ROADWAY SAFETY BENCHMARKS OVER TIME

TP 14328 E

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16. Abstract

This study identifies the most effective road engineering improvements that have been introduced in the past 40 years in Canada and the United States. It also contains research on the road safety benefits that have been achieved due to better road engineering, specifically improved road design and traffic operations. It is hoped that the study findings will help raise awareness about the important role that better road engineering has in reducing collision frequency, rate, and severity.

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15. Remarques

16. Résumé

La présente étude répertorie les améliorations d'ingénierie de la sécurité routière qui, au cours des 40 dernières années, se sont révélées les plus efficaces à prévenir les collisions sur les réseaux routiers canadien et américain. De plus, elle fait état des recherches relatives aux « gains » réalisés dans le domaine de la sécurité routière grâce à la mise en oeuvre d'améliorations d'ingénierie, en particulier celles qui ont trait à la conception du réseau routier et à la gestion de la circulation. Il est espéré que les conclusions tirées de l'étude contribueront à mieux faire connaître les liens entre un réseau routier bien conçu et le nombre, la fréquence (taux) et la gravité des collisions.

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EXECUTIVE SUMMARY

Improving road safety requires a combination of enforcement, education, and engineering initiatives. It has been well recognized that legislative and enforcement initiatives, such as seat-belt laws and impaired driving enforcement, have reduced the number of crashes on Canada's roads. Similarly, new passive in-vehicle safety systems, such as air bags and daytime running lights, have also helped to reduce collision frequency and severity.

This study identifies the most effective road engineering improvements that have been introduced in the past 40 years in Canada and the United States. It also contains research on the road safety benefits that have been achieved due to better road engineering, specifically improved road design and traffic operations. The study was jointly conducted by Hamilton Associates of Vancouver and Montufar & Associates of Winnipeg.

After an initial review of the literature, a "master list" of 41 engineering countermeasures was selected for further review. These improvements were gradually introduced in Canada from the early 1960s through to the late 1990s. A survey was then prepared and distributed to 63 experts in road safety engineering, mostly in Canada but also including the United States. The experts were asked to rate the effectiveness of each countermeasure, in terms of reducing collision frequency and severity. 26 responses were received, and the ranked list of countermeasures is shown in TABLE ES-1. The maximum point score that any one countermeasure could receive was 78 points.

The top 14 ranked countermeasures were carried forward for further analysis, plus "Roundabouts" and "Rumble Strips", to represent recent safety countermeasures from the 1990s.

TABLE ES-1 RANKED LIST OF ENGINEERING COUNTERMEASURES

	COUNTERMEASURE	POINTS	DATE		COUNTERMEASURE	POINTS	DATE
1	Divided Highways	67	mid 1960s	22	All-Red Signal Phases	35	mid 1970s
2	Intersection Channelization (left-and right-turn lanes)	58	late 1960s	22	Highly-Reflecting Pavement Markings	35	mid 1980s
3	Clear Zone Widening	55	mid 1970s	24	Highly-Reflective Signs	34	mid 1980s
4	Breakaway Devices (for luminairs, sign bases)	53	late 1970s	24	Super-elevation Improvements	34	early 1970s
4	Energy-Absorbing Barrier End Treatments	53	early 1980s	26	High Friction / Open Textured Pavement	33	mid 1980s
6	Protected Left-turn Phases	51	late 1970s	26	Travel Lanes Widening	33	early 1970s
6	Rail Crossing Warning Devices (gates, signals)	51	late 1960s	28	Shoulders Widening	32	mid 1970s
8	Access Management	50	late 1970s	29	Prohibiting Parking Along Arterials	31	mid 1960s
8	Rigid Barriers (median and roadside)	50	mid 1970s	30	Longer Taper Lengths	29	late 1970s
10	Intersection Angle Limits (to 70 ^{o} or better)	48	mid 1960s	31	Advance Warning Flashers	27	mid 1980s
11	Horizontal Curve Flattening	43	mid 1970s	31	Signal Progression along Corridors	27	late 1960s
12	Passing Lanes (along two-lane highways)	42	mid 1970s	31	Truck Escape Roads or Ramps	27	late 1970s
12	Positive Guidance	42	mid 1980s	34	Pavement Turn-Guidance Markings	24	late 1970s
14	Street Lighting	41	mid 1970s	35	Overhead Flashing Beacons	22	mid 1970s
15	Decision Sight Distance	40	mid 1970s	35	Traffic Calming	22	late 1980s
15	Roundabouts	40	late 1990s	37	Larger Traffic Signs	20	early 1990s
15	Two-way Left-turn Lanes	40	mid 1970s	37	Rest Areas	20	mid 1970s
18	Climbing Lanes (along mountainous highways)	39	mid 1970s	37	Travel Demand Management	20	mid 1980s
18	Rumble strips (edge-line or centre-line)	39	mid 1990s	40	Intelligent Transportation Systems	19	late 1990s
18	Signal Display Conspicuity	39	mid 1980s	41	Larger Street Name Signs	17	late 1980s
21	Vulnerable Road User Accommodation (s/walks, etc.)	36	late 1980s				

Notes: "Points" are the priority points as determined by the survey; "Date" is the universal date of acceptance as determined from the survey.

Detailed research was conducted on the quantifiable benefits that have been demonstrated for each countermeasure, in terms of reductions in crash frequency, rate, and severity. An estimate was then prepared, at the “order of magnitude” level of accuracy due to a lack of relevant literature, of the crash reduction benefits that have been achieved by road safety engineering countermeasures in Canada. It is estimated that approximately 11,000 lives were saved and approximately 500,000 injuries were prevented in Canada between 1979 and 2000, due to road engineering improvements.

RÉSUMÉ

L'amélioration de la sécurité routière nécessite la mise en œuvre d'un ensemble d'initiatives qui misent sur le respect de la loi, la sensibilisation et les améliorations d'ingénierie. C'est un fait bien connu que les initiatives législatives et policières (notamment celles liées au port de la ceinture de sécurité et à la prévention de la conduite en état d'ébriété) ont contribué à réduire le nombre d'accidents sur les routes canadiennes. De même, les nouveaux dispositifs de sécurité passifs présents à bord des véhicules, tels que les coussins de sécurité gonflables et les feux de jour, ont également aidé à diminuer la fréquence et la gravité des collisions.

La présente étude répertorie les améliorations d'ingénierie de la sécurité routière qui, au cours des 40 dernières années, se sont révélées les plus efficaces à prévenir les accidents sur les réseaux routiers canadien et américain. De plus, elle fait état des recherches relatives aux « gains » réalisés dans le domaine de la sécurité routière grâce à la mise en œuvre d'améliorations d'ingénierie, en particulier celles qui ont trait à la conception du réseau routier et à la gestion de la circulation. La société Hamilton Associates de Vancouver a réalisé la présente étude en collaboration avec l'entreprise Montufar & Associates de Winnipeg.

Après une première évaluation de la documentation, nous avons dressé une « liste maîtresse » de 41 mesures préventives d'ingénierie dans le but de les étudier de façon plus approfondie. Ces améliorations ont fait l'objet d'une mise en œuvre graduelle sur le réseau routier canadien du début des années 60 jusqu'à la fin des années 90. On a par la suite élaboré un questionnaire que l'on a fait parvenir à 63 experts en ingénierie de la sécurité routière; l'échantillon regroupait surtout des experts canadiens mais également des experts américains. Les répondants devaient évaluer l'efficacité de chacune des mesures préventives à réduire la fréquence et la gravité des collisions. Au total, 26 répondants nous ont expédié leur questionnaire dûment rempli. On trouvera au TABLEAU ES-1 la liste des mesures préventives classées par ordre de priorité (nota : chacune des mesures ne pouvait récolter plus de 78 points).

