Belanger, Carl

De: torsten.bergh@vv.se
Envoyé: 24 janvier 2005 13:31
À: Belanger, Carl
Objet: SV: RE : RE : Questions on 2+1 roads

Hello Carl,

We generally don't use the US terminology rolling, mountainous etc but we have some projects in fairly hilly conditions with single grades up to 5 to 6 % for 500 to 700 m. Our design guidelines recommend two lane sections to be located up-hill. We have a contionous discussion on prohibition of truck overtakings on these sections. The only major problem is grades over 4 to 5 % in winter conditions with some severe blockages.

Torsten

> -----Ursprungligt meddelande-----
> **Från:** Belanger, Carl [mailto:Carl.Belanger@mtq.gouv.qc.ca]
> **Skickat:** den 24 januari 2005 17:35
> **Till:** Bergh Torsten HKm
> **Ämne:** RE : RE : Questions on 2+1 roads
>
> Hello Torsten,
>
> It's me again, the French Canadian wondering about the applicability of the 2+1 road concept. I have an additional question, if you would be kind enough to share again your experience.
>
> The type of terrain considered in this project is fairly mountainous and I wonder if you have, in Sweden, some experience with 2+1 roads operating under such conditions. If so, are you satisfied with operational conditions (sufficiently, to plan additional 2+1 roads in mountainous areas)?
>
> Again, thanks in advance,
> Carl
>
>> -----Message d'origine-----
>> **De :** torsten.bergh@vv.se [mailto:torsten.bergh@vv.se]
>> **Envoyé :** 23 décembre 2004 01:56
>> **À :** Belanger, Carl
>> **Objet :** SV: RE : Questions on 2+1 roads
>>
>> Carl,
>>
>> No problems. We are happy to share our experience and would be interested to hear about your progress.
>>
>> Torsten
>>
>>> -----Ursprungligt meddelande-----
>>> **Från:** Belanger, Carl [mailto:Carl.Belanger@mtq.gouv.qc.ca]
>>> **Skickat:** den 22 december 2004 20:04
>>> **Till:** Bergh Torsten HKm

Ämne: RE : Questions on 2+1 roads

Hello Torsten,

Many thanks for your quick and informative answers. Obviously, I knocked at the right door! We will make some further advances in this project, and I hope we will not have to bother you too much in the future!

With my best regards and best wishes for the holiday season

Carl Belanger

-----Message d'origine-----
De : torsten.bergh@vv.se [mailto:torsten.bergh@vv.se]
Envoyé : 22 décembre 2004 11:29
À : Belanger, Carl
Objet : SV: Questions on 2+1 roads

Hello Carl,

Some quick answers below. We have much more information as we now have built some 1000 km in the last 6 years and plan for another 700-800 km in the next 3 years.

-----Ursprungligt meddelande-----
Från: Belanger, Carl [mailto:Carl.Belanger@mtq.gouv.qc.ca]
Skickat: den 22 december 2004 16:16
Till: Bergh Torsten HKm
Ämne: Questions on 2+1 roads

My name is Carl Belanger and I am a road safety engineer working for the Ministry of Transportation in Quebec, Canada.

I am writing to you regarding the concept of 2+1 roads.

In Quebec, a project is presently underway in respect to transforming a 2 lane undivided rural road into a 4 lane divided road, and the question has been raised as to whether a 2+1 design would be appropriate. A number of concerns have been expressed regarding this concept and I was wondering if you could help us in our search for answers (or if would you be kind enough to transfer my request to the right person).

In particular, we are wondering:

1) What is the longest continuous stretch of road on which this type of road design has been implemented in Sweden (or is planned to be implemented)? Our project links two administrative regions that are separated by a huge natural park and as such, the project's length is about 175 km long. It seems a very long distance for a 2+1 design ?

We don't think so. We expect to have very long 2+1-distances in a rather near future. Our longest by now is probably close to 100 km (a guess)

2) What is the average annual snow precipitation in areas where 2+1 roads have been implemented in Sweden? In our region of interest, there is close to 6 meters of snow precipitation annually. Our maintenance people are

worried about the presence of a median cable barrier (difficulties in clearing the snow efficiently and in safely fixing broken median barriers, etc.).

We are not close to that. I would guess that our maximum might be less than a meter but we have projects with occasionally very heavy snowfalls. Winter maintenance was a major concern before we started but has turned out to work better than our maintenance people feared. Snow ploughing works well. Barrier repairs in winter time needs obviously heating equipment, also working quite OK.

3) Is any information available on the relative safety performance of 4 lane roads (divided) versus 2+1 lane roads (divided) in Sweden ?

Yes, we have built a number of narrow 4-lane roads with paved widths around 16 m and some duals with carriageways of 8 m and a median of 2,5 m (broken form the paved area). Our findings, not statistically significant, are that these 4-lane designs and the 2+1-design have approximately the same safety performance at speed limit 110 kph. The 2+1 is as yet actually slightly better in statistics. There is a lot of discussions and opinions on these data in Swden.

I look forward to hearing from you and thank you in advance for sharing your experience.

Best regards,

Carl Belanger, Safety specialist, MTQ

Belanger, Carl

De:	Harri.Peltola@vtt.fi	**214**	**DA63** (document 2)
Envoyé:	23 décembre 2004 08:06		Projets d'amélioration de la route 175 des kilomètres 60 à 84 et 84 à 227
À:	Belanger, Carl		**RFL et SAG / STO-TEWK 6211-06-042**
Objet:	Re: Info request from Canada-Quebec!		

Hi Carl - nice to hear from you.
I remember you very well - actually I was very pleased to receive recently a CD ROM including the Traffic safety handbook. Congratulation - it is great.

About 2+1 lanes. In Finland we are only starting to do some sites with 2+1 lanes and middle barrier. In the project you mentioned, we were evaluating the safety potential of such arrangement based on Swedish experience. In the description was said "Maybe even a proposal of creating an evaluation tolls will be done. "
- it was meant to be evaluation tool (not toll). Such a tools was created and it suggested quite good safety records based on the Swedish experience.

I know that in Sweden they have had further tests on the 2+1 with middle barrier arrangement. I tried to find an English report from the internet but did not succeed by now. I could try again after Christmas but you could try yourself if you are in a hurry. Please try at:

www.vv.se (Swedish Road Administration) or you should get the English pages directly by choosing: http://www.vv.se/templates/page3____954.aspx

Another possibility is:
www.vti.se (VTI, the Swedish National Road and Transport Research Institute) pr directly their English pages at: http://www.vti.se/templates/Page____2783.aspx

They have many publications for downloading as a PDF file, but I could not find the right one by now. Maybe they are only internal reports in Swedish. I think the right guy to ask is Arne Carlsson. Maybe you could send e-mail directly to him if you can not find the report directly.

Sorry - I have to go for the Christmas. Please, let me know if you can not get the information you need - then I will try again.

Happy Holidays and all the best for 2005.
Harri

Harri Peltola
Senior Research Scientist
VTT Building and Transport
P.O. Box 1800, FIN-02044 VTT, Finland
Tel. + 358 9 456 6200, Mobile phone +358 40 506 9064
Fax + 358 9 464 850
Mailto:Harri.Peltola@vtt.fi
http://www.vtt.fi/rte/indexe.html

On 21.12.2004 21:02:07 "Belanger, Carl" wrote:
>Hello Harri,
>
>
>
>If your memory serves you well, you may remember me as we were both
>members of the PIARC road safety committee a few years ago (Carl
>Belanger).

>
>
>
>I am contacting you as I found that you have worked on the evaluation
>of the safety level of 2+1 lane roads. My source is :
>
>
>
>http://www.vtt.fi/rte/transport/research/traffic_safety/projects.htm
><http://www.vtt.fi/rte/transport/research/traffic_safety/projects.htm>
>
>Safety characteristics of different road-types
>To evaluate the safety of new road-types (wide-lane road, wide-shoulder
>road, 2+1 lane road and narrow motorway), the safety, severity of
>accidents and composition of accident-types will be studied. The final
>goal is to release advice for the safety evaluation of new road types.
>Maybe even a proposal of creating an evaluation tolls will be done.
>Harri Peltola
><http://www.vtt.fi/rte/transport/research/traffic_safety/contacts.htm#peltol
>a> , Susanna Ranta. Duration 11/99-12/00.
>
>
>
>I wonder if the above project (or other similar projects) has been
>completed and if you could refer me to some relevant publications
>(preferably in English!). We have a major project related to the
>conversion of a 200 km road stretch into a 4 lane road, and the
>alternative of a 2+1 lane road (with median barrier) has been
>suggested. People are scared that this latter design would be less safe
>than a conventional 4 lane divided road.
>
>I take this opportunity to wish you and your family a very nice holiday
>time, and am looking forward to hearing from you.
>
>
>
>With my best regards,
>
>Carl
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> ~ att1.htm

National Cooperative Highway Research Program

RESEARCH RESULTS DIGEST

APRIL 2003—Number 275

National Cooperative Highway Research Program

RESEARCH RESULTS DIGEST

April 2003—Number 275

Subject Area: IIA Highway and Facility Design

Responsible Senior Program Officer: B. Ray Derr

Application of European 2+1 Roadway Designs

This digest summarizes the results of NCHRP Project 20-7/Task 139, "Application of European 2+1 Roadway Designs." The great majority of U.S. rural roads have only two lanes. Under NCHRP Project 20-36, researchers conducted a scan of geometric design practices and identified the 2+1 roadway design as an alternative design used by some European countries. In NCHRP Project 20-7/Task 139, a research team led by Ms. Ingrid Potts of the Midwest Research Institute assessed whether the 2+1 design is suitable for use in the United States.

SUMMARY

A 2+1 road design has a continuous three-lane cross section with alternating passing lanes. A review of European safety and operational experience with 2+1 roads shows that they can be an attractive alternative to two- or four-lane roads in some cases. This digest describes when a 2+1 design is likely to be effective and presents some recommendations for designing 2+1 roads.

Visits were made to Germany, Finland, and Sweden to meet with agency staff, observe 2+1 roads in operation, and obtain data on their traffic operational and safety performance. Germany currently has approximately 360 km (220 mi) of 2+1 roads, which were constructed by restriping existing two-lane roadways with wide lanes or wide shoulders. Germany has found that 2+1 roads operate effectively at average daily traffic (ADT) volumes of 15,000–25,000 vehicles per day (veh/day); the maximum ADT for 2+1 roads in Germany is 30,000 veh/day. In Germany, 2+1 roads have been found to operate with accident rates 36 percent lower than conventional two-lane highways.

Finland currently has approximately 48 km (30 mi) of 2+1 roads and is planning to build more. The current 2+1 roads were implemented by restriping two-lane roads with wide lanes or wide shoulders; in the future, 2+1 roads will also be built as new construction. The 2+1 roads in Finland have annual average daily traffic (AADT) volumes of up to 14,000 veh/day, but have weekend traffic volumes as high as 20,000–25,000 veh/day. Finland has estimated that 2+1 roads operate with accident rates 22–46 percent lower than conventional two-lane highways.

Sweden currently has over 400 km (240 mi) of 2+1 roads and expects to continue converting existing two-lane highways with wide lanes to 2+1 roads at the rate of 200–250 km (120–150 mi) per year. Sweden has implemented the 2+1 concept on roads with traffic volumes ranging from 4,000 to 20,000 veh/day. While Germany and Finland have implemented 2+1 roads with the two directions of travel separated only by pavement markings, Sweden typically provides a flush divider with a cable barrier between the two directions of travel. Sweden has observed a reduction of 55 percent in fatal and injury accidents with the implementation of 2+1 roads using the cable barrier design. Previous trials of 2+1 roads without cable barriers were less effective.

Because of European experience, the use of 2+1 roads in the United States is recommended. A 2+1 road can serve as an effective design alternative for higher-volume, two-lane roads where the provision of a four-lane cross section is not practical due to budget constraints or environmental concerns. The use of 2+1 roads in level or rolling terrain is recommended. In mountainous terrain with long, steep grades, the use of conventional truck climbing lanes, with downgrade passing lanes, where needed, is likely to be more effective operationally.

It has been found that 2+1 roads improve the traffic operational level of service for two-lane

CONTENTS

roads without increasing their capacity. A 2+1 road will generally operate at least two levels of service higher than a conventional two-lane highway serving the same traffic volume. Under ideal or near ideal conditions, 2+1 roads can operate at level of service C or better for any traffic volume that does not exceed the capacity of a two-lane road. It is recommended that 2+1 roads be used for traffic flow rates up to 1,200 veh/h in one direction of travel. The use of 2+1 roads is appropriate for a broad range of traffic composition, including roads with substantial percentages of heavy vehicle traffic.

Passing lanes on 2+1 roads should generally have lengths of 1.0–1.6 km (0.6–1.0 mi). Beyond a 1.6-km (1.0-mi) length, the downstream portion of a passing lane may be underused for passing maneuvers. However, on roads with flow rates of 700 veh/h or more in one direction of travel, passing lanes up to 3.2 km (2.0 mi) in length should remain effective operationally.

2+1 roads can operate safely and effectively in areas where minor intersections and driveways provide direct access to the roadway. Major intersections should generally be located in the buffer areas between passing lanes in opposing directions of travel and should have left-turn lanes provided.

2+1 roads can operate effectively with no separation between the lanes in opposite directions of travel according to the observed safety performance of passing lanes in the United States. However, AASHTO policy states that some separation, however small, between the lanes in opposite directions of travel is desirable. Therefore, a flush separation of 1.2 m (4 ft) between the opposing directions of travel should be considered, where practical.

Sweden has implemented 2+1 roads with a cable barrier in a flush divider between the lanes in opposing directions of travel; the flush divider is generally 1.25–2.0 m (4.1–6.6 ft) wide. Finland does not currently use cable barriers between the opposing lanes, but is considering their use in future 2+1 roads. Germany considers the use of cable barriers undesirable. A potential concern with the use of cable barriers in such narrow medians in the United States is that the barrier may deflect such that the vehicle striking the barrier comes to rest within the opposing lane of traffic. It is recommended that use of cable barriers between the opposing lanes of 2+1 roads not be considered in the United States until a full evaluation of tort liability and barrier deflection issues has been completed.

INTRODUCTION

This digest presents the results of research that included a review of traffic operational and safety information related to the design of 2+1 roads in Europe, a traffic operational and safety assessment of typical passing lane designs in the United States as compared with the 2+1 design in Europe, and recommendations for the use of 2+1 designs in the United States. This first chapter presents the research problem statement, the research objectives and scope, the research approach, and the organization of this digest.

Research Problem Statement

Several European countries use a design concept identified as a "2+1" design to improve the safety and operational efficiency of selected two-lane highways. This concept involves providing a continuous three-lane cross section and striping the roadway in such a manner as to provide for passing lanes in alternating directions throughout the section, as illustrated in Figure 1. Some countries provide a barrier between the travel lanes in opposing directions; Sweden, for example, uses a cable barrier on its 2+1 facilities.

In the United States, many states build passing lanes on two-lane roadways. While some states have built extended segments with alternating passing lanes like the 2+1 roadway concept used in Europe, most states use isolated passing lanes. Passing lanes in opposite directions of travel are normally separated by sections of conventional two-lane highway. Some state highway agencies also increase passing opportunities by providing short sections of four-lane undivided highway that are, in effect, side-by-side passing lanes.

With limited resources available to many agencies for highway improvements, safe, practical, and low-cost operational improvements are of benefit to all agencies.

Research Objectives and Scope

The objectives of this research are as follows:

- To document European practice concerning 2+1 roads
- To compare and contrast that practice with U.S. practice, identifying aspects of European practice that are potentially applicable in the United States
- To assess the potential traffic operational and safety benefits of applying those practices in the United States
- To develop recommendations for the use of 2+1 designs in the United States

The scope of the project focused on European countries that currently use 2+1 roadway designs in practice. The three countries from which the researchers obtained traffic operational and safety performance data include Finland, Germany, and Sweden.

