Interchange Planning and Design—An International Perspective

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Worldwide, interchange design issues represent one of the most important challenges in highway design. Existing norms, standards, or guidelines for interchange design in eight countries on three continents were reviewed, analyzed, and evaluated. Because of space and time constraints, only important issues of interchange planning considerations and principles, interchange types, design standards, local practices, and information on traffic safety are presented. It is interesting to note that for system interchanges, the Trumpet, Y and T interchange types, cloverleaf and directional interchanges are most commonly used, whereas for service interchanges, diamond and partial cloverleaf interchange types are commonly applied.

Significant traffic increases in the industrialized countries of the world have resulted in the need to increase capacity and efficiency and to improve traffic safety. In terms of safety, grade-separated intersections (interchanges), where capacity constraints are evident, and where the largest portion of accidents occur, represent some of the major deficiencies in highway design.

As a means to familiarize highway design engineers with national/international practices and experiences in geometric design, as related to safety and efficiency, the TRB Committee on Geometric Design nominated a committee of engineers to plan, coordinate, and conduct a session on interchange design issues during the 1992 TRB Annual Meeting.

The authors were consequently asked to collect, review, analyze, and evaluate existing interchange design guidelines, standards, or manuals to obtain an international perspective of current interchange design practices. To achieve the objective of this study, letters were sent to a number of major industrialized countries requesting copies of design guidelines and other information pertaining to interchange design.

Answers were received from Australia, Austria, Germany, Greece, Ireland, Norway, South Africa, and Switzerland. Information was also received from Italy, the Netherlands, and Sweden. Unfortunately, the information received from these three latter countries had to be excluded because the language used in the guidelines was not spoken or understood by the authors. Translations were not possible because of financial and time constraints. France, Great Britain, and Japan did not respond.

Results of this study, coupled with what is known in the United States, could serve as a basis for any future international investigations of interchange design issues, which could eventually help improve interchange design guidelines.

INTERCHANGE PLANNING AND DESIGN IN AUSTRALIA

The information presented in this section is based on *Grade-Separated Interchanges: A Design Guide*, prepared by the National Association of Australian State Road Authorities (NAASRA), 1984. NAASRA has since become AustRoads, which is somewhat analogous to AASHTO.

An interchange, as it is defined in the NAASRA publication, is a combination of ramps and grade separations at the intersection or junction of two roads that is designed to eliminate at-grade turning and crossing movements on the major road carriageways. Interchanges on freeways are the only locations at which traffic can exit from or enter the through route. They should allow for the most efficient and convenient choice of route for the major traffic movements. Interchanges separate major crossing and turning movements and enable maximum traffic volumes to operate safely. Crossing conflicts are reduced or eliminated, and turning conflicts are minimized.

Interchange Planning Considerations

Justification for Providing Interchanges

Interchanges may be justified for any of the following reasons:

- To provide access to freeways,
- To increase capacity at critical intersections,
- To separate conflict points between movements with high relative speeds,
- To suit particular topography where an interchange can be built at a cost comparable to at-grade intersections, and
- To satisfy planning considerations for future traffic.

Location and Spacing

Interchanges are located in positions that provide convenient access to and from major traffic generators. Desirable mini-

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mum spacings between successive interchanges are 1.5 to 2.0 km in urban areas and 5.0 to 8.0 km in rural areas. Maximum spacings are less definite; however, a critical review should be made of traffic service provided by the total road system at spacings above 4.0 km in urban areas and 12.0 km in rural areas.

Lane Balance

Lane balance should be maintained at interchange exits and entrances by using auxiliary lanes if necessary. The three principles of lane balance are as follows:

- The number of lanes beyond the merge of two traffic streams should not be less than the sum of traffic lanes (or merging roadways) minus one, and not more than this sum.
- The number of lanes on the combined roadway before a diverge should be equal to or one less than the sum of all the traffic lanes following the diverge.
- The number of lanes on the through carriageway should be reduced by no more than one at any exit location.

However, the overriding consideration must be the achievement of a consistent level of service which will, among other things, ensure correct lane balance.

Evaluation of Alternatives

Study sketches of a range of likely layouts should be prepared after obtaining sufficient information on all factors likely to affect the choice of an interchange layout. These should be suitable to meet traffic needs and must be practical for the site and its controls. The various sketches are compared to select the most suitable layout, and preliminary designs and profiles are prepared. These preliminary designs are then analyzed with respect to design features, volume/capacity ratios and traffic performances, adaptability to possible changes, and estimated costs. A comparison of the alternatives will then enable the preferred layout to be determined.

Interchange Types

Interchanges fall into two main categories: those that join minor (secondary) road(s) with a freeway, and those that include only freeways (interstates, autobahnen).