TABLEAU ES-1 CLASSEMENT DES MESURES PRÉVENTIVES D'INGÉNIERIE

	MESURE PRÉVENTIVE	POINTS	DATE		MESURE PRÉVENTIVE	POINTS	DATE
1	Autoroutes à chaussées séparées	67	Milieu 1960	22	Phases feu rouge	35	Milieu 1970
2	Canalisation des intersections (voies pour tourner à gauche / à droite)	58	Fin 1960	22	Marquage au sol hautement réfléchissant	35	Milieu 1980
3	Élargissement des aires de sécurité	55	Milieu 1970	24	Panneaux de signalisation hautement réfléchissant	34	Milieu 1980
4	Dispositifs de bases cédant sous l'impact (pour les luminaires, bases des panneaux	53	Fin 1970	24	Améliorations des dévers	34	Début 1970
4	Systèmes d'absorption d'énergie d'extrémités des glissières de sécurité	53	Début 1980	26	Chaussées à friction élevée / à enrobé ouvert	33	Milieu 1980
6	Phases protégées pour tourner à gauche	51	Fin 1970	26	Élargissement des voies de circulation	33	Début 1970
6	Dispositifs d'avertissement aux passages à niveaux (barrières, signaux)	51	Fin 1960	28	Élargissement des talus	32	Milieu 1970
8	Gestion d'accès	50	Fin 1970	29	Interdiction de stationner le long des artères	31	Milieu 1960
8	Glissières de sécurité rigides (médianes et en bordure de route)	50	Milieu 1970	30	Voies de rétrécissement plus longues	29	Fin 1970
10	Limites des angles d'intersection (jusqu'à 70° ou plus)	48	Milieu 1960	31	Signalisation clignotante avancée	27	Milieu 1980
11	Augmentation du rayon des courbes horizontales	43	Milieu 1970	31	Signalisation progressive le long des routes	27	Fin 1960
12	Voies de dépassement (le long des autoroutes à deux voies)	42	Milieu 1970	31	Routes ou rampes de dégagements pour camions	27	Fin 1970
12	Guidage positif	42	Milieu 1980	34	Marquage au sol pour tourner	24	Fin 1970
14	Éclairage des rues	41	Milieu 1970	35	Feux clignotants aériens	22	Milieu 1970
15	Distances de réaction	40	Milieu 1970	35	Apaisement de la circulation	22	Fin 1980
15	Carrefours giratoires	40	Fin 1990	37	Panneaux de signalisation plus larges	20	Début 1990
15	Voies de dégagement à gauche dans les deux sens	40	Milieu 1970	37	Aires de repos	20	Milieu 1970
18	Voies pour véhicules lents (le long des autoroutes en montagne)	39	Milieu 1970	37	Gestion de la demande de circulation	20	Milieu 1980
18	Bandes rugueuses (bandes médianes ou latérales)	39	Milieu 1990	40	Systèmes de transport intelligents	19	Fin 1990
18	Mise en évidence des panneaux de signalisation	39	Milieu 1980	41	Panneaux de noms de rue plus larges	17	Fin 1980
21	Aménagements pour les usagers de la route vulnérables (p. ex. les trottoirs)	36	Fin 1980				

Nota : Les « points » représentent les points du classement comptabilisés dans le cadre de l'enquête; la « date » renvoie à la date universelle d'acceptation déterminée dans le cadre de l'enquête

Puis on a dressé la liste des 14 mesures qui ont reçu le pointage le plus élevé et qui feront ultérieurement l'objet d'une analyse plus approfondie (afin de représenter les mesures préventives plus récentes des années 90, on a ajouté à cette liste les mesures « ronds-points » et « ralentisseurs sonores »).

On a fait un dépouillement exhaustif de la documentation pour dégager les « gains » quantifiables et attestés aux chapitres de la réduction de la fréquence, du taux et de la gravité des collisions qui découlent de la prise de chacune des mesures préventives d'ingénierie. On a ensuite donné une estimation (d'une exactitude limitée en raison de l'insuffisance des données pertinentes citées dans la documentation) de l'efficacité de ces mesures à réduire le nombre de collisions sur les routes canadiennes. En effet, on estime, qu'entre 1979 et l'an 2000, de telles améliorations ont permis de sauver environ 11 000 vies et de prévenir 500 000 blessures corporelles au Canada.

1.0 INTRODUCTION

1.1 Background and Study Objectives

The objectives of this study are to identify the 10 to 15 most important road-related safety countermeasures that have been introduced in Canada since the mid 1960s; and estimate their safety benefits over time. It is hoped that the study findings will help to raise awareness about the important role that better road engineering has in reducing crash frequency, rate, and severity.

In general, the fatality rate in Canada per 10,000 motor vehicle registrations is on a long-term decreasing trend. This is due to a variety of factors, including better vehicle design, better legislation related to occupant restraints and impairment, and better road design.

Most road engineering safety countermeasures occur as a result of design process evolution, combined with engineering knowledge and experience. The introduction of road safety engineering countermeasures is a gradual process that is rarely accompanied by legislative or regulatory changes.

This study identifies the most important road safety engineering advancements that have helped reduce the crash risk over the past 40 years, to highlight the contribution of road engineering safety improvement to improved safety in Canada.

1.2 Study Methodology

Literature Review and Preliminary Master List of Safety Improvements. A literature review was conducted to determine the key road safety engineering countermeasures that have demonstrated safety benefits over the past 40 years. A preliminary master list of road safety engineering countermeasures was then developed from the results of the literature review.

Expert Consultation and Progress Report. The expert consultation consisted of a survey of specialists with knowledge and experience in road safety engineering from across Canada and the United States. The objectives of the survey were to determine the short list of road safety engineering countermeasures that have been most effective over the past 40 years in improving road safety.

Safety Benefit Analysis. The safety benefit analysis research provided a focused literature review to obtain a comprehensive understanding about the safety effectiveness of the selected engineering countermeasures.

2.0 EXPERT CONSULTATION

2.1 Master List of Engineering Road Safety Improvements

A comprehensive literature review was conducted to identify major road safety countermeasures which have been introduced in Canada since the 1960s. A preliminary master list of road engineering and traffic operational safety improvements that could warrant further research and investigation was prepared. The master list is shown in TABLE 2.1, with the 41 countermeasures listed in alphabetical order.

TABLE 2.1 MASTER LIST OF ENGINEERING ROAD IMPROVEMENTS

COUNTERMEASURE		COUNTERMEASURE	
1	Access Management	22	Pavement Turn-Guidance Markings
2	Advance Warning Flashers	23	Positive Guidance
3	All-Red Signal Phases	24	Prohibiting Parking Along Arterials
4	Breakaway Devices (for luminairs, sign bases)	25	Protected Left-turn Phases
5	Clear Zone Widening	26	Rail Crossing Warning Devices (gates, signals)
6	Climbing Lanes (along mountainous highways)	27	Rest Areas
7	Decision Sight Distance	28	Rigid Barriers (median and roadside)
8	Divided Highways	29	Roundabouts
9	Energy-Absorbing Barrier End Treatments	30	Rumble strips (edge-line or centre-line)
10	High Friction / Open Textured Pavement	31	Shoulders Widening
11	Highly-Reflecting Pavement Markings	32	Signal Display Conspicuity
12	Highly-Reflective Signs	33	Signal Progression along Corridors
13	Horizontal Curve Flattening	34	Street Lighting
14	Intelligent Transportation Systems	35	Super-elevation Improvements
15	Intersection Angle Limits (to 70^o or better)	36	Traffic Calming
16	Intersection Channelization (left-and right-turn lanes)	37	Travel Demand Management
17	Larger Street Name Signs	38	Travel Lanes Widening
18	Larger Traffic Signs	39	Truck Escape Roads or Ramps
19	Longer Taper Lengths	40	Two-way Left-turn Lanes
20	Overhead Flashing Beacons	41	Vulnerable Road User Accommodation (s/walks, etc.)
21	Passing Lanes (along two-lane highways)		

2.2 Survey Description

A sample survey form and the accompanying covering letter are included in APPENDIX A. The survey was sent to 63 experts in the field of road safety engineering. The experts were asked to rank the effectiveness of each of the engineering countermeasures on the master list in terms of reducing crash frequency and/or crash severity. The survey form provided space for the experts to write-in and rank additional countermeasures. The available rankings were:

- Very high effectiveness;
- High effectiveness;
- Moderate effectiveness; or,
- Low effectiveness.

In selecting the effectiveness of each countermeasure, the experts were asked to rely on their own knowledge and experience. For the countermeasures that they ranked as “very high” or “high”, the experts were asked to provide a date of “universal acceptance”, again by relying on their own experience. The experts were asked to provide the dates as a range, for example “early 1960s”, “mid 1970s” or “late 1980s”.

2.3 Profile of the Experts

The experts represented all levels of government from across the country, as well as the private sector and academia. The focus of the survey was on Canadian experts, but several noted United States experts were also included. The profile of the experts included in the survey was as follows:

- 5 Federal Government Representatives
- 12 Provincial Government Representatives
- 10 Municipal Government Representatives
- 9 academics
- 10 consultants
- 5 retirees
- 12 from the United States

The survey was distributed by e-mail, with a two week response window. A reminder e-mail was sent about four days prior to the deadline. Several experts were also verbally encouraged to respond as the deadline approached.

2.4 Survey Results

Responses to the survey were received from 26 of the experts, representing a 41 percent response rate, and are listed in APPENDIX B. Responses came from all of the categories listed in the "Profile" above, and from all geographic regions of Canada.

Ranking the Countermeasures

The results were tabulated on an Excel spreadsheet. From each response, each road safety engineering countermeasure was allocated priority points according to the ranking that it received:

- 3 points for a "very high" ranking";
- 2 points for a "high" ranking";
- 1 point for a "moderate" ranking; and
- 0 points for a "low" ranking or no ranking.

The priority points for each countermeasure were then added from all the responses. The maximum points that one countermeasure could receive were therefore 78 (3 points from each of 26 surveys). The ranked list of countermeasures is shown in TABLE 2.2.