This research was conducted as a follow-up to the *FHWA/AASHTO International Scanning Tour for Roadway*

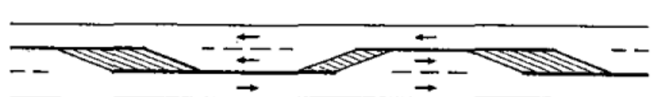


Figure 1. Schematic of 2+1 roadway.

Geometric Design conducted in June 2000 (*1*). This scan team identified 2+1 roads as an innovative treatment observed in their review of European geometric design practices and recommended that this research be performed.

The key issues in the research were (a) how passing lanes that alternate continuously between the two directions of travel perform in contrast with passing lanes provided at intervals and (b) whether the provision of a cable barrier or guardrail between the two directions of travel improves the safety performance of the passing lanes.

Organization of this Digest

The remainder of this digest is organized as described below. Chapter 2 documents European practice concerning 2+1 designs in Germany, Finland, and Sweden. Chapter 3 presents the results of traffic operational and safety comparison of 2+1 designs and conventional passing lane designs used in the United States. Chapter 4 presents recommendations for the use of 2+1 designs in the United States.

SUMMARY OF EUROPEAN PRACTICE

This chapter presents a summary of the findings from meetings with 2+1 experts and site visits to 2+1 roadway sites in Germany, Finland, and Sweden. Geometric design details, signing and marking details, and safety and traffic operational measures of 2+1 designs are presented.

European Trip

During April 2002, the principal investigator visited three European countries where 2+1 roadways are in use. Key objectives of the visit were to (1) meet with experts to discuss specific design issues related to 2+1 roadways and their safety and operational performance, (2) conduct site visits at a number of 2+1 roadways currently in use, and (3) obtain copies of design policies, plans, and traffic operational and safety performance data. The trip took place during the period April 5–19, 2002, and included the following activities:

April 8

- Meeting in Köln (Cologne), Germany, with Mr. Werner Köppel from the German Insurance Association (GDV) to discuss safety performance of 2+1 roadways
- Meeting in Bergisch Gladbach, Germany, with Dr. Roland Weber from the Federal Highway Research Institute (BASt), who is the 2+1 expert at BASt

April 9

- Meeting with Dr. Werner Brilon of Ruhr-Universität in Bochum, Germany, and Mr. Reinhard Niggemeier of Strassen.NRW (state highway agency for Nordrhein-Westfalen) to discuss geometric design and maintenance issues
- Site visits at a number of 2+1 roadways currently in use in Germany

April 11

- Meeting in Helsinki, Finland, with Mr. Pauli Velhonoja and Ms. Päivi Pesu of the Finnish Road Administration to discuss geometric design issues
- Meeting in Helsinki, Finland, with Ms. Åsa Enberg of the Helsinki University of Technology to discuss safety and operational performance of 2+1 roadways
- Meeting in Helsinki, Finland, with Dr. Heikki Summala of the University of Helsinki to learn about human factors research conducted on 2+1 roadways

April 12

- Meeting in Helsinki, Finland, with Mr. Pauli Velhonoja and Ms. Päivi Pesu of the Finnish Road Administration to obtain roadway plans and typical sections
- Site visits at a number of 2+1 roadways currently in use in Finland

April 15

- Site visits at a number of 2+1 roadways in the southern region of Sweden with Mr. Torsten Bergh, of the Swedish National Road Administration (SNRA) headquarters office, and Mr. Mikael Karlsson, of the SNRA Scania branch

April 16

- Meeting at a regional SNRA office in Kristianstad, Sweden, with Mr. Torsten Bergh and Mr. Mikael Karlsson to discuss safety and operational performance of 2+1 roadways in Sweden and view videos of maintenance crews removing the cable barrier
- Meeting at the Southeast regional SNRA office in Karlskrona, Sweden, with Mr. Torsten Bergh and Mr. Ulf Andersson, the SNRA local project manager in charge of the county of Blekinge, to discuss 2+1 roadways in that region
- Site visits at a number of 2+1 roadways currently in use in Sweden

April 17

- Meeting in Linköping, Sweden, with Mr. Arne Carlsson and Mr. Ulf Brüde of the Swedish Road and Transport Research Institute (VTI) to discuss safety and operational performance of 2+1 roadways in Sweden
- Site visit at a 2+1 roadway near Linköping, Sweden

April 18

- Meeting at a regional SNRA office in Jönköping, Sweden, with Mr. Rolf Lövkvist, project engineer, to obtain 2+1 roadway plans
- Site visits at a number of 2+1 roadways currently in use

Germany

Several years ago, two types of wider two-lane highways were used in Germany:

- Two-lane highways with wide paved shoulders intended to accommodate emergency vehicles and very slow vehicles, such as farm vehicles
- Two-lane highways with wide lanes intended to allow slower vehicles to move to the right side of their lane to allow faster vehicles to pass in the center of the roadway

These types of highway had unsatisfactory safety performance because many drivers did not use them appropriately. For example, on two-lane highways with wide shoulders, trucks used the shoulder while passenger cars used the through lane, thus treating the wide two-lane roadway as a four-lane facility and creating a potential environment for severe accidents. To improve the safety performance of these wide two-lane roadways at a minimal cost, most of them have been restriped into 2+1 roads, as illustrated in Figure 2.

Germany now has over 360 km (220 mi) of 2+1 roadway sections, all of which are in rural areas. About one-third of the 2+1 roadways have been constructed by restriping an existing two-lane roadway with wide shoulders or wide lanes. The wide shoulders or lanes are narrowed to accommodate the third lane. About two-thirds of the 2+1 roadways are new construction, most of which serve as bypass routes.

Germany does not favor the use of cable barriers between opposing directions of travel, as is done in some other countries, because of safety concerns.

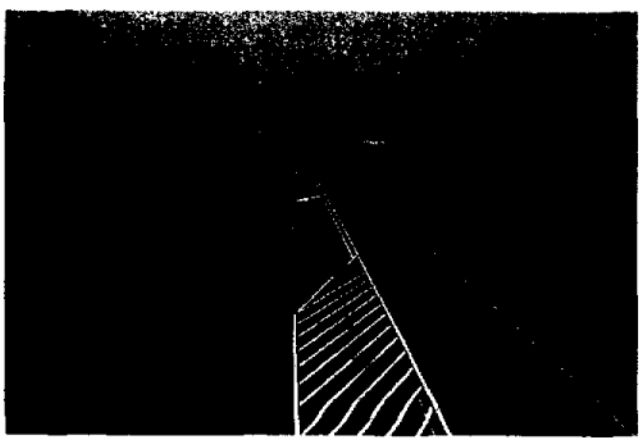


Figure 2. 2+1 roadway in Germany.

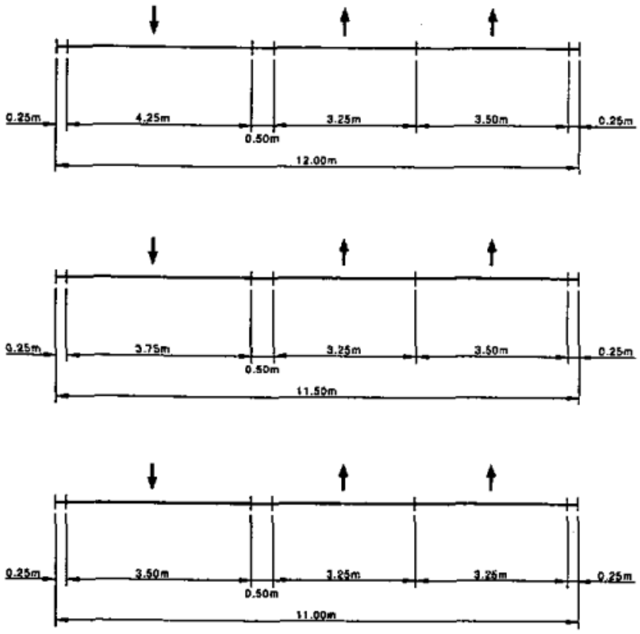


Figure 3. Typical 2+1 cross sections used in Germany.

Geometric Design

Depending on the width of the original two-lane roadway, a number of different cross sections are possible. Figure 3 illustrates three typical cross sections of 2+1 roadways in Germany.

Figure 4 illustrates two types of transitions on 2+1 roadways in Germany. A "critical" transition is one located immediately downstream of a lane drop. It is called "critical" because vehicles in the middle lane are heading toward each other before merging into the right lane; therefore, a substantial buffer between the vehicles traveling in opposite directions is needed. The length of a "critical" transition is 180 m (590 ft). A "noncritical" transition is one located immediately upstream of a lane addition. Transitions upstream of a lane addition are not as critical as those downstream of a lane drop because vehicles in the middle lane are heading away from each rather than toward each other. The length of the "noncritical" transition is at least 30 m (100 ft), but no longer than 50 m (160 ft). The taper for both types of transition is at a 45-degree angle, such that the taper length is equal to the width of the center lane.

Additional details about the geometric design of 2+1 roadways in Germany are summarized below:

- The typical length of a passing lane is 1.0–1.4 km (0.6–0.9 mi), but usually not more than 2.0 km (1.2 mi).
- While a separation of 0.5 m (1.6 ft) is typically provided between opposing travel lanes, a separation of 1.0 m (3.3 ft) with a rumble strip is under consideration.
- Lane drops and additions are placed where there is ad-

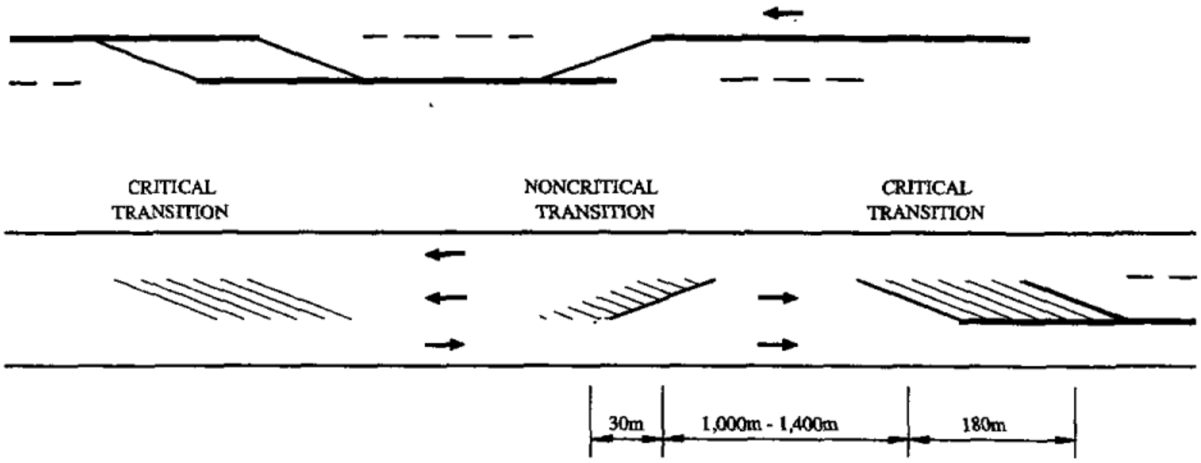


Figure 4. Dimensions for "critical" and "noncritical" transitions for 2+1 roads in Germany.

equate sight distance, but there are no specific sight distance criteria.

- A roadway may be transitioned back to a two-lane cross section on sharp curves; however, the Germans consider 2+1 facilities as generally adaptable to any terrain.
- Grade separation is used to accommodate access on semi-motorways. On conventional 2+1 highways with access, at-grade intersections are limited. The speed limit is reduced from 100 km/h (60 mph) to 70 km/h (45 mph) on an approach to an interchange or intersection.
- Two-lane highways in Germany do not have a normal crown section like those used in the United States. The cross section for 2+1 roads is a continuous cross slope from one edge of pavement to the other. Thus, German highway designers do not face a decision as to where to locate the crown or whether to transition the crown from one side of the center lane to the other at passing lane transitions. There is also no need to remove the normal crown at horizontal curves.

Signing and Marking

Figure 5 illustrates the signing and pavement markings for a lane addition. At the beginning of a passing lane, a sign is placed on the right side of the roadway to inform motorists that a passing lane has begun and to indicate the length of the passing lane. Figure 6 illustrates the signing and pavement markings for a lane drop. Advance warning signs to alert drivers of an upcoming lane drop are placed on both sides of the roadway 400 m (1,300 ft) ahead of the lane drop and again at 200 m (650 ft) ahead of the lane drop. Arrows are painted on the roadway to warn motorists in the passing lane that they must merge right. All along the 2+1 roadway section, a double white line (equivalent to a double yellow centerline in the United States) separates the two opposing directions of travel to indicate that no passing is allowed outside of the passing lane.

Safety

Table 1 presents typical accident rates for various roadway cross sections in Germany. The accident rates for 2+1 roadways are lower than those for all other two-lane highways. They are also lower than those for the four-lane undivided cross section.

Accident analyses have concluded the following:

- Conventional two-lane highways with shoulders and two-lane highways with wide lanes have lower safety performance than the 2+1 cross section does. The 2+1 cross section enables passing maneuvers within designated passing lanes without regard to the opposing traffic.
- Four-lane undivided highways have considerably lower safety performance than 2+1 roadways do.

Additional information that was learned from meetings with 2+1 experts in Germany include the following:

- The benefit-cost ratio for implementation of the 2+1 design on existing roads has been between 1 and 10.
- There have not been any safety problems in the transition areas between passing lanes in opposing directions.

Guidelines proposed in Germany in 1992 recommended the use of 2+1 roadways as appropriate for new construction of roads in the ADT range from 8,000 veh/day to 22,000 veh/day.

Traffic Operations

The speed limit on 2+1 roadways in Germany is 100 km/h (60 mph). The traffic volumes range from 15,000 veh/day to 25,000 veh/day; the maximum traffic volume level observed was 30,000 veh/day. This level represents

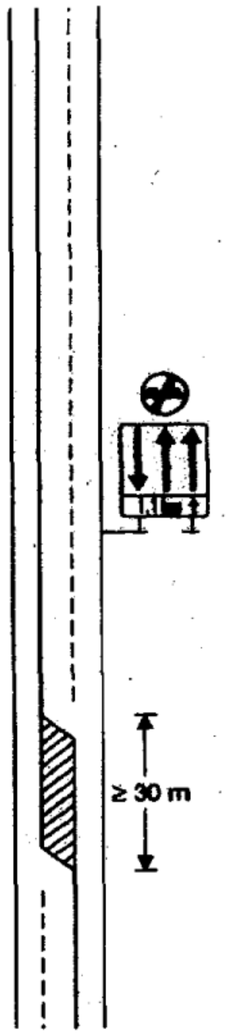


Figure 5. Signing used at the beginning of a passing lane in Germany.

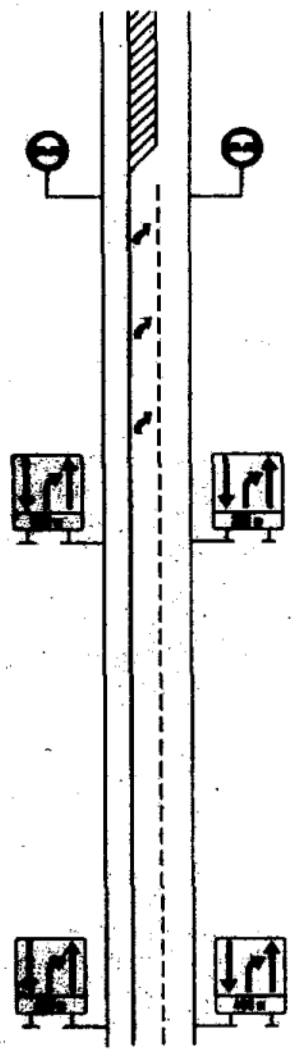


Figure 6. Signing and pavement markings used for a lane drop in Germany.