The basic forms of interchange associated with minor roads include diamond [Figure 1(*a–f*)], partial cloverleaf (parclo) [Figure 1(*g–m*)], trumpet [Figure 1(*n*)], and bridged roundabout [Figure 1(*o*)].

The basic forms of freeway-type interchanges include the Y, T, cloverleaf, and directional types [Figure 1(*p–u*)]. Note that left-hand driving is the rule in Australia.

Interchange With Minor Road

Diamond Interchanges

The most common type of interchange with a minor (secondary) road in Australia is the diamond interchange. Because of its simplicity, it is the preferred interchange type for both urban and rural areas. The conventional diamond interchange has four ramps, which provide for all movements to and from the intersecting road. The three types of basic diamond interchanges are as follows:

- Conventional [Figure 1(*a–c*)]: Adaptable to a wide range of traffic volumes, with the ramp and minor road capacity only being limited by the ramp terminals. They require a single bridge and a bridge site clear of all ramps.
- Split [Figure 1(*d* and *e*)]: Suitable where capacity limitations of the minor road system or adjacent land use precludes the use of a conventional diamond. Capacity and efficiency are normally improved because traffic is distributed over two minor roads. The ramp terminals form a simple T junction, and acquisition along the minor road is minimized.
- Half diamond [Figure 1(*f*)]: Appropriate to situations in which traffic demand is predominantly oriented in one direction. The reverse minor traffic movements are accommodated by the minor road system, possibly leading to the next interchange.

Parclo Interchanges

Parclo interchanges are usually used when physical controls in one or more quadrants of the interchange preclude the use of a diamond interchange, especially in rural situations. An interchange with loops in advance of the minor road, with direction of travel on the freeway as the reference, is a Parclo A [Figure 1(*a–i*)]. An interchange with loops beyond the minor road is a Parclo B [Figure 1(*j–l*)].

In a Parclo A interchange, right turns from the minor road are made in advance of the grade separation structure, thus improving visibility and locating the queuing area outside the interchange. The provision of entry ramps from the minor road onto the freeway in the adjacent quadrants forms a Parclo A4 and minimizes the conflict on the minor road [Figure 1(*h*)].

In a Parclo B interchange, left turns from the minor road are made in the expected direction of travel, and wrong way movements are relatively difficult to make. Ramps in the adjacent quadrants of a Parclo B interchange form a Parclo B4 interchange [Figure 1(*k*)]. This increases the capacity of the interchange, but the double exit provision from the freeway complicates directional signing.

The provision of collector-distributor (C-D) roads with Parclo type A4 (and similarly B4) reduces problems associated with the two succeeding entry ramps onto the freeway and places the exit ramp nose in advance of the bridge [Figure 1(*i* and *l*)]. A combination of half of a Parclo A and half of a Parclo B interchange results in a Parclo A-B interchange, thus providing for all movements [Figure 1(*m*)].

Trumpet Interchanges

This type of interchange is suitable for three-way junctions. It is particularly suitable for connection of a freeway to a minor road and may also be suitable for some freeway-to-freeway interchanges [Figure 1(*n*)]. All movements are ac

