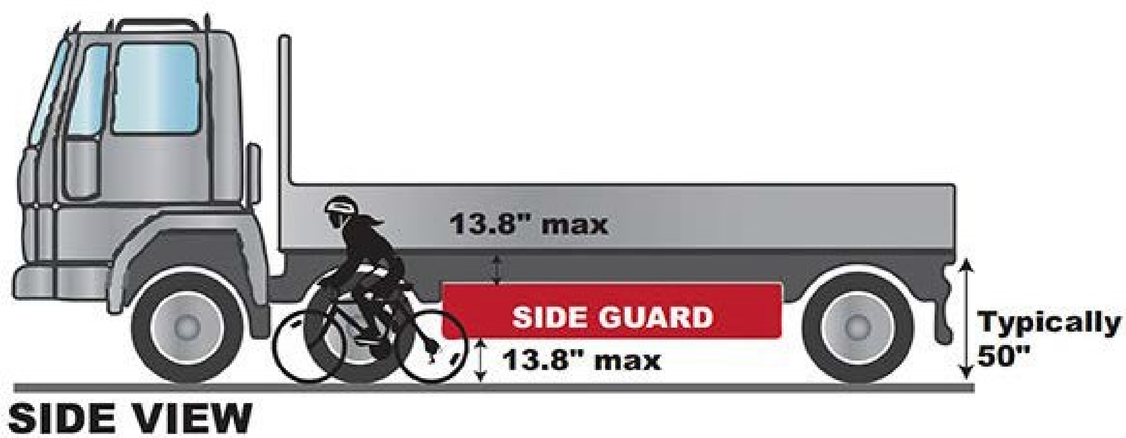
[49] Normally this would be the rear wheels, as the truck is presumed to be moving forward.

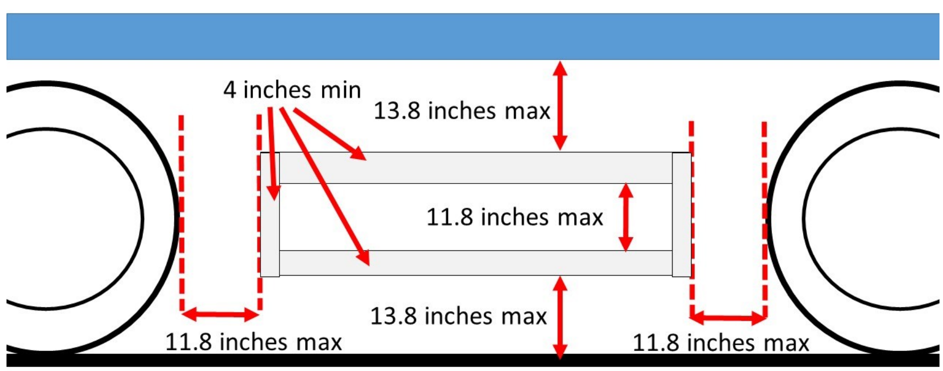
[50] The true cost is likely between the lower and higher estimates. The low estimate of $1000 was made in an article advocating for side guards. The higher estimate was made in an article explaining that the City of Halifax were not requiring them because of the cost and the fact that their effectiveness has not been proven.

with the Volpe Center at the U.S. Department of Transportation to determine the effectiveness of the guards and the best way to implement them (Vision Zero Network, 2016). The side guard requirement has also been adopted by Seattle, Portland, San Francisco, Fort Lauderdale, Orlando, Washington DC, Philadelphia, New York City, Chicago, Montreal, Halifax, and Mexico City (Volpe Center, 2019).

The United States Department of Transportation Volpe Center (Reports DOT-VNTSC-DCAS-14-01 and DOT-VNTSC-SFMTA-16-01) recommends that side guards be installed on commercial trucks. The guards should be a maximum of 13.8" off the ground and a maximum of 13.8" from the base of the truck bed (illustrated in Figure 18). Side guards should be no more than 11.8" from the tire (Volpe Center, 2019).