TABLE 1 Typical accident rates for various roadway cross sections in Germany (2)

Roadway type	ADT (veh/day)	Accident rate (per 10^6 veh-km)	
		Fatal and injury accidents	Fatal, injury, and serious PDO accidents
6-lane freeway	61,000	0.13	0.35
4-lane freeway	31,000	0.13	0.39
4-lane divided highway with wide shoulders	19,500	0.15	0.37
4-lane divided highway	16,600	0.19	0.39
4-lane undivided highway	12,100	0.21	0.39
2+1 roadway	14,100	0.16	0.28
2-lane highway with wide lanes	11,900	0.28	0.49
2-lane highway with wide shoulders[a]	9,800	0.19	0.35
2-lane highway (conventional)	10,300	0.25	0.39
2-lane highway (narrow lanes)	3,500–6,300	0.22–0.44	0.39–0.71

[a] With paved shoulders wide enough that they can be used for passing.
PDO = property damage only.

higher traffic volumes than are typically served on 2+1 facilities in Finland and Sweden. Previous research has tried to determine the capacity of 2+1 roadways in Germany. Based on speed-volume relationships observed, the capacity of 2+1 roadway sections could not be derived. Currently, Brannolte is conducting a study to evaluate the capacity and level of service of 2+1 roadways. The results of this study are not yet available, but should be available some time in 2003. Brannolte has previously stated that, from simulation runs, the 2+1 cross section shows no significant advantages in capacity over nonwidened typical rural two-lane roads (*3*). This makes sense in that the capacity of a 2+1 road is governed by the capacity of the sections with a single lane in a given direction of travel.

Additional details about the operational performance of 2+1 roadways in Germany are summarized below:

- It has been determined through observation and simulation that 2+1 roadways operate at a better level of service than conventional two-lane roadways do.
- The overall section length of 2+1 roadway that is needed to be effective is in the range of 4–6 km (2.5–3.7 mi); however, 2+1 roadway sections have been effective at lengths of up to 15 km (9.3 mi).
- No formal evaluations have been made on the effect on vehicle speeds of restriping a wide two-lane cross section to a 2+1 cross section. However, it is thought that vehicle speeds on cross sections with very wide lanes are higher than speeds on 2+1 cross sections.
- The narrow shoulders resulting from restriping a wide two-lane cross section to a 2+1 cross section present a problem for maintenance/construction vehicles and disabled vehicles.

Driver Acceptance

A driver survey was conducted at five 2+1 road sites in Germany between 1983 and 1988. Table 2 presents a summary of the survey results. Most drivers prefer 2+1 roads to normal rural roads and believe that 2+1 roads offer better passing opportunities. A majority of drivers believe that they can travel faster on 2+1 roads, but do not believe that 2+1 roads are dangerous.

Finland

With limited funds available for costly investments such as widening to four lanes, the Finnish Road Administration addressed the need to improve traffic flows on conventional two-lane highways and two-lane highways with wide shoulders by widening, where applicable, and restriping these facilities as 2+1 and wide-lane roads. These new cross sections were considered a relatively inexpensive way to improve traffic flow on roadways where the traffic volumes did not yet warrant a freeway. Figure 7 illustrates a 2+1 roadway in Finland.

The first 2+1 roadway in Finland was opened in 1991. Finland has had a total of five 2+1 facilities, but some have been widened to four lanes as traffic grew. Finland currently has two 2+1 roadway facilities in operation, both in rural areas. There are nine passing lanes on one 2+1 roadway section and 14 on the other, for a total length of 48 km (30 mi) of 2+1 roadways. Both 2+1 roadway sites have been constructed by restriping existing two-lane roadways with cross sections that were 13 m (43 ft) wide. However, there are plans to incorporate 2+1 cross sections into new construction. Currently, all 2+1 roadway facilities in Finland

TABLE 2 Results of surveys of German drivers concerning 2+1 roads

Question	Percentage of responses
How do 2+1 roads compare to normal rural roads?	
Better	92
Worse	5
No difference	3
On 2+1 roads, one can pass much better than on normal rural roads.	
Agree	92
Disagree	6
No opinion	2
2+1 roads are dangerous.	
Agree	22
Disagree	75
No opinion	3
On 2+1 roads, one can travel faster.	
Agree	80
Disagree	15
No opinion	5

NOTE: Survey is based on driver survey results conducted at five 2+1 road sites between 1983 and 1988.

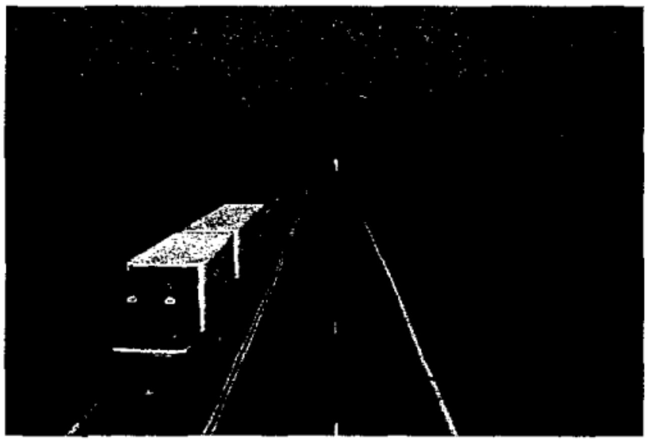


Figure 7. 2+1 roadway in Finland.

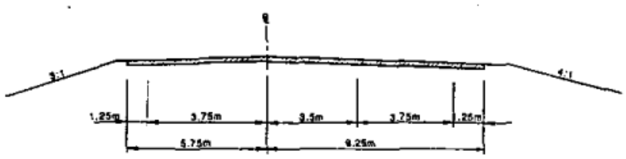


Figure 10. Recommended crowned section without median cable barrier being considered for use in Finland.

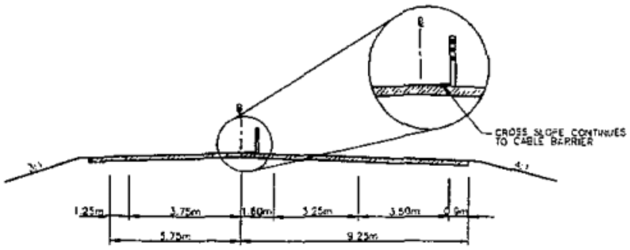


Figure 11. Recommended crowned section with median cable barrier being considered for use in Finland.

use pavement markings only. However, strong consideration is being given to using a flush divider with a cable barrier to separate opposing lanes on future 2+1 roadway facilities.

Geometric Design

Figure 8 illustrates a typical cross section for a 2+1 roadway with no median barrier in Finland. Finland does not currently use median barriers between opposing directions of travel, but plans to begin incorporating them into future 2+1 roadway designs. Figure 9 illustrates a typical cross section for future 2+1 roadways with a median barrier.

Neither of the existing 2+1 roadways in Finland has a normal crown. At both sites, the roadway has a continuous cross slope from one side of the pavement to the other. However, Figures 10 and 11 illustrate how a crowned section, without a median cable barrier and with a median cable barrier, would be handled on such a facility in Finland.

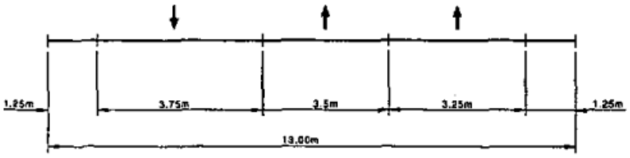


Figure 8. Cross section without median barrier used in Finland.

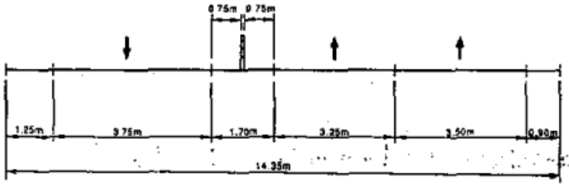


Figure 9. Cross section with median barrier being considered for use in Finland.

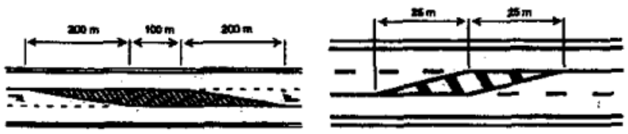


Figure 12. Dimensions of lane-drop and lane-addition transitions used in Finland.

Figure 12 illustrates the dimensions of lane-drop and lane-addition transitions in Finland. The length of the transition downstream of a lane drop is 500 m (1,600 ft), including taper. The length of the transition upstream of a lane addition is 50 m (160 ft), including taper. Figure 13 illustrates a lane-addition transition at a 2+1 roadway site in Finland. Figure 14 illustrates a lane-drop transition from two lanes to one lane at a 2+1 roadway site in Finland.

Neither of the existing 2+1 roadways have at-grade intersections. All access is accommodated at interchanges. On future 2+1 facilities, a limited number of intersections and driveways will be allowed. The specific design of these future at-grade intersections has not yet been determined.

An at-grade intersection design that is currently in use on some conventional two-lane roads with passing lanes is a right-hand diverging lane loop for left turns, as illustrated in Figure 15. The loop turn is appropriate for cross roads with very low traffic volumes, such as less than 100 veh/day. Loop turns are similar to jug handles in the United States. In making a loop turn to the left, the driver exits the roadway to the right, enters a lane loop, and then crosses the major road perpendicularly. The premise behind the loop turn is that the turning vehicle does not disturb the flow and safety of the

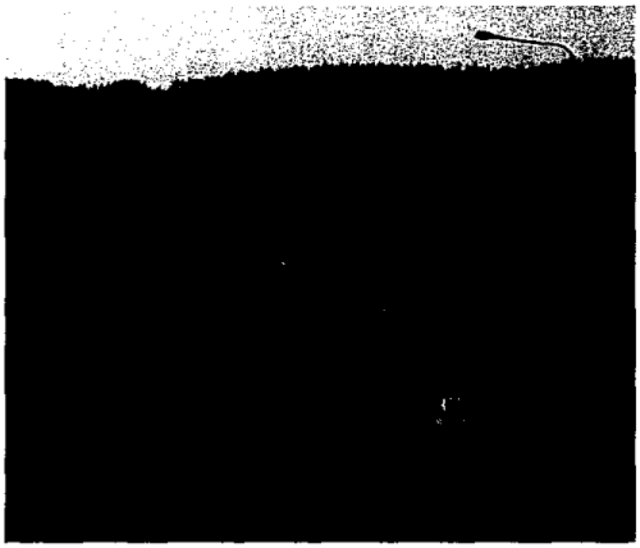


Figure 13. Example of a lane-addition transition in Finland.

Figure 14. Example of a lane-drop transition in Finland.

traffic on the major road. Many highway engineers in Finland believe that if an intersection must be accommodated on a passing lane section of a two-lane roadway, a loop turn is the best intersection design to implement. Some, however, believe that either widening the shoulder to allow through vehicles to pass to the right of a left-turning vehicle or providing a left-turn lane is a safer and more functional option. While there have been no traffic accidents as a result of the loop turns, Finland has experienced some driver behavioral and traffic operational problems. For example, some drivers either do not understand the loop turns or do not care to use them when making a left turn. Another problem involves slow farm equipment having to cross the entire width of the roadway.

Additional details about the geometric design of 2+1 roadways in Finland are summarized below:

- The typical length of a passing lane is 1.5 km (0.9 mi).
- Stopping sight distance (SSD) is provided everywhere; decision sight distance (DSD) is provided at interchanges and lane drops.

Signing and Marking

Figure 16 illustrates the signing and pavement markings along a 2+1 roadway section in Finland. A sign placed at the beginning of a passing lane notifies drivers of the length of the passing lane. Another sign, placed in each one-lane section, notifies drivers when a passing lane is 1.0 km (0.6 mi) ahead. Advance warning signs to alert drivers of an upcoming lane drop are placed on both sides of the roadway 400 m (1,300 ft) ahead of the lane drop and again at 50 m (160 ft) ahead of the lane drop.

A double barrier line is always provided as a separation between opposing travel lanes. The specified separation between the lines is 10 cm (4 in.); the width of each line is also 10 cm (4 in.).

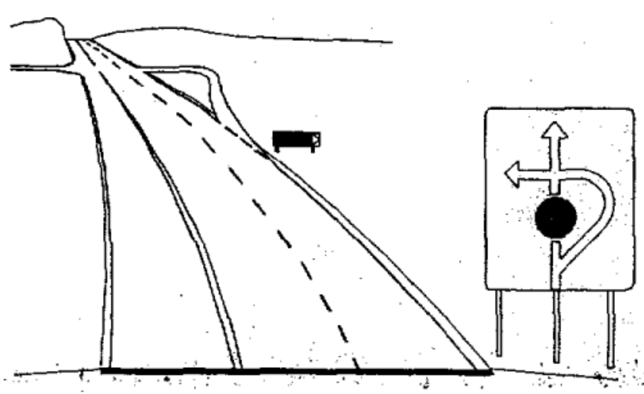


Figure 15. Right diverging lane loop for left turns used in Finland.

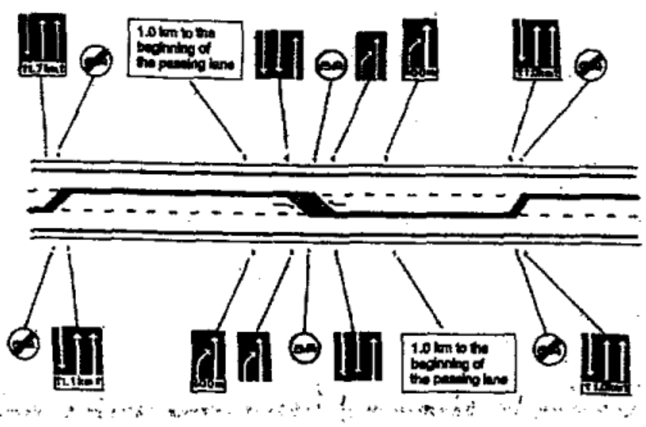


Figure 16. Signing and pavement markings along a 2+1 roadway section in Finland.

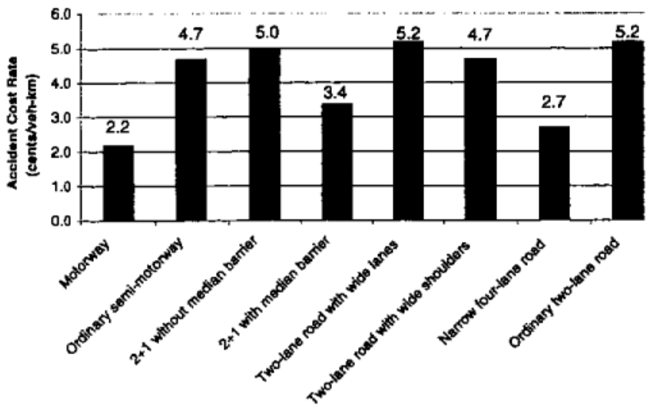


Figure 17. Estimated accident cost rates for specific road types in Finland.

Safety

The safety performance of the two existing 2+1 roadways in Finland has not been consistent. On one roadway, the safety performance has been good; the other roadway has experienced a number of accidents in the winter.

The Finnish Road Administration has estimated that traffic safety on 2+1 sections without median barriers is not much better than on ordinary two-lane roads, as illustrated in Figure 17. The passing lanes have improved traffic flow, but have not provided a substantial safety improvement. Since about half of the fatal accidents are head-on crashes, Finland is planning to incorporate cable barriers into its 2+1 design for future construction. Finns believe that a median barrier would reduce head-on accidents by 80 percent. Figure 17 shows that the estimated accident cost rate for a 2+1 roadway with a median barrier are about 30 percent less than the estimated accident cost rate for a 2+1 roadway without a median barrier. The accident cost rate is the total estimated cost of accidents of all severity levels divided by exposure in veh-km of travel.

Table 3 presents the estimated accident rates for the same roadway types as presented in Figure 17. Again, the estimated safety performance of a 2+1 roadway without a median barrier is similar to that of an ordinary two-lane road. However, a 2+1 roadway with a median barrier is expected to have a better safety performance, with nearly half the fatal accident rate as a 2+1 roadway without a median barrier and an ordinary two-lane road.