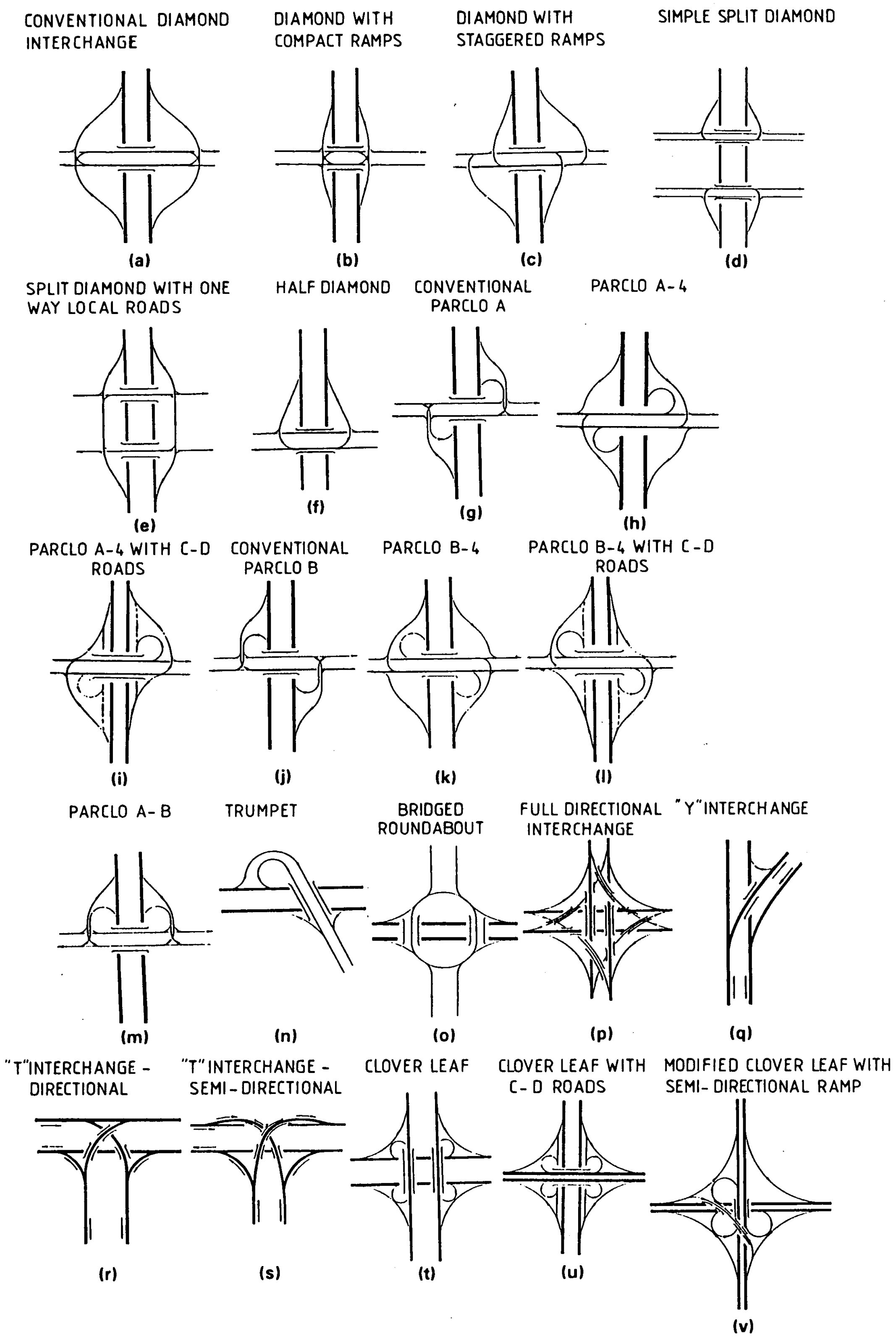

FIGURE 1 **Interchange types in Australia.**

commodated in this type of interchange, and the area of land required is relatively small, but long bridges are often necessary because of the angle of skew.

Bridged Roundabout

The bridged roundabout interchange is similar to the diamond interchange except that all turning movements are accommodated on the roundabout, which is separated from the through carriageways of the freeway. The complete interchange requires two bridge structures and four ramps. This type of interchange is particularly suitable for three or more intersecting roadways, excluding the freeway [Figure 1(*o*)]. All movements in the interchange are reduced to merges, diverges, or weaves, which facilitate ease of signing, and wrong way movements on exit ramps are less likely than at diamond or parclo interchanges.

Freeway-to-Freeway Interchanges

Directional Interchanges

A directional interchange is one in which direct ramps are provided for one or more right turn movements [Figure 1(*p*)]. A direct ramp would generally be used where the turning volume equals or exceeds the through volume. Where the right turning volume is less than the through volume, a semidirect ramp may be suitable.

Y and T Interchanges

An interchange for a three-way junction can take the form of a Y interchange with direct ramps [Figure 1(*q*)], or a T interchange with direct or semidirect ramps [Figure 1(*r* and *s*)]. The basic Y freeway-to-freeway interchange does not accommodate all movements, but is oriented to serve the major traffic demand in one particular quadrant. The T interchange accommodates all movements and, in the case of the directional interchange, the right-turning traffic to and from the leg of the T diverges and merges on the right side of the through traffic.

Cloverleaf Interchanges

The cloverleaf interchange provides indirect right turn movements in all four quadrants by means of loops. Cloverleaf interchanges are generally used where the turning and weaving volumes are relatively low [Figure 1(*t*–*v*)].

Interchange Design Standards

Tables 1 and 2 present important design parameters and speed relationships for Australian interchanges. Appropriate ranges of desirable ramp elements widths, grades on ramps, and typical design speeds for ramp tapers are also provided in the Australian Design Guidelines.

Sight Distance

The freeway alignment should desirably provide 200 to 300 m of stopping sight distance to an exit nose for high-volume, high-speed operations and up to 150 m where traffic volumes and operating speeds are relatively low. A sight distance of 200 m should be provided from 140 m before the nose to 60 m along the ramp. Where the minor road overpasses the major road, the sight distance to the ramp terminals should be consistent with the operating speed of the local through traffic. Exit ramp layouts should provide a sight distance of 120 m to the terminal traffic island to facilitate driver orientation.