TABLE 2.2 SUMMARY OF SURVEY RESULTS

	COUNTERMEASURE	POINTS	DATE		COUNTERMEASURE	POINTS	DATE
1	Divided Highways	67	mid 1960s	22	All-Red Signal Phases	35	mid 1970s
2	Intersection Channelization (left-and right-turn lanes)	58	late 1960s	22	Highly-Reflecting Pavement Markings	35	mid 1980s
3	Clear Zone Widening	55	mid 1970s	24	Highly-Reflective Signs	34	mid 1980s
4	Breakaway Devices (for luminairs, sign bases)	53	late 1970s	24	Super-elevation Improvements	34	early 1970s
4	Energy-Absorbing Barrier End Treatments	53	early 1980s	26	High Friction / Open Textured Pavement	33	mid 1980s
6	Protected Left-turn Phases	51	late 1970s	26	Travel Lanes Widening	33	early 1970s
6	Rail Crossing Warning Devices (gates, signals)	51	late 1960s	28	Shoulders Widening	32	mid 1970s
8	Access Management	50	late 1970s	29	Prohibiting Parking Along Arterials	31	mid 1960s
8	Rigid Barriers (median and roadside)	50	mid 1970s	30	Longer Taper Lengths	29	late 1970s
10	Intersection Angle Limits (to 70 ^{o} or better)	48	mid 1960s	31	Advance Warning Flashers	27	mid 1980s
11	Horizontal Curve Flattening	43	mid 1970s	31	Signal Progression along Corridors	27	late 1960s
12	Passing Lanes (along two-lane highways)	42	mid 1970s	31	Truck Escape Roads or Ramps	27	late 1970s
12	Positive Guidance	42	mid 1980s	34	Pavement Turn-Guidance Markings	24	late 1970s
14	Street Lighting	41	mid 1970s	35	Overhead Flashing Beacons	22	mid 1970s
15	Decision Sight Distance	40	mid 1970s	35	Traffic Calming	22	late 1980s
15	Roundabouts	40	late 1990s	37	Larger Traffic Signs	20	early 1990s
15	Two-way Left-turn Lanes	40	mid 1970s	37	Rest Areas	20	mid 1970s
18	Climbing Lanes (along mountainous highways)	39	mid 1970s	37	Travel Demand Management	20	mid 1980s
18	Rumble strips (edge-line or centre-line)	39	mid 1990s	40	Intelligent Transportation Systems	19	late 1990s
18	Signal Display Conspicuity	39	mid 1980s	41	Larger Street Name Signs	17	late 1980s
21	Vulnerable Road User Accommodation (s/walks, etc.)	36	late 1980s				

Notes: "Points" are the priority points as determined by the survey; "Date" is the universal date of acceptance as determined from the survey.

Only one “write-in” countermeasure was mentioned by more than one expert, namely “Grade Separation”. This was written-in by three experts and received 8 points. Grade separation was widely introduced with the construction of the United States Interstate system starting in the 1950s, prior to the 40 year period that is the main focus of this study. Grade separation is most often a capacity and operational improvement, rather than a safety improvement. Ogden (1996) states that “grade separating an existing at-grade intersection may be justified more on capacity than on safety grounds”.

Ogden also reports on a Swedish study demonstrating a 50 percent reduction in crashes when intersections were grade separated. However, the safety impacts of grade separation are highly dependent on the type of grade separation. For example, an at-grade intersection may be replaced by a diamond interchange that introduces two signalized intersections and provides full access movements, or by a fly-over that provides no new intersections and no access movements. The two concepts are likely to yield dramatically different safety impacts. “Grade Separation” was not considered further in this study.

Date of Universal Acceptance

The date of universal acceptance as determined from the survey is an approximate measure based on the personal knowledge and experience of the experts who responded. It is intended to provide an indication of when the countermeasure became commonly accepted and implemented.

The experts were only asked to provide a date of universal acceptance for the countermeasures that they ranked as "very high" or "high" in terms of effectiveness. Many survey respondents either provided no dates whatsoever, or also provided dates for countermeasures that they ranked as "low" or "moderate" in effectiveness. A variable number of responses was therefore received for each countermeasure. For each countermeasure, one year of "universal acceptance" was determined by calculating the weighted average of the dates indicated by the experts who responded (see Example). The date of universal acceptance for each countermeasure is shown in TABLE 2.2.

2.5 Selected Countermeasures

The top 14 countermeasures that emerged from the survey of experts were selected as the most important road engineering safety countermeasures to be carried forward to the next study task.

Example for Determining the Universal Date of Acceptance:

To calculate the weighted average, the following simplifications were used:

- *The 19x2 year represented the "early" period of the decade;*
- *The 19x5 year represented the "mid" period of the decade;*
- *The 19x8 year represented the "late" period of the decade.*

For example, for Countermeasure A, the universal acceptance dates indicated in the survey responses were as follows:

- *Mid 1960s: three responses*
- *Late 1960s: two responses*
- *Early 1970s: three responses*
- *Late 1970s: one response*

The weighted year was calculated as follows:

$$\text{Weighted Year} = \frac{(3 \times 1965 + 2 \times 1968 + 3 \times 1972 + 1 \times 1978)}{(3+2+3+1)}$$

The answer in this example is 1969, and the "late 1960s" is the date of universal acceptance according to the survey for Countermeasure A.

It was noted that the top 14 countermeasures were widely accepted between the 1960s and 1980s. The surveyed experts generally provided relatively lower rankings for the newer countermeasures (since the early 1990s), compared to older "tried and tested" improvements. To demonstrate the safety benefit of newer emerging engineering countermeasures, "Roundabouts" (ranked 15) and "Rumble Strips" (ranked 18) were added to the list of countermeasures carried forward in the study. The full list of the most important engineering countermeasures is therefore as follows:

1. Divided Highways
2. Intersection Channelization
3. Clear Zone Widening
4. Breakaway Devices
5. Energy – Absorbing Barrier End Treatments
6. Protected Left-Turn Phases
7. Rail Crossing Warning Devices
8. Access Management
9. Rigid Barriers
10. Intersection Angle Limits
11. Horizontal Curve Flattening
12. Passing Lanes
13. Positive Guidance
14. Street Lighting
15. Roundabouts
16. Rumble Strips

3.0 QUANTIFICATION OF SAFETY BENEFITS

This section quantifies the safety benefits of the 16 road engineering countermeasures selected for investigation. The safety benefits were derived from a focused literature review about each of these countermeasures. Textbooks, reports, published papers, conference compendia, and information on the Internet was used to quantify the safety benefits of the road engineering countermeasures.

The Information System for the Prediction of Accident Reductions (ISPAR) and the Information System for Estimating Collision Reductions (ISECR) were also queried for this purpose. Both these databases include summaries of published literature on the safety benefits of road engineering countermeasures.

APPENDIX C - Bibliography lists the references that were consulted to compile this information.

3.1 Divided Highways

These are highways where opposing traffic lanes are separated by grass or a raised median strip, or a barrier. The construction of the United States Interstate system in the 1950s, 1960s and 1970s introduced the widespread application of divided highways. By the mid 1960s, it was recognized that despite their higher operating speeds, divided highways (both freeways and highways) represented the safest form of roadway, particularly in rural contexts. The literature describes the advantages of divided highways versus undivided highways in terms of improved safety.

- BTS (2002) produces collision rates by roadway type as part of the annual publication on national transportation statistics. This publication shows that in 2000, the fatality rate for rural interstates (these are all divided highways) was 1.19 fatalities per 100 million vehicle miles. For other rural arterials (most of these are undivided highways), the rate was 2.12 fatalities per 100 million vehicle miles.

- Montufar (2002) conducted a study of heavy truck collisions in the Canadian prairie region. The study considered all reported heavy truck collisions between 1993 and 1998 on provincial highways and in urban areas. From the rate analysis, the research found that the heavy truck collision rate on undivided provincial highways in the region is about 12 percent higher than on divided highways.

- Huang et al. (2001) conducted a study of fatal and injury collisions in North Carolina between 1993 and 1997. One of the findings was that in rural settings, multilane undivided (non-freeway) highways have a collision rate 68 percent higher than multilane divided (non-freeway) highways.

- Using information from California, Michigan, North Carolina, and Washington, Council and Stewart (1999) found that conversions from two-lane undivided to four-lane divided highways result in significant safety benefits. Going from a typical two-lane undivided road to a typical four-lane divided road results in an collision per kilometer reduction of between 40 and 60 percent.

- Liu and Leeming (1996) conducted an extensive study in the United Kingdom about the statistical variations in heavy truck collision rates involving combinations of road and traffic characteristics. They found that in general, the injury heavy truck collision rate on undivided roads is two times that on divided roads.

Summary: Divided highways are significantly safer than undivided highways. The benefits of divided highways are emphasized in rural areas. Collision rate reductions of up to 60 percent can be expected when converting undivided roads into divided roads.

3.2 Intersection Channelization

Channelization is defined as "...the separation or regulation of conflicting traffic movements into definite paths of travel by traffic islands or pavement marking to facilitate the safe and orderly movements of both vehicles and pedestrians" (AASHTO, 1990). With increasing congestion, the provision of improved intersection channelization in the form of exclusive left-turn and right-turn lanes became common in the late 1960s.