Actual accident rates based on accident data from 1996 to 2000 for several roadway types are presented in Table 4. No data are presented for 2+1 roadways with median barriers because no median barriers have been implemented yet in Finland.

One of the existing 2+1 roadways experienced lower injury and fatality accident rates compared with ordinary two-lane roads, with and without passing lanes, while the other 2+1 roadway experienced higher accident rates. Many of the accidents on Site E have been winter accidents.

The transition areas downstream of a lane drop have experienced some safety problems. Higher speeds in passing lanes (15 km/h [9 mph] higher than in through lanes) and passing maneuvers just before the end of the passing lane have caused some head-on collisions.

Traffic Operations

The two 2+1 roadway sites in Finland have accommodated AADTs up to 14,000 veh/day. The capacity on one of the roads was measured to be about 1,900 veh/h in one direction in 1993. The capacity of the other road was measured to be 1,600–1,700 veh/h in one direction in 2001. On Fridays and Saturdays, traffic volumes can be as high as 20,000–25,000 veh/day. When traffic volumes are near capacity, some operational problems arise. For example, at flow rates of 1,200–1,400 veh/h, queuing begins at the lane-

TABLE 3 Estimated accident rates for specific road types in Finland

Roadway type	Injury accident rate (acc/10^8 veh-km)	Fatal accident rate (acc/10^8 veh-km)
Motorway[a]	4	0.3
Ordinary semi-motorway[a]	6	1.5
2+1 roadway without median barrier	8	1.3
2+1 roadway with median barrier	7	0.7
Two-lane road with wide lanes	8	1.3
Two-lane road with wide shoulders	7	1.1
Narrow four-lane road	6	0.5
Ordinary two-lane road[a]	9	1.3

[a] Based on accident data.

TABLE 4 Accident rates based on accident data from Finland (1996–2000)

Roadway type	Length (km)	Injury accident rate (acc/10^8 veh-km)	Fatal accident rate (acc/10^8 veh-km)
Motorway	356	4.3	0.3
Semi-motorway	152	6.2	1.5
Two-lane rural road	10,339	8.7	1.3
Two-lane road with wide lanes (semi-motorway)			
Site A	6	5.9	5.9
Site B	16	4.3	0.8
Site C	13	5.3	3.5
2+1 roadway (semi-motorway)			
Site D	26	5.5	0.8
Site E	22	8.9	3.1
Two-lane roadway with passing lane	277	8.8	1.1

NOTE: Not enough accident data to draw any final conclusions.

drop transition, with drivers leaving the queue in the rightmost lane to improve their position in the queue. The speed limit on 2+1 roadways in Finland is 100 km/h (60 mph) for passenger cars and 80 km/h (50 mph) for trucks.

Before-after studies performed using traffic analyzers, license plate surveys, and simulations reached the following conclusions:

- The number of passes increased 20–40 percent in daytime traffic and more than doubled in weekend peak-hour traffic. However, on the two-lane highway, both downstream and upstream of the 2+1 section, the number of passes per vehicle decreased. This finding is potentially positive for safety, because more risky passes in the lane normally reserved for opposing traffic are being reduced.
- Travel speeds at low flow rates were 1–2 km/h (0.6–1.2 mph) higher for the 2+1 roadway than for the two-lane cross section it replaced. At higher flow rates, the increase in travel speeds was 4–5 km/h (2.5–3.1 mph); however, the traffic flow occasionally reached a "break down" level for short periods of time, which reduced travel speeds. There was a more gradual decrease in travel speed with increasing traffic on the 2+1 roadway sections than on the previous two-lane sections.
- The capacity for one direction of travel was 1,500–1,600 veh/h for both the 2+1 roadway and the previous two-lane cross section.

Additional details about the operational performance of 2+1 roadways in Finland are summarized below:

- The optimum length for a passing lane for a 2+1 roadway section is estimated to be between 1.0 km and 1.5 km (0.6–0.9 mi).
- The benefit from the decrease in percent time spent following (PTSF) in the passing lane ends about 3.3 km (2.1 mi) downstream of the end of the passing lane. The benefit from increased speeds in the passing lane ends about 2.7 km (1.7 mi) downstream of the end of the passing lane.
- Vehicle speeds are usually higher during the day than at night.
- Mean speeds are about 4 km/h (2.5 mph) lower during snowfall and up to 7 km/h (4.3 mph) lower during slippery conditions.
- Construction costs for 2+1 roads and two-lane roads with wide lanes are, on average, about 10 percent higher than construction costs for ordinary two-lane roads. Construction costs for 2+1 roads with median barriers are expected to be 15–30 percent higher than construction costs for conventional two-lane roads.

Driver Acceptance

According to evaluations of traffic operations and driver behavior, the two existing 2+1 roadways in Finland have improved operational efficiency and have been popular with motorists. In fact, the results of a survey indicate that about 80 percent of motorists prefer the 2+1 road to a conventional two-lane road. The police have also been satisfied with the new road type, and drivers have adapted to it quickly.

Sweden

Sweden's evolution from 13-m (43-ft)-wide, two-lane roadways to 2+1 roadways is similar to the experience in Germany. Prior to the introduction of 2+1 roadways, the Swedish national road network included about 3,600 km (2,200 mi) of 13-m (43-ft) roads—2,800 km (1,700 mi) with wide shoulders and 800 km (500 mi) with wide lanes—with AADTs varying from 4,000 veh/day to 20,000 veh/day. The traffic operational performance of 13-m (43-ft) roads was good, but the safety performance, while better than that of conventional two-lane roads, was disappointing. Nearly 100 fatalities and 300 severe injuries occurred each year on 13-m (43-ft) roads because of the increasing traffic volumes. More than 50 percent of the fatalities resulted from run-off-road and head-on accidents, probably caused by driver distraction, driver fatigue, or the monotonous environment on many of the roads.

While nearly a fourth of all fatalities on state roads in Sweden occurred on 13-m (43-ft) roads, the Swedish National Road Administration (SNRA) introduced a traffic policy defining "Vision Zero" as a major objective—no one killed or severely injured in road traffic accidents. At the same time, the budget for rural road investments was substantially cut. Thus, SNRA set out to improve traffic safety on existing 13-m (43-ft) roadways using low-cost measures. They decided on a 2+1 cross section with a cable barrier and roadside improvements within the existing right-of-way, where possible. It was anticipated that this alternative would prevent up to 50 percent of all severe accidents. The safety performance of the first 2+1 roads with cable barriers was so successful that SNRA decided to restripe 13-m (43-ft) roads with the 2+1 alternative on a more widespread basis. Figure 18 illustrates a typical 2+1 roadway with a center cable barrier in Sweden.

Initially, SNRA found it very difficult to promote 2+1 roads in the political planning process. However, the 2+1 concept has turned out to be a political success in Sweden. The public, media, and politicians have changed their views almost 180 degrees since the first 2+1 roadway opened.

Sweden now has more than 400 km (240 mi) of 2+1 roadway sections, all of which are located in rural areas. In some cases, a roadway may consist mostly of a 2+1 cross section with occasional two- and four-lane sections. The Swedes expect to continue converting 13-m (43-ft) roads to 2+1 roads at a rate of 200–250 km (120–150 mi) per year. Currently, about two-thirds of the 2+1 roadways are semi-motorways, with grade separation and prohibition of farm vehicles, pedestrians, and bicyclists. The rest have direct access, including at-grade intersections and occasional driveways. Nearly all of the 2+1 roadways have been constructed by restriping existing 13-m (43-ft) roadways and narrowing the shoulders. Only one 2+1 facility is new construction, but more are in the planning or design stage.

Geometric Design

Sweden currently uses a CEN N2 barrier, which is a three- or four-cable barrier, between the travel lanes in opposing directions. The barrier is intended to prevent vehicles from entering into oncoming traffic and potentially causing a head-on collision. Quick locks make it possible to open the cable barrier in each transition and at fixed intervals along the roadway to accommodate maintenance and emergency vehicles. Where quick locks are not present, the cables can be taken down manually. Figure 19 illustrates a three-cable barrier end treatment. Several manufacturers of cable barrier exist in Sweden, so the specific type of barrier used varies from one 2+1 facility to another. The safety performance of the cable barrier and the effect of the cable barrier on the traffic operational performance of 2+1 roads are discussed later in this section.

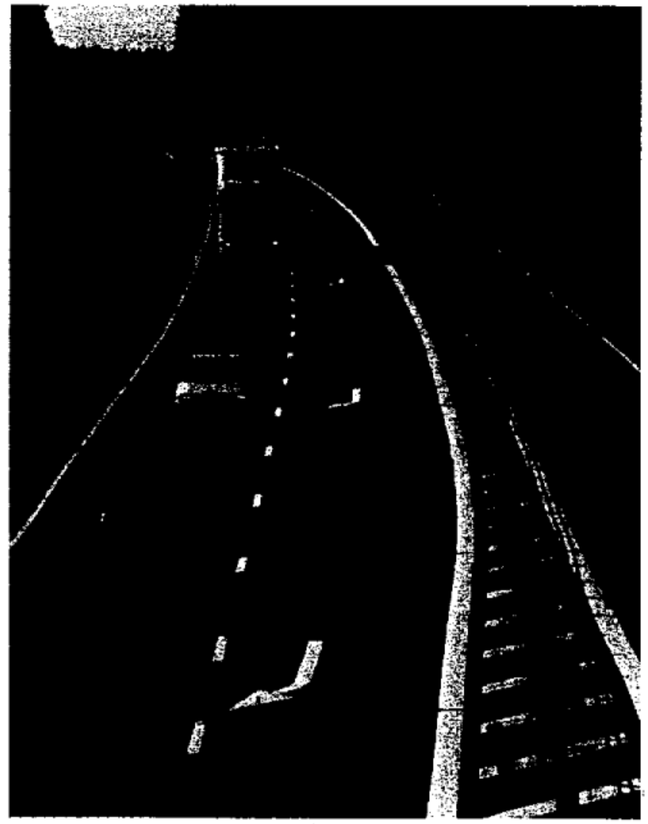


Figure 18. Typical 2+1 roadway with center cable barrier in Sweden.

Figure 20 illustrates a typical cross section for existing 2+1 roadways with cable barriers in Sweden. The 0.75-m (2.5-ft) hard outer shoulders facilitate very low-volume pedestrian and bicycle traffic. A strip of 1.0 m (3.3 ft) with full bearing capacity without overlay can be added in the one-lane direction of travel to accommodate emergency vehicles. In some cases, existing 13-m (43-ft) roadways have been widened to accommodate a wider 2+1 cross section.

Sweden has recently revised its design guidelines for 2+1 roadways. The revised guidelines state that, for rehabilitation projects, the total roadway width may remain at 13 m (43 ft) or may be widened to 14 m (46 ft); for newly constructed 2+1 roadways, a total roadway width of 14 m (46 ft) is recommended. Figure 21 illustrates the cross sections recommended in Sweden's recently revised guidelines for the following:

- Conventional 2+1 roadways with a total roadway width of 13 m (43 ft)

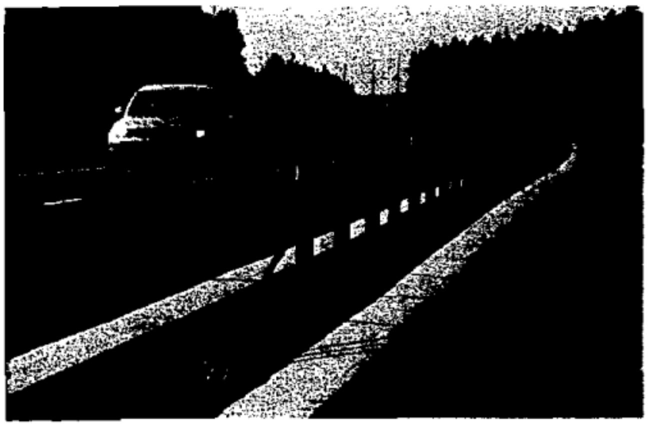


Figure 19. Cable barrier end treatment in Sweden.

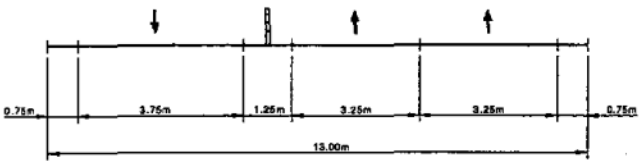


Figure 20. Cross section of existing 2+1 roadways with cable barrier in Sweden.

- 2+1 semi-motorways with a total roadway width of 13 m (43 ft)

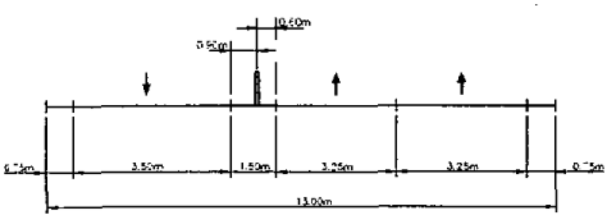
Figure 22 illustrates the cross sections recommended in the guidelines for the following:

- Conventional 2+1 roadways with a total roadway width of 14 m (46 ft)
- 2+1 semi-motorways with a total roadway width of 14 m (46 ft)

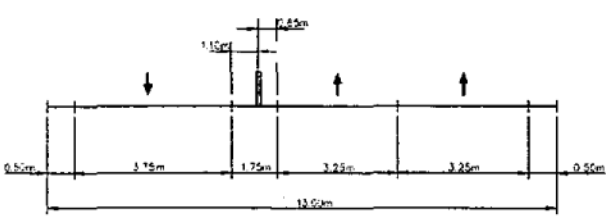
Many of the 2+1 roadways in Sweden are not semi-motorways and, therefore, accommodate at-grade intersections. Typically, at-grade intersections are located in the transition area between alternating passing lanes. In other words, when designing the layout of alternating passing lanes, designers intentionally place intersections between passing lanes in opposing directions of travel. The design of at-grade intersections in Sweden is similar to at-grade intersections on two-lane roads in the United States, with left-turn lanes and painted channelization. Figure 23 presents a photograph of a three-legged intersection on a 2+1 roadway in Sweden. Figure 24 presents a photograph of a four-legged intersection on a 2+1 roadway in Sweden.

Additional details about the geometric design of 2+1 roadways in Sweden are summarized below:

- Transition zones from two lanes to one lane ("critical" transitions) are 300 m (1,000 ft) long. Transition zones

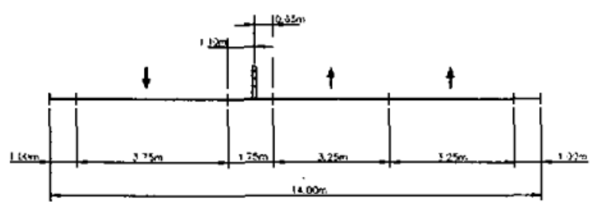


a) Conventional 2+1 roadway—13-m (43-ft) cross section

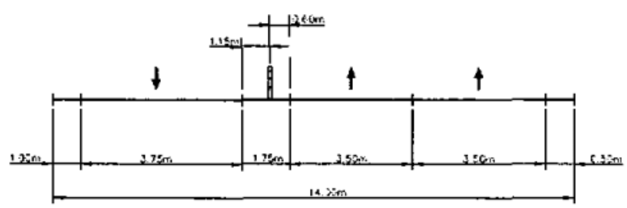


b) 2+1 semi-motorway—13-m (43-ft) cross section

Figure 21. Recommended cross sections for 13-m (43-ft)-wide 2+1 roadway with cable barrier in Sweden (conventional and semi-motorway).



a) Conventional 2+1 roadway—14-m (46-ft) cross section



b) 2+1 semi-motorway—14-m (46-ft) cross section

Figure 22. Recommended cross sections for 14-m (46-ft)-wide 2+1 roadway with cable barrier in Sweden (conventional and semi-motorway).