Auxiliary Lane

An auxiliary lane is desirable when weaving distance between an entrance ramp and a following exit ramp is less than 600

TABLE 1 Recommended Design Speeds for Interchange Elements

Form of Interchange	Type of Connection	Range of Freeway Design Speeds (km/h)		
		100-120	80-100	60-80
		Range of Ramp design speeds (km/h)		
Freeway to Freeway	Loop	50-70	40-60	40-60
	Semi-Direct	70-90	60-80	50-70
	Direct	80-100	70-90	60-80
Freeway to Minor Road	Loop	40-60	40-60	40-60
	Semi-Direct	60-80	60-70	50-70
	Direct	60-90	60-80	60-80

TABLE 2 Range of Curve Parameters for Interchange Ramps

Design Speed (km/h)	Radius (m)	Superelevation (%)	Assumed Coefficient of Side Friction
110-130	650-800	8-5	0.12-0.11
90-100	300-450	10-5	0.18-0.12
70-80	100-150	10-6	0.31-0.26
40-60	40-75	12-6	0.35-0.33

m. It can also be placed between more widely spaced ramps if a capacity analysis (taking into account grades and the percentage of trucks) indicates that an additional lane is warranted.

Clearances

For all interchange roadway elements, an absolute minimum clearance of 1 m should be provided from the outer edge of the carriageway to any lateral obstructions. In no case should vertical clearances be less than 5.5 m.

INTERCHANGE PLANNING AND DESIGN IN AUSTRIA

The information presented in this section is based on *Intersections, Mixed and Grade-Separated, RVS 3.43*, prepared by Committee on Planning and Traffic of the Austrian Association for Engineers and Architects, 1991.

General Design Considerations

The general criteria applied in the Austrian Guidelines RVS 3.43 for the design of interchanges are as follows:

- Site selection should be based on appropriate topography, right of way, and sight distance;
- In terms of conceivability, the uniform design of the single intersection parts of mixed or grade-separated intersections is more important than the uniform design of the intersections;
- Sufficient temporal and spatial distances between decision points should be strived for;
- Exits should be placed before entrances.

Interchanges in the Austrian guidelines fall into two categories: mixed (i.e., interchanges with at-grade and grade-separated intersections) (Figure 2) and system (i.e., grade-separated intersections of all traffic forms) (Figure 2).

Mixed Interchanges

The basic forms of mixed interchanges in Austria include parclo [Figure 2(*a–d*)], diamond [Figure 2(*e*)], half-diamond and quarter-cloverleaf [Figure 2(*f* and *g*)], trumpet [Figure 2(*h* and *i*)], and one-quadrant [Figure 2(*j–m*)].

The Austrian guidelines include the following mixed interchange types:

- Parclo: The first type of parclo has the best advantage of providing outside left turn movements (B-C and D-A). The distance between at-grade intersections is well defined, with minimum right-of-way (ROW) and favorable corner connections [Figure 2(*a*)].
- Diamond: Diamond interchanges are simple and accommodate all traffic movements [Figure 2(*e*)]. Half-diamond interchanges are especially suitable for half-mixed interchanges.
- Half-diamond and quarter-cloverleaf: Depending on the quadrant in which the half-diamond and quarter-cloverleaf are set up, favorable connections can be provided [Figure 2(*f* and *g*)].
- Trumpet: Examples of trumpet interchanges are shown in Figure 2(*h* and *i*) with one at-grade intersection. The one shown in Figure 2(*h*) is less economical because one more bridge is needed.
- One-quadrant: One-quadrant interchanges [Figure 2(*j–m*)] are favorable if there is only one corner connection with high traffic volume. The application of a one-quadrant interchange may fit the topography well.

System Interchanges

The Austrian guidelines included show the following system interchange types:

- Full cloverleaf interchanges are the most economical solution with little ROW.
- Full cloverleaf interchanges with one or more semi-directional ramps eliminate weaving sections for high-volume corner connections [see Figure 3(*i* and *j*)].
- Other types of interchanges are also used for certain situations.

System Selection

For the selection of an interchange system, the following factors must be considered: road-network system, traffic movements, traffic volume, traffic safety, traffic capacity, environmental impacts, economy and costs, number of conflict points, conceivability and recognition, position of roadways to be connected, topography, ROW, fixed points, spacing, and signing.