Figure 18: Side Guard Specifications[51]





[51] Images from http://sdotblog.seattle.gov/2017/02/01/guarding-safety/ and https://rosap.ntl.bts.gov/view/dot/12371

In 2014, the Boston Cyclist Union estimated that about half of the fatalities resulting from cyclist collisions with trucks could have been avoided if trucks had had side guards (Boston Cyclists Union, 2014). Langweider and Danner (1987) examined 110 collisions involving pedestrians. They concluded that side guards would reduce the likelihood of pedestrians falling under the wheels of a truck. The authors recommended that the side panels should be flat and cover the whole area between the cab and wheels. In another study (Riley, Penoyre et al., 1985), the authors looked at the effectiveness of truck side guards using a simulated cyclist collision. They found that incidents where a cyclist was run over could be significantly reduced by the presence of side guards. Bloch and Schmutzler (1998) investigated the effectiveness of side guards to prevent vehicle underrun. They found that properly designed side guards could reduce the damage resulting from vehicle underrun in a side collision.

The United Kingdom (UK) requires side impact guards and much of the evaluation of effectiveness comes from research done in the UK. Most studies and advocacy for side guards cite several British studies on the impact of sideguards. In a major research project looking at the effectiveness of side impact guards, the Transport Research Library (TRL) prepared a series of reports for the Department of Transport, UK Government. Examining the severity of collisions involving cyclists, the authors found that there was an 18.7% drop in the number of collisions between the early 1980s (1980-1982) and the early 1990s (1990-1992), after the sideguards had been mandated (Knight, Dodd et al., 2006). The studies were designed to investigate where eliminating the exemptions for sideguards would have a further benefit and provide greater safety for vulnerable road users. Knight and his colleagues found that there was a 5.7% reduction in cyclist fatalities and a 13.2% reduction in serious injuries. This was accompanied by a 6.3% increase in minor injuries, leading the researchers to conclude that there was support to the proposal that side guards did indeed reduce the severity of the injuries that occur for cyclists in these side swipe collisions, swapping fatalities and serious injuries for minor injury collisions (Knight, Dodd et al., 2006). The authors further found that when the side swipe collision occurred on the nearside, the benefits of sideguards were actually higher. In the early 1980s, there were 23 fatalities from this type of collision. In the period of 1990 to 1992, there were only 11, a reduction of 61%.[52] However, the number of serious injuries went up during this period (from 51 to 55), as did the minor injuries for cyclists. The proportion of serious injuries to the overall number of collisions did decline by 12.8% during this period, which allowed the authors to assert that the proportion of fatal and serious injuries declined from the early 1980s and the early 1990s. For pedestrians involved in side swipe

[52] These are the fatality reduction figures that are cited by advocates. However, the figures are often generalized to imply that all cyclist collisions with trucks were reduced by 61%, not just the specific side swipe collisions on the nearside of the truck.

collisions where the truck was moving straight ahead, there was a 20% reduction in fatalities, but no reduction in serious injuries. The authors also note that there is no corresponding reduction in fatalities and serious injuries from other types of collisions with trucks during this period (Knight, Dodd et al., 2006).

Side guards were primarily designed to be effective in preventing or mitigating a very specific types of collision: a side impact collision (Knight, Dodd et al., 2006; Epstein, Breck et al., 2016). Specifically, where the cyclist or pedestrian falls against or swipes the side of a passing truck while the truck is moving forward. In pedestrian collisions of this kind, there is a reduction in fatalities, but not in serious injuries (Knight, Dodd et al., 2006). Knight and his colleagues found much less evidence of the effectiveness of sideguards for other types of collisions. As the authors wrote in a later report:

> Previous accident data has shown that in general side-guards have been effective at preventing the type of accident for which they were designed. These accidents are those where an HGV overtakes a pedal cyclist or a pedestrian and they fall sideways into the side of the HGV between the front and rear axles. They were not designed to protect when a cyclist gets knocked to the ground by the cab of an HGV and then gets run over as the vehicle turns left. They cannot stop a person who is already lying on the ground from passing underneath. In general, they are not strong enough to stop a car from under-running the side the Lorry (Cookson and Knight, 2010, p. 34)

Side impact guards are a mitigating strategy, not an elimination one (Epstein, Breck et al., 2016). They do not prevent the collision from occurring, but they can help in reducing the likelihood of the collision being fatal.