In addition to improving intersection efficiency, channelization improves safety in both urban and rural settings. According to the literature, channelization (depending on whether it is left-turn or right-turn) can have significant safety benefits:

- Harwood et al. (2002) conducted a before-after evaluation of the safety effects of providing left and right turn lanes for at-grade intersections. They found that added left turn lanes are expected to reduce total intersection collisions at rural unsignalized intersections by 28 percent (for four-leg intersections) and by 44 percent (for three-leg intersections). In urban areas, at unsignalized intersections, the addition of left turn lanes is expected to reduce collisions by 27 percent (for four-leg intersections) and by 33 percent (for three-leg intersections).

  At signalized intersections in urban areas the reduction in collisions as a result of adding a left turn lane is expected to be 10 percent. The authors also found that added right turn lanes are equally effective in both rural and urban settings. Right turn lane installation reduces collisions on individual approaches to four-leg unsignalized intersections in rural areas by 27 percent, and by 18 percent at urban signalized intersections.

- A study quoted in Forbes (2003) examined the impact of adding exclusive left-turn lanes and raised medians at signalized intersections on arterial streets in the city of Hamilton, Ontario. The researchers found that collision rates were reduced by 30 to 75 percent depending on the intersection.

- Tignor (1999) presents results of research conducted in California about the safety benefits of various traffic control devices. Left-turn channelization at signalized intersections is associated with an average collision reduction of 15 percent. At unsignalized intersections, the average collision reduction is 65 percent (with curbs and/or raised bars) and 30 percent (with painted channelization).

- Studies quoted in Neuman (1999) found that the provision of left-turn lanes at signalized intersections can reduce collisions by 18 to 40 percent.

- Ward (1992) found that the use of painted channelization at rural intersections in Britain to protect turning vehicles and discourage overtaking led to a 35 percent collision reduction at studied locations.

Summary: Providing channelization for left-turn and right-turn movements can significantly improve intersection safety at both signalized and unsignalized locations. Collision rates may be reduced by up to 75 percent with the introduction of channelization.

3.3 Clear Zone Widening

The clear zone is the total unobstructed traversable space within the recovery area, available to the errant vehicle (TAC, 1999). A clear zone was first recommended in the 1967 AASHO Yellow Book (AASHO, 1967). The width of 30 feet (9.14 meters), which is not a standard, was based on General Motor's Proving Ground studies of the lateral extent of movement of vehicles inadvertently leaving their test track (Olivarez, 1988). By the mid 1970s, there was widespread acceptance that clear zones are an important part of road design. The safety benefits of clear zones as discussed in the literature are summarized as follows:

- Ogden (1996) states that the effectiveness of providing roadside clear zones is well-established. To illustrate this, he quotes two U.S. studies about the expected reduction in related collision types with increased clear zone width on both straight sections of road and horizontal curves. Sanderson (1996) reports similar findings based on research published by the FHWA. TABLE 3.1 illustrates the findings.

TABLE 3.1 COLLISION REDUCTION FACTORS FOR INCREASING CLEAR ZONE WIDTH

AMOUNT OF INCREASED ROADSIDE RECOVERY DISTANCE	REDUCTION IN RELATED COLLISION TYPES (%)	
	Straight	Curves
1.5m (5 ft)	13	9
2.4m (8 ft)	21	14
3.0m (10 ft)	25	17
3.6m (12 ft)	29	19
5.0m (15 ft)	35	23
6.0m (20 ft)	44	29

Source: Quoted in Ogden (1996)

- Tignor et al. (1982) quote an Australian study of roadsides which found that maintaining a clear recovery area of at least 30 feet would allow the majority of vehicles that leave the roadway to recover safely.

Summary: Collision reductions of up to 44 percent can be achieved with the provision of wide clear zones.

3.4 Breakaway Devices

These are devices which break away at the base when impacted. As a logical extension of the increased awareness of the importance of clear zones, breakaway devices gained in popularity starting in the late 1970s. Breakaway devices are likely to decrease crash severity rather than crash frequency. The safety effects of breakaway devices as discussed in the literature are summarized as follows:

- Cirillo (1999) indicates that the widespread use of breakaway devices has virtually eliminated fatalities from crashes into road signs and luminaries.
- Cirillo and Council (1986) report injury reductions of 30 percent from the use of breakaway luminaire supports. They also note that these supports are effective at speeds higher than 50 to 60 km/h.
- Mak and Mason (1980) conducted a study to evaluate performance, cost-effectiveness, and injury severity reduction of breakaway versus non-breakaway poles. They found that fixed poles resulted in more than three times as many fatal accidents per 100 accidents compared to breakaway poles.

Summary: Breakaway devices reduce collision severity, rather than frequency. Fatalities may be eliminated and serious injuries reduced up to 30 percent with the use of these devices.

3.5 Energy-Absorbing Barrier End Treatments

According to the Texas Transportation Institute (2001), there are about 750,000 guardrail end treatments in place in the U.S. There are also over 15,000 collisions with end treatments each year involving over 100 deaths and 5,000 injuries. Since the late 1980s, there has been a sustained and continuing effort to improve the safety of barrier end treatments. Energy-absorbing end-treatments result in reduced crash severity, but do not affect crash frequency.

AASHTO (1996) indicates that effective end treatments should not spear, vault, snag, or roll the vehicles. Since 1998, the U.S. Federal Highway Administration has required that all newly constructed guardrail end terminals on federal highways meet the National Cooperative Highway Research Program (NCHRP) Report 350 crash test criteria (Royer, 1999).

Some of the most common end treatments which meet the new NCHRP 350 crash test criteria are (Royer, 1999): (1) slotted rail terminal 350; (2) sliding extruder terminals; (3) buried end terminal; and (4) attenuated end terminal. The literature findings include:

- Proctor (1995) reviewed six sites in Birmingham, England where crash cushions were installed. He found a reduction in fatal, serious, and slight injury collisions of about 46 percent.

- Elvik (1995) conducted a systematic literature survey of 32 studies that have evaluated the safety effects of median barriers, guardrails, and crash cushions. He estimated that with the new installation of crash cushions, a collision rate reduction of 84 percent, fatal collision reduction of 69 percent, and injury collision reduction of 68 percent, would be achieved.

- Griffin (1984) conducted a study about the effectiveness of crash cushions in reducing death and injury in Texas. Four years of collision data involving ends of bridges and supporting structures at underpasses were analyzed to establish a number of deaths and injuries per collision. These averages were then compared to a sample of 560 single vehicle collisions involving crash cushions. The results indicated that crash cushions reduced fatalities by 78 percent, and injuries by 27 percent.

Summary: Energy-absorbing barrier end treatments are effective at reducing the severity of collisions. Fatalities can be reduced by up to 78 percent, and injuries by up to 68 percent, with the introduction of these devices.

3.6 Protected Left Turn Phases

Protected left-turn phasing provides an exclusive phase for left turns at signalized intersections (Noyce et al., 2000). In this type of phasing, the left turn driver is directed to turn left in a protected manner through the display of a green arrow, and then directed by the display of a circular red to wait until the next cycle and its corresponding green arrow. As urban congestion continued to increase in large cities, protected-only phases were introduced and gained acceptance in the late 1970s. Despite their proven safety benefits, their use remains relatively limited outside highly congested cities due to the trade-off in reduced intersection capacity. The literature presents the following information about this countermeasure:

- Forbes (2003) quotes studies by Upchurch (1991) and Shebeeb (1995) that demonstrate the safety benefits of protected-only left-turn phases compared to other types of left-turn control. The studies found that protected-only left-turn phasing reduces the crash risk by 50 percent or more compared to other control types.

- Michigan's Traffic Safety Manual states that the provision of left-turn signals of any type (protected, lead/lag, split) is expected to result in an overall crash reduction of 25 percent. This is based on research by the Kentucky Transportation Research Program, the Kentucky Transportation Center, and the Texas Department of Transportation.

Each of these found a reduction in collisions of about 25 percent in their studies (Southeast Michigan Council of Governments, 1997).

- Friedman et al. (1982) studied the before and after collision statistics at 28 intersection approaches in Florida where changes from protected-only to protected/permissive left-turn phasing and vice-versa had taken place recently. They found that a change from protected/permissive to protected-only left-turn phasing can sometimes produce a dramatic decrease in left-turn angle collisions.

Summary: Protected-only left-turn phasing can reduce the collision risk by at least 25 percent.

3.7 Rail Crossing Warning Devices

Awareness of the need to upgrade warning devices at rail crossings increased in the late 1960s. Warning devices include flashing lights and gates.

More recently in the 1990s, smart systems that control signal timings and queue lengths at rail crossings have been introduced, partially in response to tragic high-profile train/bus crashes in the United States. Electronic photo and video enforcement of control gates has also been introduced in the 1990s. The literature provides the following information:

- Tignor (1999) quotes findings from a study conducted in California to evaluate the safety and cost benefits of the "Rail-Highway Crossing Program" introduced in the U.S. in the mid 1970s. TABLE 3.2 illustrates the safety benefits of various measures involving railroad crossings.