Alignment and Cross-Section Design

The minimum lengths of transition curves, radii of vertical curves, superelevation rates, and minimum sight distances are based on the operating speed (V85). Operating speed is defined as the 85th-percentile speed of passenger cars under free-flow conditions for dry and clean road surfaces at a certain section of roadway. This speed depends on the horizontal alignment, expressed by the radii of curve (see Table 3), and on the vertical alignment, expressed by grades (see Table 4). Depending on the design in plan and profile, the smaller value of operating speed becomes decisive for the design. Minimum operating speeds for ramps are 40 km/hr for Interstates and freeways (30 km/hr for exceptional cases) and 30 km/hr for all other roads.

Horizontal and Vertical Alignment

1. A short tangent between circular curves in the same driving direction must be avoided.

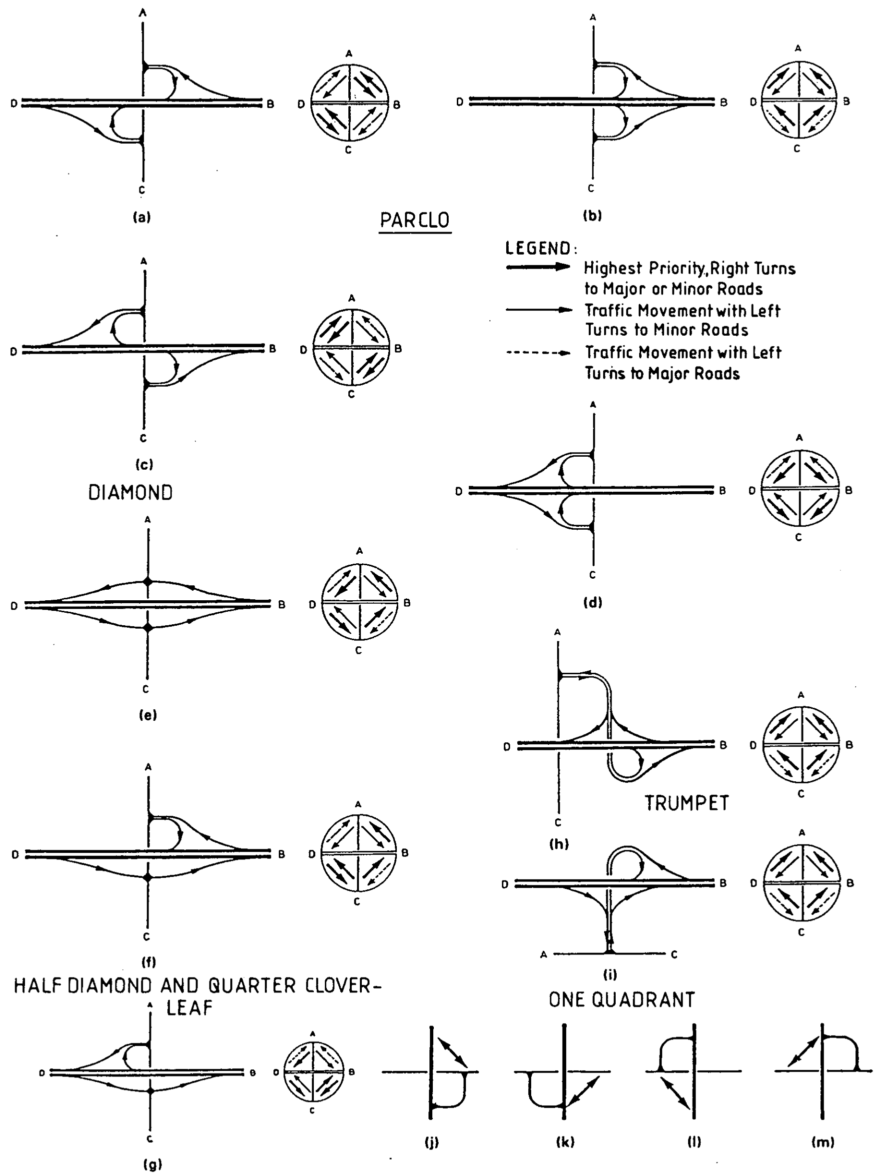

FIGURE 2 Mixed interchange types in Austria.

TABLE 3 Minimum Radii of Curve Relative to Operating Speeds

V85 (km/h)	30	40	50	60	70	80	100	130
R (m)	15	30	50	80	130	200	400	800

TABLE 4 Maximum Grades Relative to Operating Speeds

V85 (km/h)	80	90	100	110	120	130
S (%)	8	7	6	5	4.5	4

2. Because of ROW, radii as small as possible must be used
3. Minimum radii or circular curves are presented i Table 3.
4. The clothoid is considered a transition curve. Minimum lengths of clothoids are presented in Table 5. Maximum length of clothoids should not be more than double the minimum length (Lmax = 2 Lmin).
5. Maximum grades of the vertical alignment are presente in Table 4. For upgrades, the maximum grade is limited to percent; for downgrades, the maximum grade is limited to percent.
6. Minimum radii of crest and sag vertical curves are show in Table 6.