Figure 23. Three-legged intersection on 2+1 roadway in Sweden.

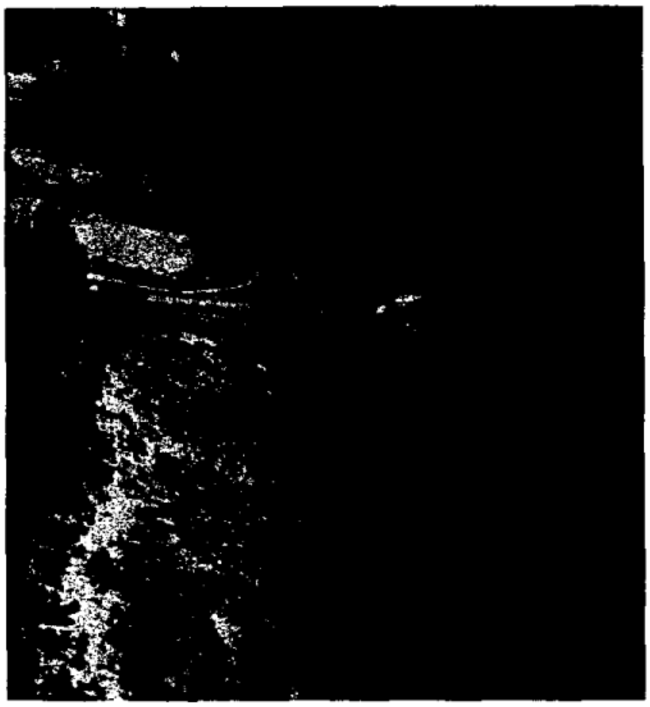


Figure 24. Four-legged intersection on 2+1 roadway in Sweden.

from one lane to two lanes ("noncritical" transitions) are 100 m (330 ft) long.

- Passing lanes are provided at intervals of 1.0–2.0 km (0.6–1.2 mi). The length depends on alignment, locations of intersections, etc. Two-lane cross sections can be provided at long bridges and on sections with frequent access roads, with frequent pedestrians and bicyclists, or where separation is not feasible.
- For rehabilitation projects, the SNRA recommends that side barriers be implemented in rock cuts, in low earth cuts, and at all embankments with poles, rocks, or trees within the clear zone. Some projects are designed with 1:6 fore slopes in one-lane sections and with clearance of hazardous objects in two-lane sections.
- Permanent emergency openings in the cable barrier are established every 3–5 km (2–3 mi) to allow emergency vehicles to make U-turns.
- Access points are limited, and separate pedestrian and bicycle facilities are provided whenever possible.
- The width of the flush median containing the cable barrier varies from 1.25 m to 2.0 m (4.1–6.6 ft).

Signing and Marking

At the beginning of the transition for a lane addition, a sign is sometimes placed on both sides of the roadway to inform motorists that a passing lane is about to begin and to indicate the length of the passing lane. Figure 25 presents a photograph of a noncritical transition at a 2+1 roadway site in Sweden.

Figure 26 illustrates the signing and pavement markings for a lane drop. Advance warning signs to alert drivers of an upcoming lane drop are placed on both sides of the roadway 400 m (1,300 ft) ahead of the lane drop and at the beginning of the transition zone. The barrier poles typically have delineator posts at a 100-m (330-ft) spacing; this spacing is decreased to 10 m (33 ft) in the transitions. Arrows are painted on the roadway to warn motorists in the passing lane that they must merge right. All along the 2+1 roadway section, a solid white line is painted on either side of the cable barrier separating the two opposing directions of travel.

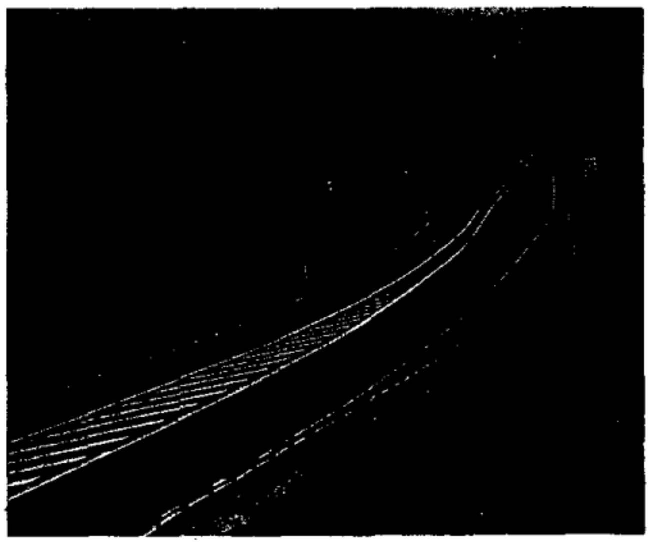


Figure 25. Example of a noncritical transition in Sweden.

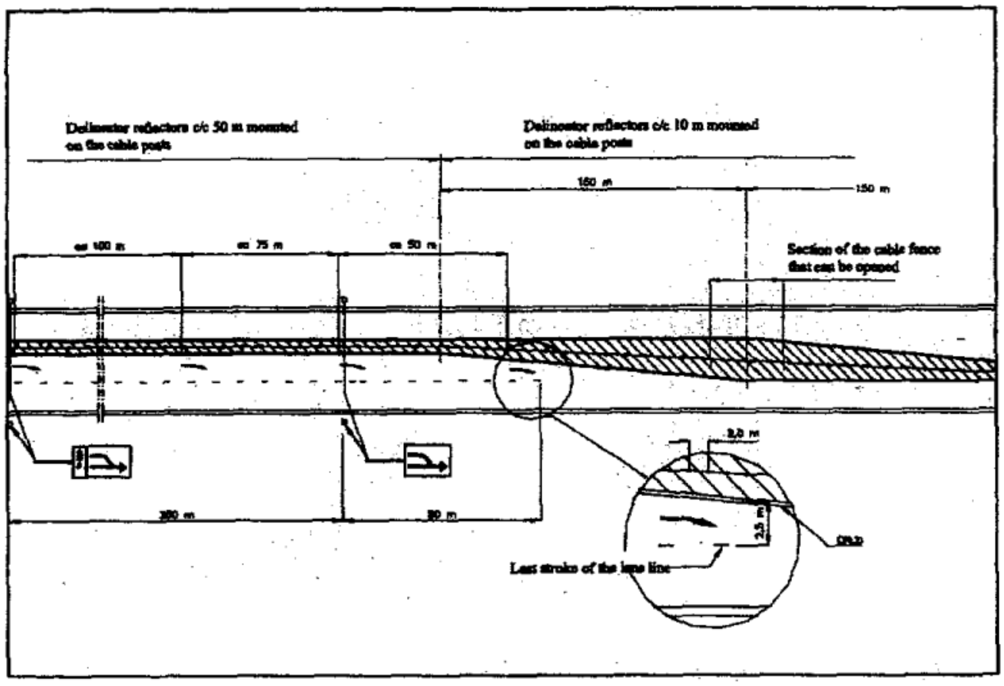


Figure 26. Signing and pavement markings for a lane drop in Sweden.

Figure 27 presents a critical transition at a 2+1 roadway site in Sweden.

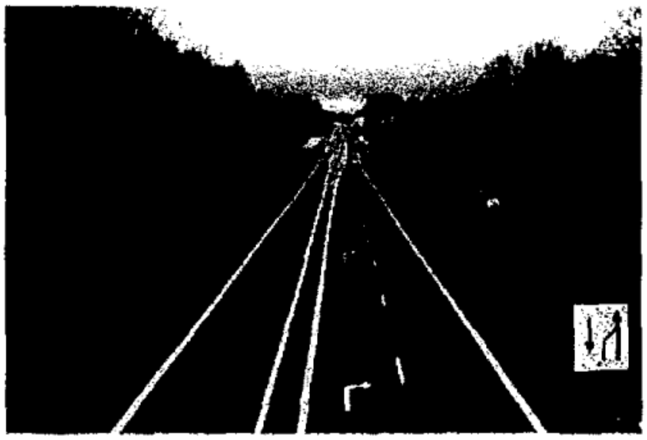


Figure 27. Example of a critical transition in Sweden.

Safety

The Swedes expected that 2+1 roadways with cable barriers would reduce accidents involving severe injuries or fatalities by up to 50 percent from ordinary 13-m (43-ft) roadways. So far, the safety performance of these roads has been even better than expected. On semi-motorways (i.e., facilities with partial access control), there has been one fatal accident and six severe injuries, representing about a 55-percent reduction in fatalities and severe injuries from ordinary 13-m (43-ft) roadways. It is worth noting that the fatal accident involved a bicyclist riding at nighttime on a 2+1 semi-motorway, where bicycle traffic is prohibited. Table 5 presents the distribution of all accidents on all 2+1 roadways in Sweden through April 2001.

The safety performance of 13-m (43-ft) roads prior to being restriped as 2+1 roads provides a framework for estimating what the safety performance would have been had these roads not been converted to a 2+1 cross section. Table 6 presents a comparison between the predicted number of accidents on ordinary 13-m (43-ft) roads with the observed number of accidents after conversion to a 2+1 cross section.

The comparison between the number of predicted and observed accidents in Table 6 suggests that converting 13-m (43-ft) roads to 2+1 cross sections with cable barriers has potentially prevented a number of fatalities and severe injuries. This prevention may be largely attributed to the median cable barrier. However, while the median cable barrier has prevented a number of potentially severe accidents, median barrier crashes are frequent, as demonstrated by the increase in property-damage-only (PDO) accidents (188 predicted versus 248 observed). In fact, the median cable barrier crash rate is about 0.5 million crashes per axle-pair-km. This crash rate translates to about one median barrier crash per week. About 60 percent of the median barrier crashes occur in the

TABLE 5 Distribution of 2+1 roadway accidents in Sweden

Accident type	Total number of accidents	Number of injuries		
		Slight	Severe	Fatalities
Single vehicle	69	18	5	0
Passing	29	5	0	0
Rear-end	14	8	0	0
Other	9	0	1	1

TABLE 6 Comparison of predicted and observed accident experience for 2+1 roads in Sweden

Accident type	Number of accidents	
	Predicted	Observed
Fatality	9	1
Severe injury and fatality	36	14
Injury	120	91
Fatality, injury, and PDO	188	248

PDO = property damage only.

one-lane section, about 55 percent occur during the winter, and about 8 percent occur in the transition from two lanes to one lane. Median barrier crashes are often caused by loss of control due to skidding or flat tires, but usually involve only property damage to the vehicle involved.

One of the concerns with median cable barriers has been how well they would perform in transition areas, particularly the lane-drop transition, and at the cable barrier ends. The lane-drop transition areas have performed well. Drivers have used the transition areas in a cautious and responsible manner. The cable barrier ends have been tested and do not cause any ramp effects. In fact, there have been no safety problems with cable barrier ends on any of the 2+1 roadways in Sweden.

Another concern with median cable barriers has been the extent to which it deflects when struck by a vehicle. In other words, a vehicle that strikes the median cable barrier should not get "trapped" in the cables with the front of the vehicle projecting into the opposing travel lane. The median cable barrier used on 2+1 roadways in Sweden complies with Swedish N2 regulation that states that a passenger car striking the barrier at a 20-degree angle at 100 km/h (60 mph) should cause a deflection in the barrier between 1 m and 2 m (3.3–6.6 ft). Given the 1.25-m (4.1-ft) separation between the two lanes of opposing traffic and the typical distance a driver keeps between the vehicle and the edge line, SNRA considers that a deflection between 1 m and 2 m (3.3–6.6 ft) should not cause a greater safety problem than would occur without a barrier. Furthermore, the cables are attached to "breakaway" posts. Thus, a vehicle that strikes the cable barrier generally snaps off the posts and gets redirected by the cables back into the travel lane. While the cable barriers have not been tested with trucks, they have withstood heavy vehicle crashes at narrow angles. In fact, at least two 60-ton trucks have been "caught" by the barrier.

In the 1980s and 1990s, Sweden constructed five 2+1 roadways with pavement markings only. Since using cable barriers on its 2+1 roadways, Sweden has found that the safety performance of its 2+1 roadways with cable barriers has been much better than the safety performance of its 2+1 roadways with pavement markings only.

Traffic Operations

When SNRA initiated the program to restripe 13-m (43-ft) roads to 2+1 cross sections, it faced criticism about the narrow one-lane sections potentially having a negative effect on speed performance. The Swedes expected that 2+1 roadways with cable barriers would reduce speeds by 2–4 km/h (1.2–2.5 mph). However, the average speed has increased by 2 km/h (1.2 mph). Overall, the speed performance on 2+1 roadways is the same as or even better than normal 13-m (43-ft) roads at one-directional flow rates up to 1,400 veh/h.

On existing semi-motorways in Sweden, speed limits of 90 km/h and 110 km/h (55 mph and 70 mph) have been used. Recently revised Swedish guidelines recommend speed limits of 110 km/h (70 mph) for new 2+1 roads on semi-motorways and speed limits of either 90 km/h or 110 km/h (55 mph or 70 mph) for new conventional 2+1 roads. The speed limit for trucks on 2+1 roads is 80 km/h (50 mph). An evaluation of travel speeds was conducted on one of the 2+1 facilities in Sweden using the following techniques:

- Before-after spot speed measurements compared with a control section on an adjacent 13-m (43-ft) road
- Floating car studies in high traffic volumes
- Continuous lane-based spot speed measurements at the beginning of a one-lane section in one direction of travel and at the end of a two-lane section in the other direction of travel

Bergh and Carlsson present the following conclusions based on early speed performance of the first 2+1 roadways in Sweden (*4*):

- Average travel speeds for passenger cars increased about 2 km/h (1.2 mph) at a speed limit of 90 km/h (55 mph) when a 13-m (43-ft) roadway was restriped to a 2+1 cross section.
- The average spot speed for passenger cars on roadways with a 90-km/h (55 mph) speed limit is 101 km/h (63 mph). The average spot speed for passenger cars on roadways with a 110-km/h (70-mph) speed limit is 107 km/h (66 mph).
- Spot speeds for passenger cars at the beginning of one-lane sections range from 93 km/h to 100 km/h (58–62 mph) at traffic flows between 1,200 veh/h and 1,350 veh/h.
- Spot speeds for passenger cars in the passing lane range from 110 km/h to 120 km/h (68–75 mph), far above the official speed limit of 90 km/h (55 mph) (before April 1999).
- On average, there is about a 5-km/h (3-mph) difference in average travel speeds for passenger cars between one-lane and two-lane sections.
- Average passenger car spot speeds on two-lane sections are 4 km/h (2.5 mph) higher on a 2+1 roadway with a median cable barrier than on a 13-m (43-ft) roadway with wide lanes.
- The spot speeds on the two-lane section are slightly higher on a 2+1 roadway without a median cable barrier than on a 2+1 roadway with median cable barrier.
- Five percent of the hourly speeds are below 90 km/h (55 mph) on roadways with a 90-km/h (55-mph) speed limit.
- At one-directional flows above 900 veh/h, there is considerable variation in speed profile among the different segments.
- Side cable barriers located 1 m (3.3 ft) from the pavement do not affect speeds.

The level of service on 2+1 roadways in Sweden has been better than originally anticipated. The capacity of a 2+1 roadway is estimated to be 1,600–1,700 veh/h in one direction during a 15-min period. This value is estimated to be about 300 veh/h less than for an ordinary 13-m (43-ft) road with wide lanes. Floating car studies confirm a good level of service at traffic flows up to 1,300–1,400 veh/h in one direction. AADTs for which 2+1 roadways have been used vary from 4,000 veh/day to 20,000 veh/day.