TABLE 3.2 SAFETY BENEFITS OF TRAFFIC CONTROL DEVICES AT RAILWAY CROSSINGS

ITEM	REDUCTION IN COLLISION FATALITY RATES (%)	REDUCTION IN COLLISION INJURY RATES (%)	REDUCTION IN COLLISION RATES (%)
Upgraded railroad flashing lights	87	36	46
New railroad flashing lights	85	76	78
New railroad flashing lights and gates	91	83	84
New railroad gates	91	74	78

Source: Quoted in Tignor (1999)

- Pinnell et al. (1982) quote an extensive study conducted by the California Public Utilities Commission about the relative effectiveness of active devices in reducing crossing collisions. The study found that the use of active devices resulted in reductions of 69 percent in vehicle-train collisions, an 86 percent reduction in fatal collisions, and an 83 percent reduction in injury collisions. Also, the provision of lighting resulted in a 52 percent reduction in the total collision rate and a 65 percent reduction in the night-time collision rate at crossings with reduced alignment standards.

Summary: Warning devices at rail crossings can reduce the overall collision rate by up to 84 percent, and the fatal crash rate by up to 91 percent.

3.8 Access Management

Access management is the process of balancing the competing needs of traffic movement and land access (Stover and Koepke, 2000). It is used to improve traffic performance and safety on highways. The two basic types of access management are roadside and median (Stover, Tignor, and Rosenbaum, 1982).

The need for access management gained prominence in the late 1970s, as increasing suburbanization in North America collided with the commercialization of major arterials used heavily by commuters. Several studies have indicated that access management has a positive effect on safety. The literature results are summarized as follows:

- Gluck and Levinson (2000) report on a comprehensive analysis of collision information obtained from eight U.S. states where 240 roadway segments, involving more than 37,500 collisions were analyzed. Using 10 access points per mile as the base, it was found that each additional access point per mile increases the collision rate by about 4 percent.

- Preston (2000) states that access management is a legitimate public safety issue. This observation is based on a comprehensive study conducted in Minnesota about the relationship between access management and collisions. The study found that the number of collisions increases as the number of access points increases along a facility.

- Brown and Tarko (1999) developed a series of models to predict collision rates on multi-lane arterial road sections in Indiana, based on geometric and access control characteristics. They found that the number of collisions increases as the access density and proportion of signalized access points increase.

- Gattis (1996), in a study of three segments in a small Oklahoma city, found that the segment with the highest access control had collision rates approximately 40 percent lower than the other two segments.

- Sanderson (1996) reports research published by the FHWA showing that the number of collisions increases with the number of access points and average daily traffic. On low-volume roads, the risk of collisions can increase by more than twice on road sections with more than 60 driveways per mile compare to sections with less than 30 driveways per mile.

- Stover, Tignor, and Rosenbaum (1982) quote a study to the U.S. congress which states that access control is “the most important single design factor ever developed for collision reduction”.

Summary: Limiting the number of access points along a roadway has important safety benefits, and could reduce the collision risk approximately by half.

3.9 Rigid Barriers

All safety barriers must be capable of redirecting and/or containing an errant vehicle without imposing excessive deceleration forces on the vehicle occupants (Ogden, 1996). Rigid (or concrete) barriers have different types of cross sections (i.e., New Jersey shape, F-shape, and constant slope).

The most widely used concrete barrier is the New Jersey barrier. This type of barrier is commonly used in the median of divided highways or as a component of a bridge barrier.

Awareness of the need for rigid barriers increased in the mid 1970s at the same time as the clear zone concepts were evolving. Designers recognized that where hazards such as steep embankments, trees, opposing traffic or utility poles in the desired clear zone could not be removed or relocated, barriers need to be provided to protect errant vehicles from more severe impacts.

Rigid barriers tend to result in a higher frequency of crashes, since the barrier itself represents a fixed-object hazard. However, high-severity head-on and off-road crashes are typically reduced or eliminated when barriers are introduced. The literature findings are summarized as follows:

- Zein and Rocchi (1999) reviewed the available literature and concluded that with the introduction of median barriers, median-related fatality crashes are likely to be reduced by an average of 40 percent, median-related injuries are likely to be reduced by an average of 20 percent, and total median-related crashes are likely to increase by an average of 30 percent.

- Zein and Rocchi (1999) also reviewed the available literature related to roadside barriers, and concluded that with the introduction of rigid roadside barriers, a 27 percent decrease in the collision rate can be expected, and the likelihood of an injury or fatality crash would decrease 44 and 52 percent respectively.

- Mak and Sicking (1990) note that "the degree to which the concrete safety-shaped barrier has been successful in reducing deaths and serious injuries is unknown." However, they also note that "hundreds, perhaps thousands, of lives may be saved each year because of the deployment of these barriers."

- Cirillo and Council (1986) indicate that the severity of collisions has been reduced at locations where concrete barriers replaced other types of barriers.

Summary: Rigid barriers tend to reduce the frequency of high-severity collisions, while possibly increasing the frequency of lower-severity crashes. The introduction of barriers can reduce the likelihood of fatality crashes by up to 52 percent.

3.10 Limiting Intersection Angles (70^o or better)

Intersection angles that are close to 90^o are considered safer than severely acute and obtuse angles. Modern design guidelines tend to limit intersection angles to 70^o (110^o) or better. The findings of the literature review on this topic are summarized as follows:

- Staplin et al. (2001), in the Highway Design Handbook for Older Drivers and Pedestrians state that “decreasing the angle on the intersection makes detection of and judgments about potential conflicting vehicles on crossing roadways much more difficult”. They indicate that skewed intersections pose particular problems for older drivers due to the decline in head and neck mobility which usually accompanies advancing age.

- ITE (1999) states that “crossing roadways should intersect at 90 degrees if possible, and not less than 75 degrees." It further states that: "Intersections with severe skew angles (e.g., 60 degrees or less) often experience operational or safety problems. Reconstruction of such locations or institution of more positive traffic control such as signalization is often necessary."

  Regarding intersection design issues on two-lane rural highways, ITE (1999) states that: "Skew angles in excess of 75 degrees often create special problems at stop-controlled rural intersections. The angle complicates the vision triangle for the stopped vehicle; increases the time to cross the through road; and results in a larger, more potentially confusing intersection."

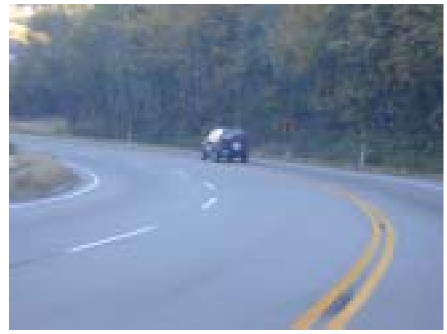
- Walker (1993) states that AASHTO recommends intersection angles of between 60 and 120 degrees, while TAC limits these to between 70 and 110 degrees. He mentions that the greater the angle, the greater the area of conflict, the more limited visibility is, the larger the turning roadway areas are for trucks, and the longer the exposure time for vehicles through the intersection.

- Kuciemba and Cirillo (1991) reviewed the safety implications of T and Y-intersections in rural municipalities in the U.S. Of 500 intersections analyzed, it was found that the collision rate for T-intersections was 34 percent lower than for Y-intersections (1.22 collisions per million entering vehicles for Y-intersections versus 0.80 for T-intersections).

Summary: Although data is limited, intersections at angles closer to 90 degrees are generally significantly safer than acute intersections.

3.11 Horizontal Curve Flattening

Horizontal curves require more driver attentiveness than tangent road sections. Horizontal curves with sharp (small) radii tend to be associated with a higher crash risk. Safety can usually be improved by flattening curves to increase the radius. There are several studies that address the relationship between horizontal alignment and safety:



- According to Hauer (1999), based on a review of literature about safety and degree of curve, most studies find that collision rate increases as degree of curve increases.

- Sanderson (1996) reports research published by the FHWA indicating that collisions are reduced by reducing the degree of curve. For example, reducing the degree of a curve from 30 to 5 degrees results in a reduction of 83 percent of related collision types. These related collision types include run off the road, head-on, opposite and same direction sideswipes.

- Karl-Olov (1989) indicates that collision rates tend to increase sharply for radii under 1000 meters. He cites a Swedish study which found that for roadways with a 90 km/hr speed limit, increases in radii reduce collision rates by the factors shown in Table 3.3.

TABLE 3.3 COLLISION REDUCTION FACTORS FOR VARIOUS INCREASES IN HORIZONTAL RADII

FROM (m)	TO (m)		
	500	700	1500
300	0.25	0.35	0.45
500		0.10	0.30
700			0.20

Source: Karl-Olov (1989)

The safety of a roadway that features a series of horizontal curves can be improved if the principles of design consistency are applied. Design consistency promotes predictable operating speeds thereby reducing the driver work load and the undesirable element of surprise that occurs when one horizontal curve requires a significant speed adjustment compared to the surrounding roadway (Lamm, 1999)

Summary: The crash risk generally decreases as the curve radius is increased. Significant collision reduction factors of up to 0.45 can be achieved when tight radii are improved. Proving design consistency is desirable from a safety perspective.