There are different types of side guards (see Figure 19), which can affect the effectiveness and strength of the guard. In discussing the effectiveness and limitations of the current side guard designs, Cookson and Knight noted that a substantially stronger side guard might be able to protect car occupants and motorcycle riders during the side swipe collisions with trucks (Cookson and Knight, 2010)

Figure 19: Side Guard Examples

Side Guards[53]

Moveable Side Guard[54]

Side Guard[55]

From the studies done in Britain, it is clear that sideguards can effectively reduce fatalities for cyclists involved in side swipe collisions (Knight, Dodd et al., 2006; Cookson and Knight, 2010). It is less clear if side guards would help in pedestrian collisions or with other types of collisions (Cookson and Knight, 2010). However, a study done by Patten and Tabra for the National Research Council of Canada (2010) stated: "it is not clear if side guards will reduce deaths and serious injuries or if the guards will simply alter the mode of death and serious injury" (p. vi). Instead, "side guards will simply minimize the risk that VRUs will be dragged under the wheels of the vehicles" (p. 56). The authors also indicated that side guard design is an important issue. Some are designed for safety, but there are others which are actually intended to reduce aerodynamic drag, rather than to improve safety. While Patten and Tabra are not adverse to side guards (they actually acknowledge the studies in which their effectiveness has been shown), they do note that side guards by themselves will not eliminate the problems of serious injuries.

Looking at the data from the Toronto Police Service presented in Table 1 and Table 2, it is clear that collisions with trucks disproportionately result in fatalities for both pedestrians and cyclists. Given that side impact guards are generally only effective in collisions involving side swipes where both the vehicle and the VRUs are going straight, it is important to reflect on the data from Tables 3 and 4. Of the 331 pedestrian collisions resulting in a fatality or serious injury from an identifiable collision with a truck between 2007 and 2017, only 92 of the police reports indicated the direction or maneuvering of the truck, with 35 resulting in fatalities and 58 resulting in serious injuries. Four of these 35 fatal collisions (11.4%) involved the vehicle going forward. Of the 58 pedestrian collisions with trucks resulting in serious injuries, six of these collisions (10.3%) involved the vehicle going forward. For the 32 cyclist collisions resulting in a

[53] Photo from https://www.cbc.ca/news/canada/ottawa/ottawa-snow-plow-side-guard-1.4525594
[54] Photo from https://airflowdeflector.com/rail/
[55] Photo from http://bphc.org/onlinenewsroom/Blog/Lists/Posts/Post.aspx?ID=706

fatality or serious injury from an identifiable collision with a truck between 2007 and 2017, 30 of the police reports indicated the truck's direction or maneuvering; four resulted in fatalities and 26 resulted in serious injuries. Two of the four fatal collisions (50%) involved a side swipe where both the truck and cyclist were going forward. Knight et al., (2006) found that side guards led to a reduction of 61%. This would translate into a reduction of one of the cyclist fatalities between 2007 and 2017 in Toronto. For the 26 cyclist collisions with trucks resulting in serious injuries which reported the truck's direction or maneuvering, 13 of these collisions (50.0%) involved side swipes where both the truck and cyclist going forward. However, Knight et al., did not find a reduction in serious injuries for cyclists involved in truck collisions. They suggested that this was because potential fatalities were mitigated to serious injuries in these types of collisions. Pedestrians are much less likely to be involved in these types of collisions. Side swipes involving pedestrians occurred in 11.4% of fatalities and 10.3% of serious injuries. Knight et al., (2006) showed that side guards helped reduce 20% of the fatalities, but had no impact on serious injuries. For the 35 pedestrian fatalities between 2007 and 2017, this would mean a reduction of 0.8 fatalities.

Several potential adverse effects exist with the installation of side guards. The addition of side guards can negatively affect the weight and aerodynamics of the truck, making it less fuel efficient. Side guards may affect the brake cooling and break-over angle, increase the snow and mud collection, and reduce access to the underbody of the truck for inspections and maintenance (Galipeau-Bélair, 2014).

Conclusions

The purpose of this report was to investigate the types and availability of municipal service vehicles, particularly fire trucks, emergency services vehicles, solid waste vehicles, and snow plows, as well as to investigate the effectiveness of truck safety guards and physical barriers.

Vision Zero programs have been instituted in large cities throughout the world. As the goal of these programs are to improve transportation safety and to explicitly reduce the likelihood and effects of collisions, it is natural to look at the role that trucks have in these collisions. The results of this analysis support other findings that collisions involving trucks are more likely to result in fatalities and serious injuries among both pedestrians and cyclists.