Additional details about the operational performance of 2+1 roadways in Sweden are summarized below:

- The maintenance problems experienced so far are basically as expected. The main difficulty has been with traffic work zone safety, especially at barrier repairs.
- The frequency of cable barrier repair has been 0.1–0.9 crashes per million axle-pair-kilometer, with an average of 0.5 crashes per million axle-pair-kilometer. This frequency is in line with the expected frequency of cable barrier repair, which was 0.5–1.0 crashes per million axle-pair-kilometer.
- Winter maintenance has been much better than expected. In fact, snow plowing and removal are not as costly as estimated. Snow is removed in the first 0.4 m (1.3 ft) of the median. The visibility of edge lines is maintained.
- Emergency vehicle operations and tow agencies have complained that their working conditions and service at emergency sites have deteriorated. With limited space in the median, emergency and towing personnel work in proximity to moving traffic. However, these agencies have become more supportive of 2+1 roadways over time.
- Bridge inspections and overlay repairs are coordinated to minimize the number of traffic diversions. Delineator post washing is performed during low-traffic-volume conditions.
- There has been some concern that pavements may deteriorate more quickly on 2+1 roads because of the narrower traffic lanes and the resulting heavy traffic traveling closer to the pavement edge or on the shoulder, where the pavement may not be stabilized.

Driver Acceptance

Drivers adapted quickly to the concept of a 2+1 roadway in Sweden. In fact, since the first 2+1 roadway opened in Sweden, 2+1 facilities have become popular with the public, media, and politicians.

Other Countries

In addition to the three countries that were visited—Germany, Finland, and Sweden—the research team obtained information on 2+1 roadways in Denmark and other countries. The information on these countries is less extensive, but provides a useful supplement to the review of European practice related to the design of 2+1 roads.

Denmark

The information on 2+1 roadways in Denmark, presented below, is taken from a paper by Herrstedt (*5*).

In 1993, prompted by the positive experience with 2+1 roadways in other countries, the Danish Road Directorate converted three rural roadway sections to 2+1 roadways. Each roadway section was resurfaced in combination with remarking with 2+1 markings, partly to avoid the "scars" left by removing existing road markings. Each roadway section is described below.

The first 2+1 roadway section is 5.2 km (3.2 mi) long. It had previously been marked partly as a three-lane road and partly as a two-lane road. The speed limit is 80 km/h (50 mph). The section is now marked as a 2+1 roadway, consisting of seven passing sections that range from 400 m to 750 m (1,300–2,450 ft) in length. The AADT is less than 7,000 veh/day, with 11 percent heavy vehicles.

The second 2+1 roadway section is about 10 km (6 mi) long. It is an expressway with a speed limit of 90 km/h (55 mph). This section had previously been marked as a 2+1 roadway, consisting of six passing sections that ranged from 0.7 km to 1.8 km (0.4–1.1 mi) in length, but was restriped to consist of seven passing sections that range from 0.9 km to 1.4 km (0.6–0.9 mi). The AADT is about 14,000 veh/day, with 6–8 percent heavy vehicles.

The third 2+1 section is about 9 km (5.6 mi) long and has a speed limit of 80 km/h (50 mph). It had previously been marked partly as a three-lane road and partly as a wide two-lane road. The section is now marked as a 2+1 roadway, consisting of eight passing sections that range from 0.35 km to 1.55 km (0.2–1.0 mi) in length. The AADT is about 11,500 veh/day, with 10–12 percent heavy vehicles. During peak summer holiday periods, traffic volumes increase throughout the section. In fact, during the first weekend of the summer holiday period, traffic volumes up to 16,400 veh/day have been observed (15,300 veh/day since conversion to the 2+1 road marking).

Safety. A preliminary accident analysis was performed on the three roadway sections in 1996, followed by another accident analysis in 1999. It was concluded that the 2+1 roadway markings have not significantly impacted the number of injury and PDO collisions. However, there has been a decrease in the severity of accidents. In fact, the number of fatalities for all three sections combined was lower in the after period. Table 7 presents the number of accidents before and after the 2+1 roadway markings were installed.

Traffic Operations. A number of speed and driver behavior studies have been conducted to evaluate the 2+1 roads as an alternative to three-lane roads and wide two-lane roads in Denmark.

Traffic counts, average speed measurements, speed profile measurements, and travel speed measurements have been conducted on the three test sections in Denmark. Findings of these studies include the following:

- Speeds before and after conversion to 2+1 roadway markings were above the posted speed limit on all three test sections.
- Speeds are especially high in the passing lanes.
- Speeds are higher in the two-lane direction of passing sections than in the one-lane direction.
- Speeds in the passing lane increase at the critical transition section.
- Overall, the 2+1 road markings have not led to a significant change in travel speeds.

Driver behavioral studies of drivers merging from two lanes to one were conducted. Drivers were observed on the last 100 m (330 ft) of the passing lane sections to determine the percentage of vehicles that cross the chevron markings or brake during the merge. Findings of this study include the following:

- About 2–6 percent of vehicles pass on the last 100 m (330 ft) of the passing section.
- An increase in traffic volume may lead to an increase in the percentage of vehicles making passing maneuvers on the last 100 m (330 ft) of the passing section.
- On the two test sections with posted speed limits of 80 km/h (50 mph), about 60 percent of vehicles merge from the passing lane into the right lane before the transition from two lanes to one lane, about 30 percent merge within the transition, and 12–14 percent cross the chevron markings during merging.
- On the other test section, which is an expressway with a posted speed limit of 90 km/h (55 mph), a somewhat larger percentage of the merging occurs in the transition. However, only 5–7 percent of the vehicles passing on the last 100 m (330 ft) cross the chevron markings.
- About 80 percent of merging is performed without braking.

TABLE 7 Number of accidents before and after installation of 2+1 roadway markings in Denmark *(5)*

Accident type	Observed		Expected
	Before period	After period	After period
Injury	61	49	50
Injury + PDO	103	99	85
Injury + Fatality	100	83	83
Fatality	11	3	9

PDO = property damage only.

- In 2–3 percent of merging maneuvers, it is necessary for the vehicles to brake.
- The passing vehicle has to brake in 10–20 percent of merging maneuvers.
- In the majority of cases, merging at the end of the passing section takes place without problems.
- When traffic volumes are high (e.g., during the morning rush hours), traffic in the passing lane has been observed to stop and wait for an opportunity to merge back into the main lane.

In Denmark, the most effective length for passing sections has been found to be 1 km (0.6 mi). On shorter passing sections of 400–600 m (1,300–2,000 ft) in length, relatively few vehicles (i.e., not more than 10 percent) make passing maneuvers. On longer passing sections, the number of vehicles making passing maneuvers decreases in the latter part of the passing section.

Driver Acceptance. Interviews were conducted with drivers on two of the three test sections. The findings of the interviews include the following:

- A majority of drivers believe that it is easier to make passing maneuvers on the 2+1 roadways.
- A majority of drivers think that the 2+1 roadway makes drivers feel safer.
- A majority of drivers think that the passing sections are of a suitable length.
- Over 80 percent of those interviewed had a generally positive attitude toward the 2+1 roadway markings.

Other International Applications of 2+1 Roads

The 2+1 road concept has also been used in France, Italy, Spain, and the United Kingdom, but no traffic operational or safety performance measures are available for 2+1 road applications in those countries.

TRAFFIC OPERATIONAL AND SAFETY ASSESSMENTS

An important goal of the research was to assess the potential applicability of the 2+1 road concept in the United States. To meet this objective, analyses were performed to compare the traffic operational and safety performance of 2+1 roadways with conventional passing lane designs like those used in the United States. Both the traffic operational and safety analyses provided results that are applicable to developing specific recommendations for the potential use of 2+1 designs in the United States. The results of the traffic operational and safety assessments are presented in this section.

Traffic Operational Assessment

An analysis was conducted to compare the traffic operational performance of the 2+1 designs used in Europe with conventional passing lane designs used in the United States. The objective of the analysis was to determine how passing lanes that alternate continuously between the two directions of travel perform (i.e., what levels of service can be achieved) under U.S. conditions in contrast to passing lanes provided at intervals, as is the most common practice in the United States. A series of representative roadway types were included in the analyses:

- Two-lane roadway with no passing lanes
- Two-lane roadway with minimal passing lane frequency
- Two-lane roadway with intermediate passing lane frequency
- 2+1 roadway with continuously alternating passing lanes

Each representative roadway section is 24 km (15 mi) long. The roadway types range from no passing lanes provided on a conventional two-lane roadway to continuously alternating passing lanes provided on the 2+1 roadway. The two-lane roadway with minimal passing lane frequency consists of two 1.6-km (1-mi) passing lanes in each direction of travel, separated by a distance of 11 km (7 mi). The two-lane roadway with intermediate passing lane frequency consists of four 1.6-km (1-mi) passing lanes in each direction of travel, each separated by a distance of 4.8 km (3 mi). The 2+1 roadway with continuously alternating passing lanes consists of one 2.4-km (1.5-mi) passing lane followed by six 1.6-km (1-mi) passing lanes in each direction of travel, each separated by a distance of 1.6 km (1 mi). Figure 28 and Table 8 summarize the layout of the roadways that were compared.

The comparison was made with the TWOPAS model, a state-of-the-art computer simulation model of two-lane highway traffic operations. Traffic operational analyses were performed for both level and rolling terrain and for a variety of combinations of traffic volume and directional split. Specifically, the analyses included traffic volumes ranging from 400 veh/h to 2,800 veh/h in each direction. Three combinations of directional split were analyzed: 50/50, 60/40, and 70/30. The traffic composition consisted of 4 percent trucks and 3 percent recreational vehicles. Tables 9 through 12 present the results of the traffic operational analyses for the four representative roadway types in level terrain. The same analyses were performed for rolling terrain, but the results were nearly identical. In the tables, Direction 1 refers to the direction of travel with the higher traffic flow rate. For example, for the analyses of the 60/40 directional split, Direction 1 is the direction of travel that carries 60 percent of the traffic and Direction 2 is the direction of travel that carries

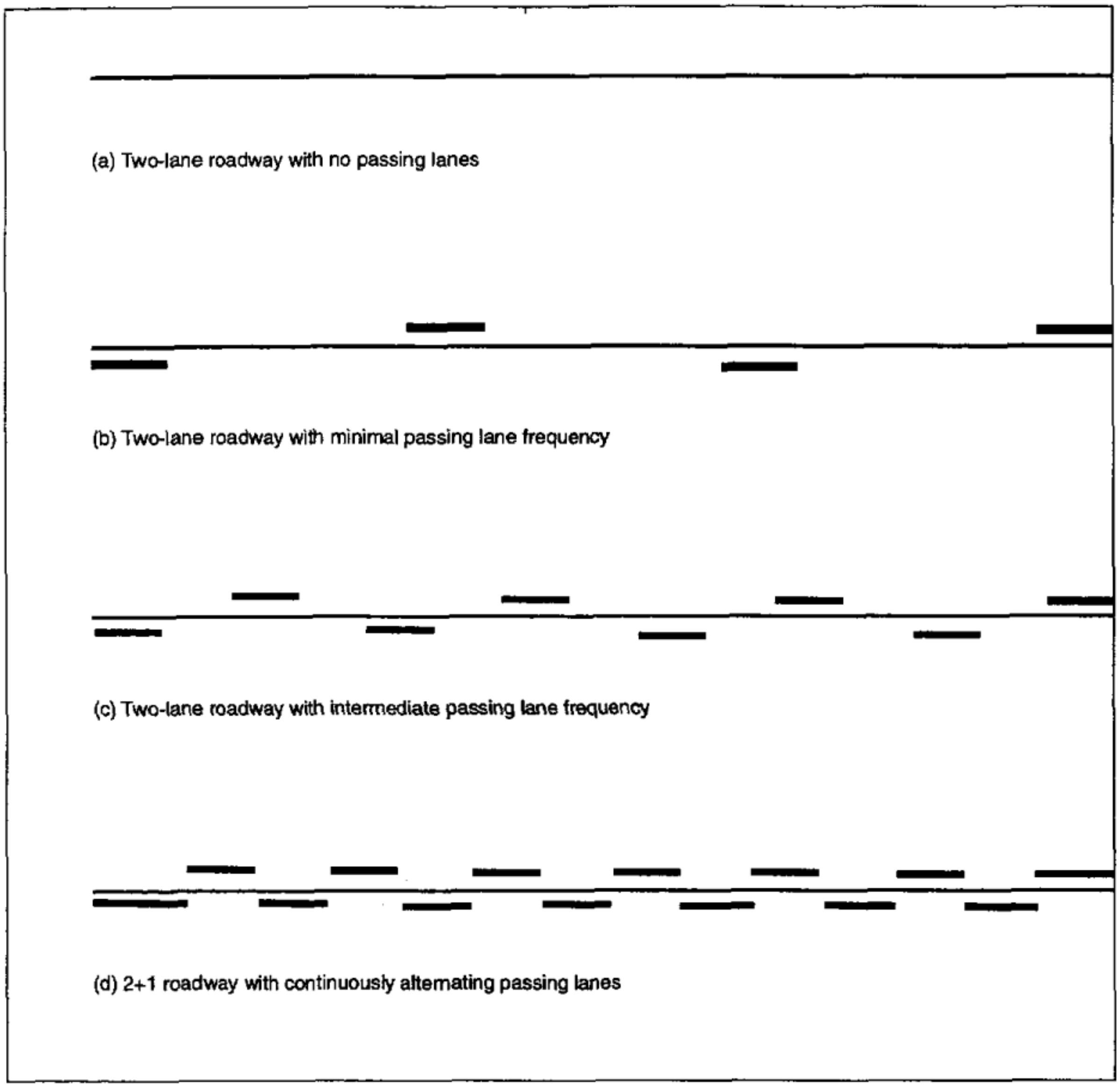


Figure 28. Layout of roadways analyzed by TWOPAS.

TABLE 8 Arrangement of passing lanes on roadways analyzed by TWOPAS

Passing lane frequency	Total roadway length	Number of passing lanes in each direction of travel	Length of each passing lane (mi)	Spacing between passing lanes in each direction of travel[a] (mi)	Percentage of total roadway length with passing lanes in each direction of travel
None	15	0	—	—	0
Minimal	15	2	1	7	13
Intermediate	15	4	1	3	27
Continuously alternating (2+1)	15	7	1[b]	1	47

[a] Distance from end of one passing lane to beginning of the next.
[b] First passing lane in each direction of travel = 1.5 mi.

TABLE 9 Two-lane roadway with no passing lanes

Directional split	Two-way volume (veh/h)	Mean speed (mph) Direction 1	Direction 2	Combined	Percent time spent following Direction 1	Direction 2	Combined	LOS
50/50	400	59.1	59.4	59.2	39.8	36.6	38.4	B
	800	57.8	57.6	57.7	54.4	56.7	55.6	C
	1,200	56.3	56.5	56.4	68.2	67.7	67.9	D
	1,600	55.4	55.5	55.5	76.2	75.7	76.0	D
	2,000	54.7	54.9	54.8	81.7	80.2	81.0	E
	2,400	54.3	54.1	54.2	84.4	84.5	84.5	E
	2,800	53.6	53.3	53.5	87.8	88.5	88.1	E
60/40	400	59.1	59.5	59.2	39.7	35.7	38.4	B
	800	58.1	57.7	58.0	51.3	56.0	53.3	C
	1,200	56.6	56.3	56.5	65.7	69.8	67.4	D
	1,600	55.4	55.7	55.5	75.3	75.7	75.5	D
	2,000	54.7	55.1	54.8	81.6	79.8	80.9	E
	2,400	53.8	54.5	54.1	86.4	83.6	85.3	E
	2,800	—	—	—	—	—	—	—
70/30	400	59.4	59.5	59.4	38.3	34.0	37.1	B
	800	58.2	57.8	58.1	51.6	54.3	52.5	C
	1,200	56.7	56.6	56.7	65.0	68.5	66.1	D
	1,600	55.5	55.9	55.6	75.5	73.9	75.1	D
	2,000	54.4	55.5	54.8	82.8	78.4	81.5	E
	2,400	—	—	—	—	—	—	—
	2,800	—	—	—	—	—	—	—

NOTE: LOS = level of service based on 2000 *Highway Capacity Manual* definitions.