3.12 Passing Lanes

Passing lanes are usually added to two-lane highways to provide passing opportunities, thereby reducing platoon buildups that leads to driver frustration. Several studies have assessed the safety effects of passing lanes:

- Research quoted by Ogden (1996) reported a 25 percent reduction in collisions when passing lanes were provided in rural roads in Australia. He also notes that the safety benefits of passing lanes depend on the location, the spacing between passing lanes, and the number of passing lanes provided in relation to the traffic flow and terrain.

- Ogden and Pearson (1991) refer to a study conducted in the U.S. where it was found that sites with passing lanes had a 38 percent fewer collisions overall and 29 percent fewer fatal and injury collisions than sites without passing lanes.

- Pak-Poy and Kneebone (1988) report an earlier study in California which found that the provision of passing lanes reduced collisions by about 25 percent.

Summary: Passing lanes on two-lane highways can be expected to reduce all collisions by up to 38 percent and severe collisions by up to 29 percent.

3.13 Positive Guidance

Alexander (2001) states that positive guidance means giving drivers the information they need to avoid hazards, when and where they need it, in a form they can best use it. With increasingly complex and congested driving environments, positive guidance principles gained prominence in the mid 1980s. Although the literature does not typically identify “positive guidance” as a specific countermeasure, various sub-components, such as advanced warning signs, improved delineation, advanced warning flashers, and hazard warning signs, have been studied. The literature results include:

- Sayed (1998), using before-and-after analysis and collision prediction models, conducted a safety study of advance warning flashers in Vancouver. The flashers had a safety impact at 25 out of 106 signalized intersections. At these locations, the total number of collisions was reduced by 8 to 18 percent, while severe collisions decreased by 10 to 14 percent.

- Tignor (1993) quoted U.S. studies which indicate that, with the introduction of warning signs, the expected benefit is a 29 percent reduction in fatal collision rates and a 14 percent reduction in injury collision rates. The average number of collisions reduced was estimated as 20 and 36 percent with the installation of curve warning signs and advisory speed signs respectively.

- With the introduction of chevrons that provide advance warning of horizontal curves, the UK County Surveyor's Society (1989) found a statistically significant reduction in collisions at 9 out of 18 surveyed sites, and the number of associated collisions reduced by up to 70 percent.
- Pak-Poy and Kneebone (1988) quoted a U.S. study which suggested collision reductions of around 20 to 30 percent for other warning signs, such as side-road signs.

- Bissel (1983) reported a U.S. study which found that run-off-the-road collisions were reduced by 30 percent with the installation of post-mounted delineators.

Summary: There are various kinds of devices that contribute to positive guidance. The safety benefit that can be expected with these devices is in the range of 10 to 30 percent.

3.14 Street Lighting

According to Hasson and Lutkevich (2002), roadway lighting serves several purposes: (1) it provides improved visibility for users of roadways; (2) it reduces crashes by helping drivers obtain sufficient visual information; and (3) it supplements vehicle headlights, when warranted.

Providing lighting to decrease crash risks gained prominence starting in the mid 1970s. The light poles themselves may constitute a fixed-object hazard; therefore, the net change in daytime and nighttime crash frequency and rate need to be considered when assessing the impacts of adding lighting. Various studies have examined the safety effectiveness of lighting:

- Hasson and Lutkevich (2002) quote a Federal Highway Administration Study which showed that installing lighting has the highest benefit-cost ratio of all safety improvements. The authors go on to say that roadway lighting is a proven countermeasure for a variety of road safety problems, but more research is needed about specific safety problems so that better use can be made of roadway lighting.

- Wilken et al. (2001) indicate that road lighting reduces the incidence of nighttime collisions. The extent of reduction depends on road class and collision type. Studies quoted in this report indicate the following about the safety benefits of street lighting in some European countries:

  a) Finland reported a 20 to 30 percent reduction in collisions after the introduction of lighting.

  b) A Norwegian study reported a 65 percent reduction in nighttime fatalities, a 30 percent reduction in injury collisions, and a 15 percent reduction in property damage collisions.

  c) Dutch studies showed reductions of 18 to 23 percent in collisions after the introduction of lighting.

- Tignor (1999) quotes results of research conducted in California about the safety benefits of various traffic control devices. New safety lighting is found to have an average nighttime collision reduction of 75 percent (at intersections), 60 percent (at railway crossings), and 50 percent (at bridge approaches).

- Ogden (1996) quotes U.S. studies which indicated a reduction of 41 percent in fatal collisions and 16 percent in injury collisions, with an overall benefit to cost ratio of 12:1 from lighting improvements. At intersections, up to 75 percent of night time collisions can be affected by lighting.

- The International Commission on Illumination (CIE) Technical Report "Road Lighting as a Collision Countermeasure, (1992)" provides a detailed summary of 62 studies from 15 countries that have investigated the relationship between lighting and collisions. Approximately 85 percent of the results show that lighting reduces the incidence of nighttime collisions. Depending on the road class and the collision classification involved, the statistically significant reports show collision reductions of between 13 and 75 percent.

Summary: Increasing lighting is a proven safety countermeasure, particularly at night. Nighttime collision reductions of up to 75 percent can be expected with the introduction of street lighting.

3.15 Roundabouts

Modern roundabouts are designed to control traffic flows at intersections without the use of stop signs or traffic signals. Crash reductions resulting from the conversion of conventional intersections to modern roundabouts can be attributed primarily to two factors: 1) reduced traffic speed and 2) elimination of angle collision risks. Modern roundabouts began to gain a measure of acceptance in some parts of North America in the late 1990s. Several studies indicate that modern roundabouts are safer than other methods of intersection traffic control:

- Persaud et al. (2000) conducted a study to evaluate changes in motor vehicle crashes following the conversion of 24 intersections from stop sign and traffic signal control to modern roundabouts, located in 8 states. The empirical Bayes procedure estimated highly significant reductions of 39 percent for all crash severities combined, and 76 percent for all injury crashes. The reduction in the number of fatal and incapacitating injury crashes was estimated to be about 90 percent.

- The NCHRP Report 264 Modern Roundabout Practice in the United States (Jacquemart, 1998) collected before-and-after crash statistics for 11 roundabouts in the United States. The results indicated that the number of total crashes was reduced by 37 percent, injury crashes decreased by 51 percent, and property-damage-only crashes decreased by 29 percent. Significant crash reductions were identified for small-to-moderate roundabouts with outside diameters less than 37 metres.

- Elvik et al. (1997) conducted a thorough review of the literature and concluded that converting from yield, two-way stop, or traffic signal control to a roundabout reduces the total number of injury crashes by 30 to 40 percent. Reductions in the number of pedestrian crashes were in the same range and bicycle crashes were reduced by approximately 10 to 20 percent.

- Schoon and van Minnen (1994) studied 181 Dutch intersections converted from stop-control or yield-control to roundabouts and reported that crashes and injuries were reduced by 51 and 72 percent respectively.

- Troutbeck (1993) conducted a before-and-after study in Victoria, Australia and reported a 74 percent reduction in the rate of injury crashes following the conversion of 73 intersections to roundabout control. The reduction was more pronounced for lower volume roundabouts, but remained significant for all categories.

Summary: The safety benefits of roundabouts are significant, particularly for injury and fatality collisions. A reduction in high severity crashes of up to 90 percent can be expected with the introduction of a roundabout.

3.16 Rumble Strips

Rumble strips are raised or grooved patterns placed on the edge or centerline of a road to provide a sudden audible and tactile warning to the drivers. This device may be used on the shoulder, the edge line, or the centre line of a road, primarily to counter driver fatigue or inattention. Edge-line rumble strips were introduced in North America in the mid 1990s, and have gained relatively quick acceptance.

Data on the safety benefits of centerline rumble strips is not yet available as applications have been recent and limited. The safety benefits of edge-line rumble strips are summarized as follows:

- Zein and Rocchi (1999) reviewed the available literature and concluded that with the introduction of edge-line rumble strips, the average expected reduction in off-road crashes is in the range of 35 to 60 percent, depending on site-specific conditions. The expected benefit to cost ratio is in the range of 30:1 to 182:1.

- Griffith (1999) conducted a before-after safety evaluations of projects involving the installation of rolled-in continuous shoulder rumble strips on rural and urban freeways in Illinois and California. He found that in Illinois, rumble strips reduced single-vehicle run-off road collisions by 21 percent in rural areas. In California, combining urban and rural data, it was found that rumble strips reduced the number of single vehicle run-off road collisions by 7 percent.

- Harwood (1993) summarized U.S. experience and indicated that continuous rumble strips installed at regular intervals along extended sections of roadway have generally reduced the rate of run-off-road collisions by 20 percent or more. On the highways with extremely monotonous driving conditions, such as freeways in desert regions, the number of run-off-road collisions was reduced by about 50 percent.

- The UK County Surveyor's Society (1989) reported that on a motorway, the total number of collisions decreased by 37 percent in the three years following the installation of shoulder rumble strips, and the number of collisions involving vehicles leaving the outside edge of the road was reduced by 76 percent.

Summary: Rumble strips are an effective road safety countermeasure that can reduce the frequency of off-road collisions by up to 76 percent.