TABLE 5 Minimum Lengths of Clothoids Relative to Operating Speeds

V85 (km/h)	30	40	50	60	70	80	90	100	110	120	130
Lmin (m)	10	15	20	30	39	44	50	56	61	67	72

TABLE 6 Minimum Radii for Crest and Sag Vertical Curves Relative to Operating Speeds

V85 (km/h)	30	40	50	60	70	80	90	100	110	120	130
Rmin (m) (Crest)	175	375	700	1200	2000	3000	4500	6500	9000	12000	15000
Rmin (m) (Sag)	200	400	650	900	1300	1700	2100	2600	3100	3700	4500

Cross Section

The pavement widths for one-lane ramps are presented below relative to radius of curve.

Radius R (m)	*Pavement Width (m)*
$R \geq 50$	4.0
$30 < R < 50$	4.0
$R \leq 30$	5.0 + widening

A paved shoulder of 0.5 m must always be provided. A divided two-lane ramp is justified when traffic volume exceeds 1,500 vehicles per hour and the percentage of trucks is about 15 percent.

The minimum superelevation rate is 2.5 percent. The maximum superelevation rate for ramps of mixed interchanges is 7 percent; for system interchanges, the maximum superelevation is 6 percent. Other values of superelevation rates that apply to specific situations are presented in the guidelines. They are not included here because of space constraints.

Sight Distance

Two types of sight distances, both related to operating speeds, are distinguished in the Austrian guidelines: stopping sight distance and operating sight distance. Values for these sight distances are presented in the guidelines. They are not presented here because of space constraints. Means of calculating sight distances, as in other guidelines, take into account perception and reaction times, as well as braking distance.

The operating sight distance is based on a new concept, and is presented for the first time in this study of international interchange design guidelines. The operating sight distance is defined as the distance required by a driver to stop his or her vehicle in front of a large, unexpected obstacle (usually a stopped vehicle) by an operating braking maneuver (i.e., emergency braking does not have to be used). Therefore, the factor of wet pavement for calculating stopping sight distance is not significant here to operating braking maneuvers. Operating sight distances are, therefore, longer than stopping sight distances.

INTERCHANGE PLANNING AND DESIGN IN GERMANY

The information presented in this section is based on *Guidelines for Highway Design of Rural Roads (RAL): Part III: Intersections (RAL-K), Section 2: Grade-Separated Intersections (RAL-K-2)*, prepared by the German Road and Transportation Research Association, 1976.

A grade-separated intersection (interchange) is a combination of several parts, consisting of through lanes, ramp exits and entrances, connecting ramps, and the like, which require various actions by drivers. Therefore, an important element of interchange design is the proper assembly of these single parts. In the German design guidelines, interchanges fall into two main categories: those that include only interstates (autobahnen), and those that join secondary road(s) with an interstate outside built-up areas.

Principles of Interchange Design

General Requirements

The following principles should be followed in the design and equipment of grade-separated intersections:

- A safe flow for all traffic movement should be provided.
- The capacity of single intersection parts should be well dimensioned in order to provide a smooth traffic flow with road sections outside the interchange.
- An interchange must be easily perceived and should be well designed to provide easy maneuvering by drivers (a safety criterion).

Safety

Distinct (easily recognized) and well-timed and well-placed signing are keys to safe and efficient operation, for informing, warning, and controlling drivers. This is especially important for drivers who are not familiar with the area. Exit and entrance areas have to be distinguished by the alignment itself, by vertical and horizontal guidance, and by signing devices. Distinctness is guaranteed if, for each intersection part, sufficient sight distances are provided, which would allow the driver to easily perceive upcoming design elements. In terms of conceivability, the proper design of the individual intersection parts of grade-separated intersections is important. The key is to strive for adequate temporal and spatial distances between decision points. Minimum design elements, such as breaks in the horizontal alignment, which would require operating speed reductions, must be clearly visible. In these cases, proper signing, including chevrons in some cases, should improve perception considerably. The "easy-to-follow" requirement for a grade-separated intersection is made available when sufficiently long transition sections are provided for necessary operating speed changes and when the design of loop to ramps satisfies sound driving dynamic considerations.

Capacity

The capacity of one through traffic lane is about 1,800 vehicles per hour. Exceeding this traffic volume could result in an inadequate quality of traffic flow in entrance, exit, and weaving sections.