40 percent of the traffic. The levels of service shown in the tables are based on the 2000 *Highway Capacity Manual* (HCM) procedures for two-lane highways *(6)*.

Comparing the two-lane roadway with no passing lanes to the two-lane roadway with minimal passing lane frequency, it can be seen that the addition of even a few passing lanes improves the level of service in many cases. The pattern of traffic operational improvement continues as more passing lanes are added, as on the two-lane roadway with intermediate passing lane frequency and on the 2+1 roadway. As expected, the 2+1 roadway performs at the highest overall level of service. The smallest increment of level of service improvement occurs between the two-lane roadway with minimal passing lane frequency and the two-lane roadway with intermediate passing lane frequency.

Table 13 summarizes the results of the level of service comparison. This comparison shows that, at medium and high volumes, 2+1 roadways provide an improvement by two levels of service over a conventional two-lane highway without passing lanes and an improvement of at least one level of service over two-lane highways with less frequent passing lanes, which is typical of current U.S. practice. Perhaps the most attractive feature of 2+1 roads shown in this analysis is that they provide traffic operations at level of service C for all combinations of traffic volume and directional split considered that do not exceed the capacity of a two-lane roadway.

Like all roadways with passing lanes, 2+1 roads have the potential to improve the traffic operational level of service without increasing the capacity of the roadway. In all cases, the capacity of the roadway is controlled by the sections with one lane in a given direction of travel. The HCM indicates that the capacity of a normal two-lane highway is 1,700 passenger cars per hour for one direction of travel, and this capacity constraint is not affected by the presence of passing lanes. Since 2+1 roadways do not increase the roadway capacity, they may be an acceptable alternative at locations where air quality or limits-to-growth requirements restrict capacity increases.

Ultimately, the traffic operational considerations in whether to choose a conventional two-lane highway, a two-lane highway with passing lanes at intervals, a 2+1 roadway, or a four-lane roadway will be based on level of service considerations. Table 13 gives guidance on what levels

TABLE 10 Two-lane roadway with minimal passing lane frequency

Directional split	Two-way volume (veh/h)	Mean speed (mph) Direction 1	Direction 2	Combined	Percent time spent following Direction 1	Direction 2	Combined	LOS
50/50	400	59.5	59.6	59.5	33.9	32.7	33.4	A
	800	58.2	57.9	58.0	49.1	51.2	50.3	C
	1,200	56.8	56.8	56.8	61.7	62.1	61.9	C
	1,600	55.8	55.9	55.9	69.7	69.0	69.3	D
	2,000	55.1	55.2	55.1	74.2	74.4	74.3	D
	2,400	54.6	54.6	54.6	77.5	77.6	77.5	D
	2,800	54.0	53.8	53.9	80.6	81.1	80.9	E
60/40	400	59.6	59.6	59.6	33.1	32.5	33.1	A
	800	58.4	58.1	58.3	47.9	50.0	48.8	B
	1,200	56.6	56.9	56.7	62.6	61.6	62.2	C
	1,600	55.7	56.2	55.9	70.5	67.5	69.3	D
	2,000	54.9	55.6	55.2	75.9	71.8	74.3	D
	2,400	53.9	55.1	54.4	80.6	75.3	78.5	D
	2,800	—	—	—	—	—	—	—
70/30	400	59.6	59.9	59.7	33.3	29.1	32.2	A
	800	58.3	58.4	58.3	47.7	46.4	47.4	B
	1,200	56.6	57.4	56.8	62.8	57.7	61.3	C
	1,600	55.6	56.6	55.9	71.4	64.3	69.3	D
	2,000	54.5	56.1	55.0	77.6	68.8	74.9	D
	2,400	—	—	—	—	—	—	—
	2,800	—	—	—	—	—	—	—

NOTE: LOS = level of service based on 2000 *Highway Capacity Manual* definitions.

of service can be expected from each roadway type. While the table does not show the levels of service for four-lane highways under comparable traffic volumes, they would be at level of service A or a high level of service B in all cases. The decision about when to provide a four-lane highway should be based on whether an acceptable level of service can be attained with one of the two-lane highway or passing lane alternatives shown in Table 13. If the level of service attainable with a two-lane highway with passing lanes is not acceptable or cannot be sustained over the design life of a project, a four-lane highway is needed. However, with many highway agencies facing funding limitations or environmental considerations that restrict building as many four-lane highways as might be desirable from the standpoint of traffic operations, a two-lane highway with passing lanes or a 2+1 road may be the best available alternative. In situations where a four-lane cross section is ultimately what is needed to accommodate future traffic projections, a 2+1 road may serve as an intermediate cross section, or a type of "staged construction," until funding for a four-lane roadway becomes available.

Safety Assessment

The safety investigation was based on a comparison of safety performance data for 2+1 roadways in Europe with the known safety performance of passing lanes in the United States based on published literature. The objectives of the safety assessment were (1) to determine what safety benefits the 2+1 design has in comparison with typical passing lane designs used in the United States and (2) to determine what effects on safety may be obtained by placing a traffic barrier between the two directions of travel, as is now being done in Sweden.

Overall Accident Reduction Effectiveness of 2+1 Roads

Table 14 compares the safety effectiveness of 2+1 roads, expressed as a percentage reduction in accident frequency, in comparison with a conventional two-lane roadway for Germany, Finland, Sweden, and the United States. The effectiveness estimates for Germany, Finland, and Sweden are based on the data presented in Chapter 2 of this

TABLE 11 Two-lane roadway with intermediate passing lane frequency

Directional split	Two-way volume (veh/h)	Mean speed (mph) Direction 1	Direction 2	Combined	Percent time spent following Direction 1	Direction 2	Combined	LOS
50/50	400	59.5	59.5	59.5	32.0	32.2	32.1	A
	800	58.4	58.0	58.2	45.2	48.6	47.0	B
	1,200	57.2	57.1	57.1	55.7	57.3	56.5	C
	1,600	56.3	56.2	56.3	62.3	63.3	62.8	C
	2,000	55.6	55.5	55.6	67.2	67.9	67.5	D
	2,400	55.1	55.0	55.1	70.1	70.7	70.4	D
	2,800	54.4	54.2	54.3	73.4	73.8	73.6	D
60/40	400	59.4	59.8	59.5	33.3	29.1	31.9	A
	800	58.2	58.4	58.3	47.0	44.8	46.1	B
	1,200	56.8	57.2	57.0	58.1	55.1	56.9	C
	1,600	55.8	56.7	56.2	65.4	60.0	63.2	C
	2,000	55.2	56.1	55.5	69.7	64.3	67.5	D
	2,400	54.2	55.6	54.8	73.9	67.6	71.4	D
	2,800	—	—	—	—	—	—	—
70/30	400	59.4	59.9	59.5	34.4	26.6	32.3	A
	800	58.1	58.8	58.3	48.0	39.9	45.7	B
	1,200	56.5	57.9	57.0	60.5	49.5	57.2	C
	1,600	55.5	57.2	56.0	67.4	55.7	63.8	C
	2,000	54.6	56.7	55.3	72.5	59.6	68.5	D
	2,400	—	—	—	—	—	—	—
	2,800	—	—	—	—	—	—	—

NOTE: LOS = level of service based on 2000 *Highway Capacity Manual* definitions.

digest and include safety effectiveness measures by accident severity level, where such estimates were available.

The 2+1 road configuration has been used in only limited situations in the United States, so there are no formal U.S. evaluations of the 2+1 road configuration's safety effectiveness. Therefore, safety effectiveness can be estimated from only what is known about the general safety effectiveness of passing lanes. An evaluation by Harwood and St. John (7) concluded that passing lanes reduce accidents by 25 percent. This result was based on an analysis of a combined data set, including data obtained from 11 states by Harwood and St. John (7) and data from California analyzed

TABLE 12 2+1 roadway with continuously alternating passing lanes

Directional split	Two-way volume (veh/h)	Mean speed (mph) Direction 1	Direction 2	Combined	Percent time spent following Direction 1	Direction 2	Combined	LOS
50/50	400	60.1	60.1	60.1	23.7	23.2	23.6	A
	800	59.0	58.6	58.8	35.5	38.3	37.0	B
	1,200	58.1	57.8	58.0	42.9	45.1	44.0	B
	1,600	57.3	57.3	57.3	48.7	49.3	49.0	B
	2,000	56.6	56.5	56.6	53.1	53.6	53.3	C
	2,400	56.1	56.0	56.0	56.3	56.7	56.5	C
	2,800	55.3	55.1	55.2	59.7	60.3	60.0	C
60/40	400	59.8	60.3	60.0	26.0	21.3	24.3	A
	800	58.8	59.3	59.0	37.6	32.5	35.6	B
	1,200	57.5	58.2	57.8	46.8	41.4	44.6	B
	1,600	56.7	57.8	57.2	52.7	45.4	49.7	B
	2,000	56.1	57.2	56.5	56.3	49.5	53.6	C
	2,400	55.0	56.8	55.7	60.5	52.9	57.5	C
	2,800	—	—	—	—	—	—	—
70/30	400	59.7	60.5	59.9	28.7	19.1	26.1	A
	800	58.4	59.8	58.8	41.1	26.6	36.9	B
	1,200	57.3	58.9	57.8	49.5	35.6	45.3	B
	1,600	56.3	58.3	56.9	55.4	41.1	51.0	C
	2,000	55.1	57.8	56.0	59.9	45.0	55.3	C
	2,400	—	—	—	—	—	—	—
	2,800	—	—	—	—	—	—	—

NOTE: LOS = level of service based on 2000 *Highway Capacity Manual* definitions.

by Rinde (*8*). This effectiveness measure is the same for all accident severity levels; that is, no difference in the safety effectiveness of passing lanes by severity levels was found. This 25-percent accident reduction effectiveness estimate for passing lanes has been incorporated in the crash prediction algorithm for the FHWA Interactive Highway Safety Design Model (IHSDM) (*9*).

The 25-percent effectiveness estimate for passing lanes, discussed above, applies only to the portions of the roadway where passing lanes are provided. An advantage of 2+1 roads is that passing lanes are provided over a greater proportion of the roadway than is the case for isolated passing lanes. Table 8 shows that the two-lane highway with minimal passing lane frequency studied in the traffic operational analysis provides passing lanes over 13 percent of the roadway in each direction of travel; comparable estimates are 27 percent for a two-lane highway with intermediate passing lane frequency and 47 percent for a 2+1 road with continuously alternating passing lanes. Thus, the total percentage of roadway length with passing lanes added in one direction or the other is 26 percent for minimal passing lane frequency, 54 percent for intermediate passing lane frequency, and 94 percent for a 2+1 road (see Figure 26).

Table 14 includes estimates of the expected percentage accident reductions, in comparison with a conventional two-lane roadway, based on U.S. data for the three passing lane configurations discussed above. If passing lanes were provided over the entire roadway length, the best available safety effectiveness estimate for U.S. conditions would be a 25-percent reduction in accidents. The 2+1 road provides added lanes over 94 percent of the roadway length (with only small gaps at transition areas), so the expected effectiveness would be 24 percent (0.94 times 25 percent). The effectiveness estimates for the two-lane highways with intermediate and minimal passing lane frequencies would be proportionally smaller—14 percent and 7 percent, respectively.

Overall, Table 14 shows that the safety performance of 2+1 roads in Europe in countries other than Sweden is not too different from what would be expected from 2+1 roads if they were used more widely in the United States. The projected 24-percent reduction in accident frequency in the United States is quite comparable to the 28- to 36-percent range observed in Germany and the 11- to 25-percent range observed in Finland. The 55-percent accident reduction effectiveness for 2+1 roads in Sweden is extraordinarily high compared with any effect observed for passing lanes in the

TABLE 13 Comparison of level of service analysis results

Two-way volume (veh/h)	Level of service by passing lane frequency: None	Minimal	Intermediate	Continuously alternating (2+1)
50/50 Directional Split				
400	B	A	A	A
800	C	C	B	B
1,200	D	C	C	B
1,600	D	D	C	B
2,000	E	D	D	C
2,400	E	D	D	C
2,800	E	E	D	C
60/40 Directional Split				
400	B	A	A	A
800	C	B	B	B
1,200	D	C	C	B
1,600	D	D	C	B
2,000	E	D	D	C
2,400	E	D	D	C
2,800[a]	—	—	—	—
70/30 Directional Split				
400	B	A	A	A
800	C	B	B	B
1,200	D	C	C	B
1,600	D	D	C	C
2,000	E	D	D	C
2,400	—	—	—	—
2,800[a]	—	—	—	—

[a] Combination of two-way volume and directional split exceeds the capacity of a two-lane highway.

United States or for 2+1 roads in Germany or Finland. The relationship of the superior performance of 2+1 roads in Sweden to the use of median barrier is discussed below.

The overall finding of the safety analysis is that, were 2+1 roads to be used extensively in the United States, they would achieve an overall reduction in accident frequency of 25 percent within the areas where passing lanes are provided. This reduction, if the passing lanes were nearly continuous except for transition areas, would be equivalent to a reduction in accident frequency over nearly the entire roadway length. This finding is based on U.S. research of passing lanes and is consistent with the effectiveness of 2+1 roads observed in Germany and Finland.

Use of Cable Median Barrier on 2+1 Roads

European experience indicates not only that the use of cable median barriers in the center of a 2+1 roadway holds promise for the improvement of safety on 2+1 roads, but also that the use of cable barriers has sufficient disadvantages that it has been accepted in some, but not all, countries. European experience can be summarized as follows:

- Sweden uses cable barriers widely on 2+1 roads and has achieved good results.
- Finland has not used cable barriers in its existing 2+1 roads, but plans to use it in the future and expects benefits from its use.
- Germany does not consider the use of cable barriers desirable.

The performance of 2+1 roads in Sweden is very favorable, and the reported 40- to 55-percent decrease in fatal and serious injury accident frequency, in comparison with a conventional two-lane road, is the highest reported safety effectiveness measure. It is apparent from Swedish data that the presence of the cable barrier leads to an increase in PDO accidents, and possibly minor injury accidents, but no specific data on the magnitude of that increase are available.

The disadvantages of cable median barrier are the potential increase in minor injury and PDO accidents, the potential for the barrier to deflect into the opposing lanes of travel when struck, and the need for maintenance activity after each barrier collision. U.S. highway agencies are in a very different tort liability situation than highway agencies in Europe are. A barrier collision resulting in a barrier de-

TABLE 14 Comparison of U.S. and international safety performance for two-lane highways with passing lanes and 2+1 roads

Country	Design alternative	Median barrier used?	Estimated percent reduction in accident frequency compared with a conventional two-lane highway			
			Fatal accidents	Injury accidents	Fatal plus injury accidents	All severity levels combined
Germany	2+1 road	No	—	—	36	28
Finland	2+1 road[a]	No	0	13	11	—
	2+1 road[a]	Yes	46	22	25	[b]
Sweden	2+1 road on semi-motorway	Yes	60–70	—	40–55[c]	[b]
	Conventional 2+1 road	Yes	45–55	—	30–50	[b]
	Conventional 2+1 road	No	—	—	5–10	[b]
U.S.	Minimal passing lane frequency[d]	No	7	7	7	7
	Intermediate passing lane frequency[d]	No	14	14	14	14
	Continuous alternating (2+1)[d]	No	24	24	24	24

[a] Based on estimates from limited data.
[b] No data are available for property damage only (PDO) accidents; however, PDO accidents may have increased because of the presence of the cable barrier.
[c] Includes fatal and serious injury accidents only.
[d] Based on the same passing lane configurations shown in Figure 28 and Table 8; percentage reduction in accidents estimated with results from Harwood and St. John (7) for passing lane lengths shown in Table 8.

flection into the opposing travel lane, with the possibility of the vehicle that struck the barrier coming to rest in the opposing lane, could make the highway agency liable for an accident when the agency might not have been liable had there been no barrier. (That is, the argument could be made that neither the barrier nor the vehicle that struck the barrier would have come to rest in such an exposed position had the barrier not been installed by the highway agency.)