As noted, there is significant variation in the types of vehicles used both within the City of Toronto and with other municipalities. The findings indicate that smaller trucks are generally safer for VRUs when collisions occur, but it is actually the visibility of the driver that is a primary concern. Smaller trucks tend to have greater driver visibility, in addition to less momentum and kinetic energy during operation. Visibility for truck drivers can be improved through engineering and design (including improving the design of vehicle mirrors and windows) and the adoption of cameras and sensors to assist the driver in seeing people and objects in traditional “blind spots”. Therefore, visibility should be a factor for consideration in the type of trucks used. For some applications, smaller capacity trucks would actually lead to an increased likelihood of collisions as the kilometres travelled needs to increase to complete tasks.

All trucks in Canada must have rear underride guards to prevent (or reduce) the damage caused in a rear-end collision with a passenger vehicle. There are no mandatory requirements for front and side guards currently. Front guards are generally designed to protect the vehicle. There is no indication that front guards are considered beneficial for reducing collisions with VRUs or the impact of these collisions.

There has been building momentum for the use of side impact guards in recent years as many cities are requiring them to support greater safety for VRUs. Studies have shown that these side impact guards can be effective in reducing the likelihood of fatalities and serious injuries in side swipe collisions between cyclists and trucks, where the cyclist and truck are moving in the same direction. An expected 2 of the 4 fatalities and 14 of the serious injuries for cyclists between 2007 and 2017 could have been avoided or reduced. The effectiveness of side guards for collisions with pedestrians is less, with an approximately 20% reduction in the likelihood of a fatality in the 11.4% of pedestrian collisions in which the truck and pedestrian are moving in the same direction. Between 2007 and 2017, there were 93 pedestrian collisions with trucks, resulting in 35 fatalities. Based on the studies, 0.8 fatalities could have been avoided during this period with the installation of side guards. Based on the research conducted for this report, there is evidence that installing well-designed side guards to all trucks would be expected to result in fewer fatalities and serious injuries among pedestrians and cyclists in certain types of collisions.

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Appendix A: Selected Manufacturers

Fire Truck Manufacturers

Fire Truck Manufacturers	Location
1st Attack Engineering, Inc.	Indiana
4 Guys Stainless Tank and Equipment	Pennsylvania
Alexis Fire Equipment	Illinois
Amtech Emergency Product Co.	Iowa
Battleshield	Ontario
Blanchat Manufacturing	Kansa
Bluegrass Fire Apparatus	Kentucky
Boise Mobil Equipment, Inc.	Idaho
Custom Fab & Body LLC	Wisconsin
Custom Fire Apparatus, Inc	Wisconsin
Danko Emergency Equipment	Nebraska
Deep South Fire Trucks, Inc.	Mississippi
Dependable	Ontario
E-ONE	Florida
Emergency Vehicles, Inc. (EVI)	Florida
Ferrara Fire Apparatus	Louisiana
Firetrucks Unlimited	Nevada
Fort Garry Fire Trucks Ltd.	Manitoba
Fouts Bros. Fire Equipment	Georgia
Freedom Fire Equipment	Georgia
Green Acres	Manitoba
Hackney Emergency Vehicles	North Carolina
HMA Fire	Wisconsin
HME Ahrens – Fox	Michigan
Hub Fire Engines	British Columbia
Keystone Fire Apparatus, Inc.	Pennsylvania
KME Fire Apparatus	Pennsylvania
Marion Body Works, Inc.	Wisconsin
Metalfab Fire Trucks	New Brunswick
Midwest Fire Trucks	Minnesota
Monroe Truck Equipment	Wisconsin
Neel Fire Protection Apparatus, Inc.	Texas
Pierce Mfg.	Wisconsin
Precision Fire Apparatus	Missouri
Rosenbauer International	Wyoming
Seagrave Fire Apparatus, Inc.	Wisconsin
Smeal Fire Apparatus	Nebraska
Spartan Motors	Michigan

S & S Fire Equipment	Indiana
Southern Fire Apparatus	Georgia
Spartan ERV	SD
Spencer Manufacturing	Michigan
Summit Fire Apparatus	Kentucky
Sutphen Corporation	Ohio
SVI Trucks	Colorado
Toyne, Inc.	Iowa
U.S. Tanker Fire Apparatus	Wisconsin
Welch Fire Equipment	Wisconsin
West-Mark Fire Apparatus	California
W.S. Darley $ Co.	Illinois
Wynn Fire Equipment	Kentucky