Location and Spacing

The selection of through lanes in a grade-separated intersection depends on the location of the interchange, traffic volume, characteristics of intersecting roads, and turning movements. For interstate-to-interstate interchanges, the through lanes are assessed on the basis of the dominant traffic directions within the observed road network. For interchanges with secondary roads, the interstate (autobahn) is always the dominant road; through lanes follow the course of the interstate. Entrance and exit ramps should always be located in straight (tangent) sections. Allowable minimum spacings between successive interchanges are 1.1 to 1.6 km. Desirable minimum spacings have to be calculated from given equations. On average, minimum spacings are 3.2 to 3.7 km for interstate-to-interstate interchanges, 2.7 to 3.2 km for interchanges with minor roads (high traffic volume), and 2.2 to 2.7 km for interchanges with secondary roads (low traffic volume).

Interchange Types

The basic forms of interstate-to-interstate interchanges in Germany include trumpet, T and Y, cloverleaf, and directional. The basic forms of interchanges associated with minor roads include parclo and diamond. For grade-separated intersections, three types of ramps are used, depending on traffic movements: direct [Figure 3(*a*)], semidirect [Figure 3(*b*)], and indirect [Figure 3(*c*)].

Interstate-to-Interstate (Autobahn) Interchanges

Related to interstates (autobahnen), several different forms of three- and four-leg interchanges are used in Germany.

Trumpet

The Trumpet Interchange has the following characteristics [Figure 3(*d*)]:

- Suitable for three-way junctions,
- Limited ROW,
- Economical solution,
- Small radii and low operating speeds in ramps, and
- Accommodates all traffic movements.

T and Y Interchanges

T interchanges have the following characteristics [Figure 3(*e* and *f*)]:

- Suitable for three-way junctions,
- Semidirectional turning movements,
- Higher ROW and costs than those of trumpet interchanges,
- Generous ramp design,
- Design speed up to 50 mph (80 km/hr), and
- Caters to all traffic movements.

Y interchanges [Figure 3(*g*)] serve major traffic demand in one particular quadrant.

Cloverleaf Interchanges

All left-turn traffic movements in the cloverleaf interchange are carried out by means of loops. This is the most economical type of freeway-to-freeway interchange as it requires only one bridge structure, a compact loop, and tangent ramps. This type of interchange is the most widely used four-leg interstate interchange in Germany. Unlike the United States, the Germans have had good experiences with cloverleaf interchanges.

The characteristics of cloverleaf interchanges are as follows:

- Suitable for four-leg intersection,
- Limited ROW,
- Economical solution,
- Low to moderate capacity,
- Collector-distributor lanes may be incorporated for ca[pacity] reasons, and
- Accommodates all traffic movements.

The speed limit for through lanes should not exceed 80 t[o] 100 km/hr. The weaving lane should be at least 300 m lon[g] (distance between exit and entrance ramp noses). In referenc[e] to the four-quadrant interchange in Figure 3(*h*), different va[rieties] of designs of loops, tangent ramps, and distributor lane[s] are introduced in Germany, depending on terrain, ROW[,] location, access, network, traffic requirements, and the lik[e]. Modified cloverleaf interchanges with semidirectional ramp[s] for left turn movements of high traffic volumes are shown i[n] Figure 3(*i* and *j*).

Directional Interchanges

Semidirectional interchanges [Figure 3(*k*)] and full-direction[al] interchanges [Figure 3(*l*)] are applied when the capacity [of] cloverleaf interchanges, because of loop ramp design and lim[ited] lengths of weaving lanes, is no longer sufficient. In the[se]