From the available data, it is recommended that the 2+1 road concept be considered proven technology, but inclusion of cable barriers between the lanes in opposite directions of travel should not be considered unless a full tort liability assessment of their use is conducted and, then, only after some trial installations are built and their performance assessed under U.S. conditions. While the research team does not recommend cable barriers for immediate implementation on 2+1 roads in the United States, the excellent safety performance of 2+1 roads reported in Sweden makes further consideration of the potential use of cable barriers desirable.

RECOMMENDATIONS FOR USE OF 2+1 ROADS IN THE UNITED STATES

The research team's finding is that 2+1 roadways have potential application in the United States. The configuration may be a suitable treatment for roadways with traffic volumes higher than can be served by isolated passing lanes, but not high enough to justify a four-lane roadway. The configuration is also potentially applicable where a four-lane roadway would be desirable, but sufficient funds are not available to construct a four-lane facility. In this age of limited resources, this application for 2+1 roadways may become increasingly important. In addition, 2+1 roads are appropriate for use at locations where environmental concerns make provision of a four-lane facility infeasible.

Using the research results, the research team developed specific recommendations for the use of 2+1 designs in the United States. These recommendations take into consideration the following factors: terrain, traffic volume, traffic composition, passing lane length, location and transition of crown, superelevation, level of access, lane and shoulder widths, and separation of opposing lanes.

Terrain

Most of the 2+1 roadways in Europe are located in either level or gently rolling terrain. In a few cases, the grades are steep enough to become a consideration in locating the passing lanes. In such cases, passing lanes are strategically placed on the upgrades to serve as climbing lanes for trucks, recreational vehicles, and other slow-moving vehicles. A 2+1 roadway may be transitioned back to a conventional two-lane cross section on sharp curves; however, the Germans consider 2+1 facilities generally adaptable to any terrain.

It is recommended that 2+1 roads be used in the United States in level or rolling terrain. In mountainous terrain or on isolated steep grades, the use of conventional truck climbing lanes is more appropriate. AASHTO's *A Policy on Geometric Design of Highways and Streets (10)*, commonly known as the Green Book, provides criteria to identify where truck climbing lanes are needed. Passing lanes may also be provided on steep downgrades to allow faster vehicles to pass slow-moving trucks.

Traffic Volume

In Germany, traffic volumes on 2+1 roadways range from 15,000 veh/day to 25,000 veh/day; the maximum traffic volume level observed was 30,000 veh/day. This level represents higher traffic volumes than are typically served on 2+1 facilities in Finland and Sweden. In Finland, 2+1 roadways have accommodated traffic volumes of up to 14,000 veh/day. On Fridays and Saturdays, recreational traffic volumes can be as high as 20,000–25,000 veh/day. In Sweden, ADTs for which 2+1 roadways have been used are 4,000–20,000 veh/day. Two-lane highways in the United States have traffic volumes that span the full range of traffic volumes observed for 2+1 roads in Europe.

With respect to hourly volumes, the capacity of one of the 2+1 roadways in Finland was measured to be about 1,900 veh/h in one direction, and the capacity of the other 2+1 roadway was measured to be 1,600–1,700 veh/h in one direction. In Sweden, the capacity of a 2+1 roadway is estimated to be 1,600–1,700 veh/h in one direction during a 15-min period. Floating car studies confirm a good level of service at traffic flows up to 1,300–1,400 veh/h in one direction. The HCM *(6)* indicates that the capacity for one direction of travel on a two-lane highway occurs at a flow rate of 1,700 passenger cars per hour; the capacity for both directions of travel combined is 3,200 passenger cars per hour. However, passing lanes are not normally used at such high flow rates approaching capacity because congestion is likely to develop at the lane drop transitions. Finland has experienced just such congestion on one particular 2+1 road where weekend recreational traffic peaks exceed the capacity of the road. In fact, at flow rates of 1,200–1,400 veh/h in one direction of travel, Finland has experienced queuing at the beginning of the lane-drop transition, with drivers leaving the queue in the right-most lane to improve their position in the queue.

Because of experience in Finland, it is recommended that 2+1 roads not be considered where current or projected flow rates exceed 1,200 veh/h in one direction of travel. A four-lane roadway is more appropriate at such high flow rates.

Traffic Composition

Traffic composition is another consideration in designing 2+1 roadways. Heavy vehicles—including trucks, recreational vehicles, and agricultural vehicles—can have a large effect on passing demand. Agricultural vehicles are not an issue on many of the 2+1 roadways in Europe because many of the 2+1 roadways are operated on semi-motorways, where agricultural and other very slow-moving vehicles are prohibited. In Europe overall, 10–20 percent of heavy vehicles are on 2+1 roadways, which is comparable to the traffic composition on most two-lane roadways in the United States.

The 2+1 roadway concept appears to be appropriate over a broad range of traffic composition. The need for 2+1 roadways, or other methods of providing more passing opportunities, increases as the percentage of heavy vehicles increases.

Passing Lane Length

In Germany, the typical length of a passing lane within a 2+1 roadway is 1.0–1.4 km (0.6–0.9 mi), but usually not more than 2.0 km (1.2 mi). In Finland, the optimum length for a passing lane is estimated to be 1.0–1.5 km (0.6–1.0 mi); the typical length of a passing lane is about 1.5 km (1.0 mi). Sweden provides passing lanes at intervals of 1.0–2.0 km (0.6–1.2 mi). The length depends on alignment, locations of intersections, etc. Two-lane cross sections can be provided at long bridges; on sections with frequent access roads, pedestrians, and bicyclists; or where separation is not feasible.

European practice related to passing lane length, with passing lanes ranging 1.0–2.0 km (0.6–1.2 mi), is similar to U.S. practice. Harwood and Hoban provide guidance on passing lane length in an FHWA report entitled *Low-Cost Methods for Improving Traffic Operations on Two-Lane Roads (11)*. This report states that the optimal length of a passing lane to reduce platooning is usually 0.8–1.6 km (0.5–1.0 mi). Harwood and Hoban recommend that passing lanes not be shorter than 0.3 km (0.2 mi) long because this minimum length is needed to ensure that delayed vehicles have an opportunity to complete at least one pass in the passing lane. Shorter passing lanes, with lengths of 0.4 km (0.25 mi) or less, are not very effective in reducing traffic platooning. As the length of a passing lane increases above 1.6 km (1.0 mi), passing lanes generally provide diminishing operational benefits. Passing lanes more than 1.6 km (1.0 mi) in length are generally appropriate only on higher-volume facilities, with flow rates over 700 veh/h. Table 15 presents the optimal design lengths for passing lanes in the United States, as developed by Harwood and Hoban *(11)*. These optimal pass lane lengths are consistent with European practice for 2+1 roads and are recommended for use in the United States.

Location and Transition of Crown

Two-lane highways in Germany do not have a normal crown section like those used in the United States. The cross section for 2+1 roads is a continuous cross slope from one edge of pavement to the other. Thus, German highway designers do not face a decision as to where to locate the crown or whether to transition the crown from one side of the center lane to the other at passing lane transitions. There is also no need to remove the normal crown in superelevation transitions at horizontal curves.

Where existing two-lane highways with a normal crown are converted to 2+1 roadways, the location and transition of the crown is perhaps one of the more complicated design issues. In Sweden, most of the 2+1 roadways were implemented by restriping 13-m (43-ft)-wide, two-lane roadways with a normal crown in the center. During the conversion to a 2+1 cross section, no attempt was made to position the existing crown under the cable barrier or along the edge of a lane. In fact, when such roadways are restriped to accommodate three lanes within the same cross section, the crown typically falls about a foot or two inside the center lane, depending on the specific lane and shoulder widths of a given roadway. Sweden has not experienced any problems with drivers getting "hung up" on the crown or feeling their vehicles pull toward the cable barrier. In the transition between passing lanes in opposite directions, the crown remains in the same actual location within the cross section while the barrier is transitioned from one side of the center flush median to the other. In this process, the crown is effectively transitioned from a point located just inside the passing lane in one direction of travel to a point located just inside the passing lane in the other direction of travel.

Neither of the existing 2+1 roadways in Finland has a normal crown. At both sites, the roadway has a continuous cross slope from one side of the pavement to the other. However, Figure 11 illustrates how Finland plans to handle a normal crown on future 2+1 roadways with a median barrier. Pavement would be added to extend the cross slope up to the barrier, creating a light "drop off" directly under the barrier. It is not clear how a normal crown will be transitioned at the buffer areas between passing lanes in opposing directions on 2+1 roadways without a median barrier in Finland.

While 2+1 roadways have not been formally adopted in the United States, several states have constructed continuously alternating passing lanes on sections of two-lane highway. At least one of these states has accommodated the crown by keeping it in the center of the roadway and widening the two-lane highway on both sides, rather than adding pavement to one side only. Thus, the crown is located in the center of the passing lane, which alternates between the two directions of travel. Other states that have passing lanes on two-lane highways implement a variety of practices in handling the crown on passing lane sections, and there is no indication of safety problems related to any of these practices.

According to both European and U.S. experience, there is no known difference in safety between placing the roadway crown at a lane boundary and placing it within a lane. In design of a new 2+1 road, it would be preferable to locate the crown at a lane boundary, but the location of the crown should not be an impediment to obtaining safety benefits by converting existing wider two-lane highways to 2+1 roadways.

As a maintenance issue, if the location of the crown is within a lane, rather than at a lane line, snow plowing operations may become difficult. However, there is no indication of any adverse effect on snow plowing operations in Sweden.

Superelevation

Because 2+1 roadways in Germany have a continuous cross slope, superelevation is handled in the same manner as other roadways with a continuous cross slope. In Sweden, superelevation is handled no differently on 2+1 roadways than on the 13-m (43-ft)-wide, two-lane roadways that the 2+1 roadways replaced, since the conversion to a 2+1 roadway involved restriping only.

It is recommended that horizontal curves on 2+1 roadways be superelevated in accordance with the AASHTO Green Book. Superelevation should be handled no differently on 2+1 roadways than on conventional two-lane or four-lane undivided roads.

Level of Access

In Germany and Finland, most 2+1 roadways are constructed as semi-motorways with full access control. However, if application of 2+1 roadways were limited to facilities with full access control, their application in the United States might be quite limited. Sweden has demonstrated that 2+1 roadways can be operated safely with at-grade intersec-

TABLE 15 Optimal design lengths for passing lanes in the United States *(11)*

One-Way Flow Rate (veh/h)	Optimal Passing Lane Length (mi)
100	0.50
200	0.50–0.75
400	0.75–1.00
700	1.00–2.00

tions. In Sweden, major at-grade intersections are located in the buffer areas between opposing passing lanes; the center lane is used for left-turn lanes at the intersection (see Figures 21 and 22). Thus, major at-grade intersections on 2+1 roadways in Sweden are designed and operate in a similar manner as at-grade intersections on two-lane highways in the United States. Furthermore, there is no indication that at-grade intersections on 2+1 roadways cannot accommodate the same turning volumes as at-grade intersections on two-lane highways in the United States with similar ADTs. In Sweden, minor driveways serving individual residences and small commercial entrances are permitted along passing lane sections, but their frequency is minimized.

The location of major intersections and high-volume driveways should be a key consideration when selecting passing lane locations on 2+1 roadways in the United States. Proper placement of passing lanes and transition sections with respect to higher-volume intersections will minimize the number of turning movements within the passing lane sections. Major intersections should be located in the buffer or transition areas between opposing passing lanes, and the center lane should be used for left-turn lanes at the intersection. Low-volume intersections and driveways may be accommodated safely within passing lane sections.

Lane and Shoulder Widths

Lane widths for 2+1 roads in Europe are 3.25–4.25 m (10.6–13.9 ft). Cross sections for some 2+1 roads in Europe incorporate a wider lane for the direction of travel with one lane than for the direction of travel with two lanes; some 2+1 roads also incorporate slightly wider lanes for the left or passing lane than for the right lane in the direction of travel with two lanes.

Shoulder widths on 2+1 roads in Europe vary from 0.25 m (0.8 ft) in Germany to 1.0 m (3.3 ft) where stabilized shoulders are provided in Sweden. Thus, shoulders on 2+1 roads in Europe are generally narrower than those recommended for use on two-lane highways in the United States.

It is recommended that lane and shoulder widths on 2+1 roads in the United States be comparable to those recommended for conventional two-lane highways in the AASHTO Green Book. European practice indicates that narrow lanes and shoulders may be used safely. It is recommended that narrower lanes and shoulders be considered in the United States, where appropriate, through the design exception process.

Separation of Opposing Lanes

The separation of opposing lanes is another important design issue. In Germany, a separation of 0.5 m (1.6 ft) is typically provided between opposing travel lanes; however, a separation of 1.0 m (3.3 ft) with a rumble strip is under consideration. Finland typically provides a separation of 0.5 m (1.6 ft) and 1.7 m (5.6 ft) on 2+1 roadways without a median barrier and with a median barrier, respectively. In Sweden, where cable barriers are provided on nearly all 2+1 roadways, a separation of 1.25 m (4.1 ft) is typically provided between opposing travel lanes.

While no separation of opposing lanes is needed unless a cable barrier is to be provided, the AASHTO Green Book states that some separation between the lanes in opposing directions of travel, however small, is always desirable. Therefore, a small separation between the opposing directions of travel of 1.2 m (4 ft) should be considered, where practical.

Summary of Recommendations

Presented below is a summary of specific recommendations for the use of 2+1 designs in the United States:

- 2+1 roadways have been shown in Europe to have substantial safety benefits, and their use in the United States is recommended. 2+1 roads may be a suitable treatment for roadways with traffic volumes higher than can be served by isolated passing lanes, but not high enough to justify a four-lane roadway. They are also potentially applicable where a four-lane roadway would be desirable, but sufficient funds are not available to construct a four-lane facility.
- 2+1 roadways are most appropriate for use in level or rolling terrain. In mountainous terrain and on isolated steep grades, it is normally more appropriate to have truck climbing lanes on upgrades and, where needed, passing lanes on downgrades than to have 2+1 roadways.
- It is recommended that 2+1 roadways be considered in the United States for highways with traffic flow rates up to 1,200 veh/h in one direction of travel.
- Passing lane lengths on 2+1 roadways should be consistent with optimal lengths for isolated passing lanes on two-lane highways. To ensure efficient traffic operations, recommended values for passing lane length relative to the flow rate in one direction of travel are as follows:

One-Way Flow Rate (veh/h)	Optimal Passing Lane Length (mi)
100	0.50
200	0.50–0.75
400	0.75–1.00
700	1.00–2.00

- A variety of practices relate to the location of the crown on 2+1 roadways. For newly designed 2+1 roads, it is recommended that the crown be placed at a lane boundary. However, where an existing two-lane highway is restriped as a 2+1 road or widened to become a 2+1 road, the placement of the crown within a travel lane may be permitted.

- Horizontal curves on 2+1 roadways should be superelevated in accordance with the AASHTO Green Book. Superelevation should be handled no differently on a 2+1 road than on a comparable two-lane or four-lane undivided road.
- Major intersections should be located in the buffer or transition areas between opposing passing lanes on 2+1 roads, and the center lane should be used to provide left-turn lanes at the intersection. Low-volume intersections and driveways may be accommodated within passing lane sections.
- The use of cable barrier between the opposing lanes of a 2+1 road has been found in Sweden to have substantial safety benefits. Where a cable barrier is used, a separation of 1.2–1.8 m (4–6 ft) between the opposing directions of travel is desirable. However, the use of a cable barrier for 2+1 roadways in the United States is not recommended until a full evaluation of tort liability and barrier deflection issues is completed.
- While no separation of opposing lanes is needed unless a cable barrier is to be provided, the AASHTO Green Book states that some separation between lanes in opposing directions of travel, however small, is always desirable. Therefore, a flush separation of 1.2 m (4 ft) between the opposing directions of travel should be considered, where practical.

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