3.17 Estimate of Canada-Wide Safety Benefits

The above 16 safety road engineering safety countermeasures are shown in FIGURE 3.1 according to the universal date of acceptance, along with the Canadian fatality rate trend.

The engineering road safety improvements that were introduced in the mid to late 1970s have likely contributed to the steadily declining fatality rate that has been recorded since the late 1970s.

In the existing literature, there are no available estimates of the total number of lives saved (or the total number of crashes prevented) on a Canada-wide basis due to the introduction of road safety engineering safety improvements.

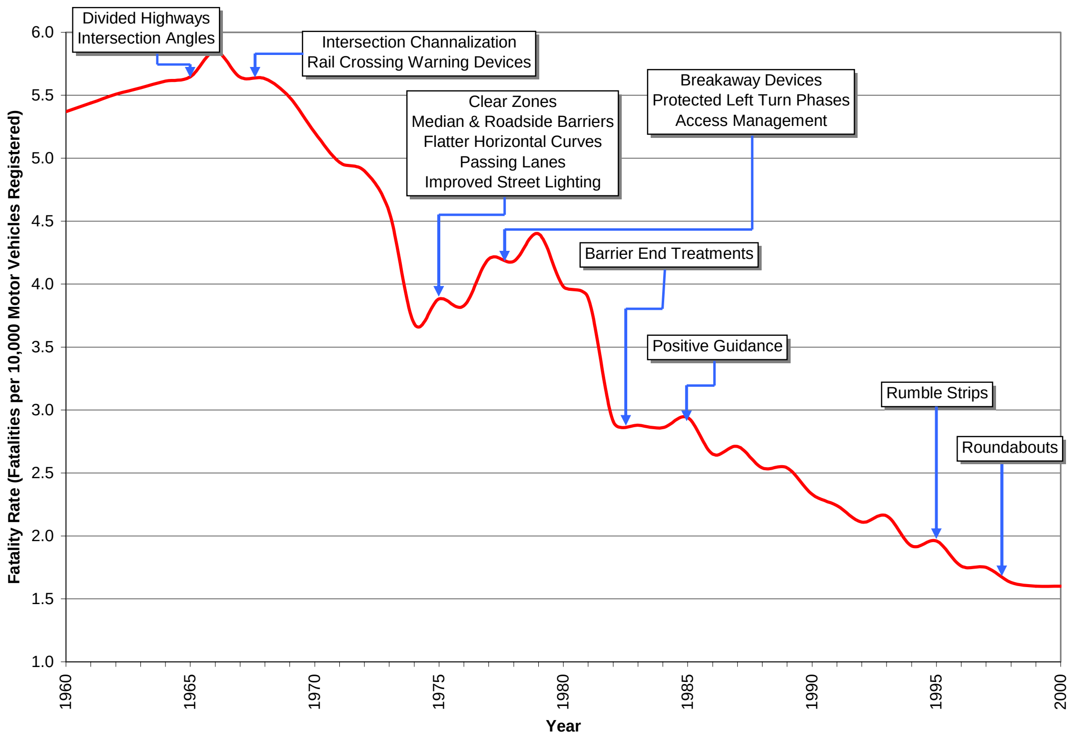


FIGURE 3.1 ENGINEERING SAFETY COUNTERMEASURES AND FATALITY RATES IN CANADA

Engineering improvements are typically gradually introduced over time; they are gradually adopted by various jurisdiction and geographical regions, and are rarely accompanied by evaluation studies (beyond local, project-specific monitoring that sometimes occurs).

Canada's annual number of traffic fatalities peaked in 1979 at more than 5,800 fatalities. The number of fatalities has been gradually decreasing since then. In the year 2000, just over 2,900 traffic fatalities were recorded. The reduction is due to a combination of engineering, enforcement, education, vehicle design, and macro-economic factors.

Compared to the year 1979 annual number of fatalities, a total of about 42,000 Canadian lives were saved due to the combined effect of these factors between 1979 and 2000. This value may be conservative; compared to the1979 rate of fatalities, a significantly larger number of lives have been saved, but it is unlikely that the 1979 rate of 4.4 fatalities per 10,000 vehicles would have held constant with increasing urbanization and congestion (the year 2000 rate is 1.6).

About 16,000 lives have been saved between 1982 and 2000 primarily due to education, vehicle design, and enforcement-type activities (see Section 3.18 and TABLE 3.4). This value can be increased to 20,000 to cover the period between 1979 and 2000, and to include other non-engineering initiatives not covered in the table.

Therefore, approximately 22,000 lives have been saved due to macro-economic and engineering factors. Conservatively, about half of these savings may be attributed to engineering improvements in Canada, or about 11,000 lives saved between 1979 and 2000. The other half may be attributed to macro-economic conditions, particularly reduced travel activity during the deep recessions of the early 1980s and early 1990s.

This order-of-magnitude number (11,000 fatalities saved due to engineering countermeasures) is supported by literature from the United States (www.saferoadsforamerica.org) that indicates about 5,500 lives are saved and 250,000 injuries prevented every year due to relatively low cost road engineering improvements.

Applying a rough factor of 1:10 to represent Canadian conditions, and assuming that these savings did accrue on average between 1979 and 2000, then approximately 11,000 lives were saved and approximately 500,000 injuries were prevented in Canada between 1979 and 2000 due to road engineering improvements.

Information about the distribution of these Canada-wide benefits according to the different types of engineering countermeasures is also not available. However, it has been estimated that the following eight countermeasures are likely responsible for the majority of lives saved and injuries prevented:

1. Divided Highways
2. Intersection Channelization
3. Clear Zone Widening
4. Breakaway Devices
5. Energy Absorbing Barrier End Treatments
6. Protected Left-Turn Phases
7. Rigid Barriers
8. Horizontal Curve Flattening

These measures are selected as having been most effective due to their high rate of acceptance and use across the country, and their proven high effectiveness in reducing collision frequency and/or severity in all light, weather, and terrain conditions. Significantly more detailed research will be required in order to better quantify the cumulative macro-level achievements of individual road safety engineering countermeasures.

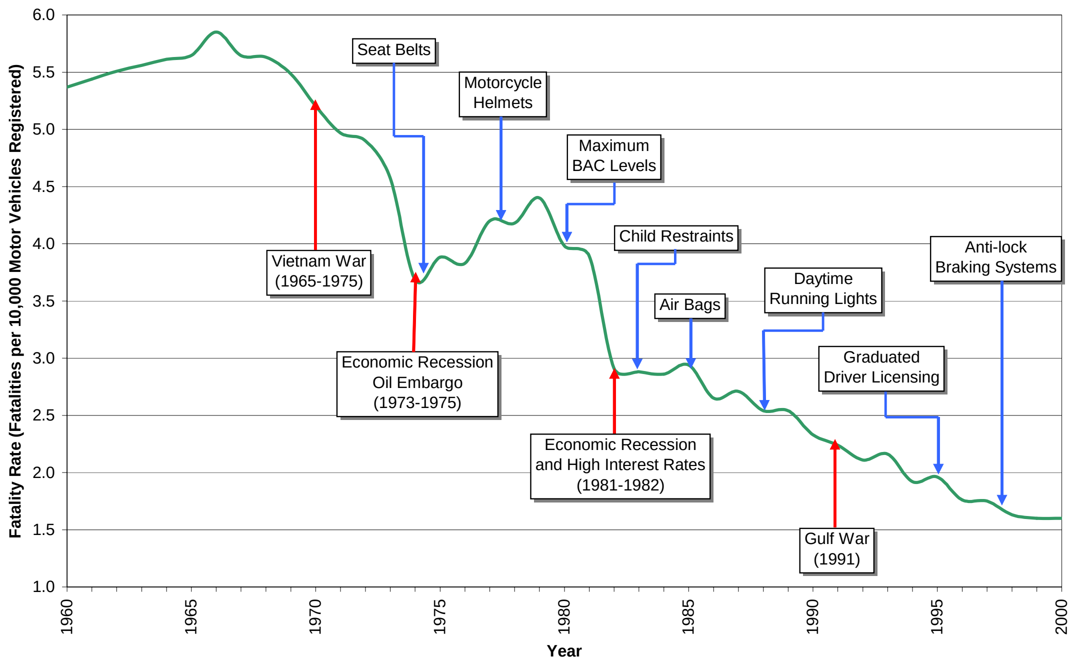
3.18 Overview of Other Traffic Safety Countermeasures

Transportation safety consists of five components: legislation, regulation, enforcement, education and engineering. The last three items (usually called "three Es") are all required components of a good safety program. Engineering type traffic safety countermeasures include both road and vehicle related initiatives. This study addressed the major road-related engineering safety initiatives that have been introduced over the past 40 years.
Examples of non-road engineering countermeasures that have been introduced in North America since the 1960s include:

- Mandatory requirements to wear seat-belts;
- Mandatory use of child restraints;
- Mandatory requirements to wear motorcycle helmets;
- The introduction of maximum blood alcohol content levels to define impairment;
- The introduction of graduated driver licensing;
- The use of in-vehicle air bags; and
- The use of anti-lock braking system.