Ambulance Manufacturers

Ambulance Manufacturers	Location
American Emergency Vehicles – AEV	North Carolina
Braun Industries, Inc.	Ohio
Crestline Coach, Ltd.	Saskatchewan
Demers Ambulances	Quebec
Excellance, Inc.	Alabama
Frazer, Ltd.	Texas
Global Emergency Vehicles	Pennsylvania
Horton Emergency Vehicles	Ohio
Leader Industries	California
Life Line Emergency Vehicles	Louisiana
Marque Inc.	Indiana
McCoy Miller Corporation	MA
Medix Specialty Vehicles, Inc.	Indiana
Miller Coach Company	Missouri
Odyssey Emergency Vehicles	New Jersey
Osage Ambulances	Missouri
PL Custom Emergency Vehicles	New Jersey
Road Rescue, Inc.	Minnesota
Taylor Made Ambulances	Arkansas
Wheeled Coach Industries	Florida

Municipal Solid Waste Truck Manufacturers

Municipal Solid Waste Truck Manufacturer	Location
Autocar	Indiana
Bridgeport Manufacturing	Texas
Dadee Manufacturing	Arizona
Durabac	Quebec
El Industries International Inc.	Florida
EZ Pack	Kentucky
F.F. Gomez	California
Freightliner	
Haul-All Equipment Systems	Alberta
Heil Environmental	Tennessee
Kann Manufacturing Corp.	Iowa
LaBrie Enviroquip Group	Quebec
LoadMaster	Michigan
Mack Trucks	
McNeilus	Minnesota
NewWay Refuse Trucks	Canada
Pak-Mor Ltd.	Texas
Scranton Manufacturing	Iowa
Universal Group	Ontario
Waste Management of Canada Corporation	Ontario
Wayne Engineering	Iowa

Winter Road Maintenance Equipment Manufacturers

Winter Road Maintenance Equipment Manufacturers	Location
Boss Snow Plow	Michigan
Buyers	Ohio
Commercial Truck Equipment	Ontario
Falls	Minnesota
Goodwin Manufacturing	North Carolina
Henderson	Iowa
Heil Environmental	Tennessee
Henke Manufacturing	Kansas
Hi -Way	Iowa
Kenworth	Washington
Tenco	Ontario
Torwell	Massachusettts
Truck Equipment Inc.	Wisconsin
Truck Equipment Network	New York
Universal Truck Equipment	Wisconsin

Appendix B: Fire Trucks in Hamilton

A Comparison of the composition of the fleet for the City of Hamilton was presented as a comparison in Table 6. Below is an example of the specification and size differences for two fire trucks used in Hamilton.

Examples of Pumpers and Rescue Truck used in the City of Hamilton

	Aerial Ladder[56]	Pumper[57]
Picture		
Cab/Chassis	Severe Service LFD	Severe Service LFD
Manufacturer	KME	KME

[56] https://i.pinimg.com/originals/1b/e8/e9/1be8e9bd8bcddd403a7e8f2cbdf66dbb.jpg

[57] https://c1.staticflickr.com/2/1825/41943018495_61fa48f55f_b.jpg; http://www.kmefire.com/landing-pages/calendar/2017/may

Appendix C: Author's Biography

Dr. Beth-Anne Schuelke-Leech is an Assistant Professor of Engineering Management and Entrepreneurship at the University of Windsor in Canada. Professor Schuelke-Leech earned an undergraduate degree in Mechanical Engineering from McMaster University, a Masters of Business Administration from York University, and a PhD in Public Policy at the University of Georgia. Before undertaking her doctoral studies, she worked for 12 years as a professional engineer, primarily in product development for General Motors of Canada in Oshawa, Ontario.

Dr. Schuelke-Leech's research sits at the nexus of technological innovation, engineering, business, and public policy. Her work focuses on the innovation process, technological entrepreneurship, and sustainability within engineering systems. She is the Secretary of the IEEE Society for the Social Implications of Technologies Standards Committee (IEEE SSIT SC). She is also a liaison from the IEEE and the Standards Council of Canada to the International Standards Organization (ISO) JTC1/SC42 on Artificial Intelligence, where they are looking to create international standards on the development, application, and use of AI and autonomous systems.

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