Safety on the roads is also a function of macro-economic conditions and global factors. For example, in times of war and economic recession, there tends to be less overall travel and consequently a lower risk of crashes.

FIGURE 3.2 shows the fatality rate trend in Canada, and some of the above-described safety benchmarks.



Note: The fatality rate between 1960 and 1975 is estimated by Hamilton Associates.

FIGURE 3.2 CANADIAN TRAFFIC FATALITY RATE AND NON-ROAD ENGINEERING INTERVENTIONS

TABLE 3.4 provides an estimate of the number of lives saved by some non-road engineering safety improvements over time.

Some research has been conducted or is on-going in different countries to measure the relative benefits of road engineering, vehicle engineering, enforcement, and education type programs. The United Kingdom's Road Safety Strategy document (2000) estimates that road safety engineering programs could reduce fatal and serious injury collisions by 7.7 percent, compared to an 8.6 percent reduction for vehicle safety initiatives.

TABLE 3.4 ESTIMATES OF LIVES SAVED IN CANADA BY NON-ROAD ENGINEERING SAFETY IMPROVEMENTS OVER TIME

SAFETY IMPROVEMENT	PERIOD	CANADIAN LIVES SAVED	NOTES	SOURCE
Seat Belts	1990 to 2000	11,700	Drivers & Front Passengers	Transport Canada
Air Bags	1990 to 2000	310		
Maximum BAC Laws	1987 to 2000	3,700	Estimated from alcohol-related fatalities	
Child Restraints	1982 to 1996	270	Estimated from US sources	NHTSA

In a separate paper presented in 2000 by Allsop at the Road Safety Research, Policing, and Education conference, he estimates that had measures to reduce drinking and driving not been taken in the United Kingdom, the number of people killed or seriously injured in traffic crashes would have increased by 10.6 percent. The comparative values are 6.5 percent for road safety engineering initiatives and 14.7 percent for vehicle safety devices. Additional similar research is being conducted in New Zealand and the United States.

The research results generally confirm that road safety engineering initiatives have a significant and measurable benefit in reducing traffic casualties, alongside the vehicle, education, and enforcement programs.

APPENDIX A

SAMPLE SURVEY FORM

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September 27, 2002

Dear Transportation Engineering Professional:

Re: Assessment of Road Safety Engineering Improvements

Transport Canada is conducting a study to identify the most effective road safety engineering “benchmarks” that have been introduced in the past 40 years. Hamilton Associates is conducting the study on behalf of Transport Canada. The study objectives are to:

1. identify the road safety engineering improvements that have had the greatest impact in reducing crash frequency and severity over the years;

2. establish in general terms the date when the road safety improvements gained universal acceptance; and,

3. quantify the typical benefits achieved by the road safety engineering benchmarks.

The study requires input from experts in the field of transportation engineering to qualitatively assess the effectiveness of various road safety improvements. Only about 65 transportation engineers in North America have been selected to provide this input.

The attached survey will require about 10 minutes of your time. On the attached three tables, simply mark the appropriate column next to each listed road safety improvement, to indicate the relative effectiveness of each improvement in reducing crash frequency and severity. For the improvements that you rate as “high” or “very high”, please indicate the approximate year of universal acceptance. Simply use your own judgment and experience to fill out the tables. Once you have completed the three tables, please return them to us:

by e-mail: szein@gdhamilton.com
or by fax: (604) 684-5908

The deadline for returning the survey is Friday October 11, 2002. All those who return completed surveys by this deadline will receive a free copy of the completed study report. If you have any questions about this survey, please contact Mr. Sany R. Zein of Hamilton Associates at (604) 684-4488, or Ms. Leanna Belluz of Transport Canada, at (613) 998-1943. Thank you very much for your participation and input.

Yours truly,

G.D. HAMILTON ASSOCIATES CONSULTING LTD.

Zein

per: Sany R. Zein, M.Eng., P.Eng.
Vice President, Transportation

ASSESSMENT OF ROAD SAFETY BENCHMARKS
TABLE 1 OF 3

BENCHMARK		EFFECTIVENESS IN REDUCING CRASH RISK (Frequency and/or Severity)				APPROXIMATE DATE OF UNIVERSAL ACCEPTANCE*
No.	DESCRIPTION	Very High	High	Moderate	Low	
1	Providing intersection channelization (left-turn and Right-turn lanes)					
2	Limiting the angle of intersecting roads to 70^{o} or better					
3	Providing two-way left-turn lanes along arterials					
4	Providing wider clear zones along highways and freeways					
5	Providing divided highways					
6	Providing wider travel lanes					
7	Providing wider shoulders					
8	Designing according to decision sight distance					
9	Providing flatter horizontal curves					
10	Providing improved super-elevation					
11	Providing passing lanes along two-lane highways					
12	Providing climbing lanes along mountainous highways					
13	Providing longer taper lengths					
14	Providing truck escape roads or ramps					
15	Providing rest areas					

*Only for the Benchmarks that you rate as “High” or “Very High”. Use general terms like “mid 1960s” or “late 1970s”.

ASSESSMENT OF ROAD SAFETY BENCHMARKS
TABLE 2 OF 3

BENCHMARK		EFFECTIVENESS IN REDUCING CRASH RISK (Frequency and/or Severity)				APPROXIMATE DATE OF UNIVERSAL ACCEPTANCE*
No.	DESCRIPTION	Very High	High	Moderate	Low	
16	Providing high friction / open textured pavement					
17	Providing rigid barriers (median and roadside)					
18	Providing energy-absorbing barrier end treatments					
19	Providing breakaway devices (for luminaries, sign bases, etc.)					
20	Providing rumble strips (edge-line or centre-line)					
21	Implementing access management along corridors (frontage roads, driveway closures / relocations)					
22	Prohibiting parking along arterials					
23	Providing protected left-turn phases at signalized intersections					
24	Providing all-red phases at signalized intersections					
25	Providing signal progression along corridors					
26	Implementing intelligent transportation systems along a corridor or network					
27	Providing rail crossing warning devices (gates, signals)					
28	Providing advance warning flashers on signalized intersection approaches					
29	Providing overhead flashing beacons at unsignalized intersections					
30	Providing more conspicuous signal displays (12 inch signals, left- and right-side signals, per-through-lane signals, backplates, LEDs)					

*Only for the Benchmarks that you rate as “High” or “Very High”. Use general terms like “mid 1960s” or “late 1970s”.

ASSESSMENT OF ROAD SAFETY BENCHMARKS
TABLE 3 OF 3

BENCHMARK		EFFECTIVENESS IN REDUCING CRASH RISK (Frequency and/or Severity)				APPROXIMATE DATE OF UNIVERSAL ACCEPTANCE*
No.	DESCRIPTION	Very High	High	Moderate	Low	
31	Providing roundabouts for traffic control at intersections					
32	Providing larger street name signs					
33	Providing positive guidance on approach to complex decision points					
34	Providing larger traffic signs					
35	Providing pavement turn-guidance marking					
36	Providing sign sheeting with improved reflectivity					
37	Providing pavement markings with improved reflectivity					
38	Providing traffic calming in residential neighbourhoods					
39	Providing facilities for vulnerable road users (special crosswalks, pedestrian signal heads, audible signals, wider curb lanes to accommodate bikes)					
40	Implementing travel demand management strategies					
41	Improved Street Lighting					
42	Other - Please Describe:					
43	Other - Please Describe:					

*Only for the Benchmarks that you rate as “High” or “Very High”. Use general terms like “mid 1960s” or “late 1970s”.

APPENDIX B

EXPERTS WHO RESPONDED TO THE SURVEY

APPENDIX B

EXPERTS WHO RESPONDED TO THE SURVEY

Federal Government Representatives
Doug Bowron, Transport Canada
Ralph Jones, Transport Canada
Randy Sanderson, Transport Canada

Provincial Government Representatives
Eric Christiansen, Manitoba Transportation
Peter Cooper, Insurance Corporation of British Columbia
Paul Hunt, Saskatchewan Highways and Transportation
Allan Kwan, Alberta Transportation
Paul Smith, Nova Scotia Transportation and Highways

Municipal Government Representatives
Ian Adam, City of Vancouver
Dave Banks, Regional Municipality of Waterloo
Gord Cebryk, City of Edmonton
Luis Escobar, City of Winnipeg
Steve Kodama, City of Toronto
Chi Lee, City of Red Deer
Cam Nelson, City of Calgary

Academics
Dr. Alan Clayton, University of Manitoba
Dr. Frank Navin, University of British Columbia
Dr. Bhagwant Persaud, Ryerson University

Consultants
Merv Clark, EBA Engineering
Dr. Paul de Leur
Gerry Forbes, Intus Road Safety Engineering Inc.
Dave Wilson, National Capital Engineering

Retirees
Dr. John Morrall, formerly with the University of Calgary

United States
Michael Baglio, Pennsylvania Department of Transportation
Ray Krammes, Federal Highway Administration
Dr. Martin Lipinski, University of Memphis

APPENDIX C

BIBLIOGRAPHY

APPENDIX C

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