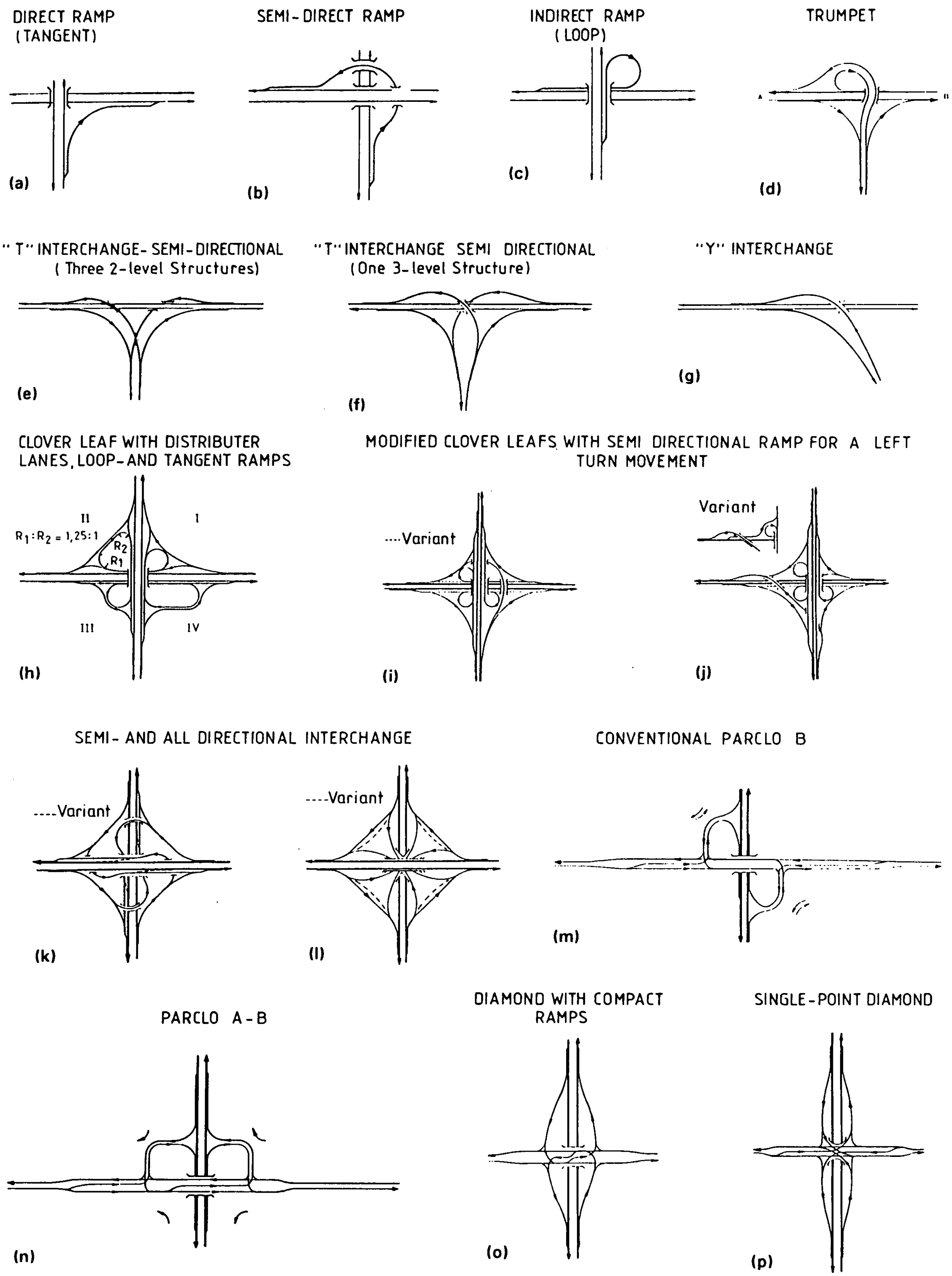

FIGURE 3 Interchange types in Germany.

cases, all or several left turn traffic movements are improved by semidirectional or full-directional ramps.

Interchanges With Secondary Roads

Parclo

In the German guidelines, parclo interchanges are applied in the same manner as, for example, in Australia and the United States. Therefore, this type of interchange is not discussed further here. Figure 3(m) shows, for example, the most commonly used Parclo B form. Other varieties in use are shown in Figure 1. A Parclo A-B type is shown in Figure 3(n).

Diamond

A diamond interchange has the particular advantage that it can be located within a relatively narrow land area because it needs little extra width beyond that required for the major road itself. Because of its simplicity, a diamond interchange is especially preferred in urban areas. Diamond interchanges usually require signalization where cross streets are carrying moderate-to-large traffic volumes. Often, clear (conceivable) signing is difficult to provide; consequently, wrong-way entry is possible, especially on the at-grade parts of the intersection. Typical diamond interchanges are shown in Figure 3(o and p). Numerous other configurations are in use (see Figure 1).

Interchange Design Standards

The road characteristic of through lanes in an interchange should be the same as that for those outside the interchange. Therefore, large differences in design speeds are not desirable. These are allowed only in exceptional cases when, for example, high traffic volumes in entrance, exit, or weaving sections may affect safety, capacity, and traffic flow. Only in these cases must speed limits be posted. Related to connecting ramps are two groups of ramps (Figure 4): connection between interstates (grade-separated to grade-separated) and connection of an interstate with a minor (secondary) road (grade-separated to at-grade). Various types of ramps are shown in Figure 4. Also in the figure are recommended speeds for unadjusted and adjusted ramps. Unadjusted means that local or spatial design constraints are nonexistent. Limiting values for design parameters, with respect to design speeds, are presented in Table 7.

INTERCHANGE PLANNING AND DESIGN IN SOUTH AFRICA

The information presented in this section is based on the *Manual for the Preparation of Detailed Geometric Design Plans for National Roads-G2*, prepared by the South African Roads Board (former the National Transport Commission), February 1984.

The Geometric Planning Manual defines the geometric design standards applicable to all declared national roads in

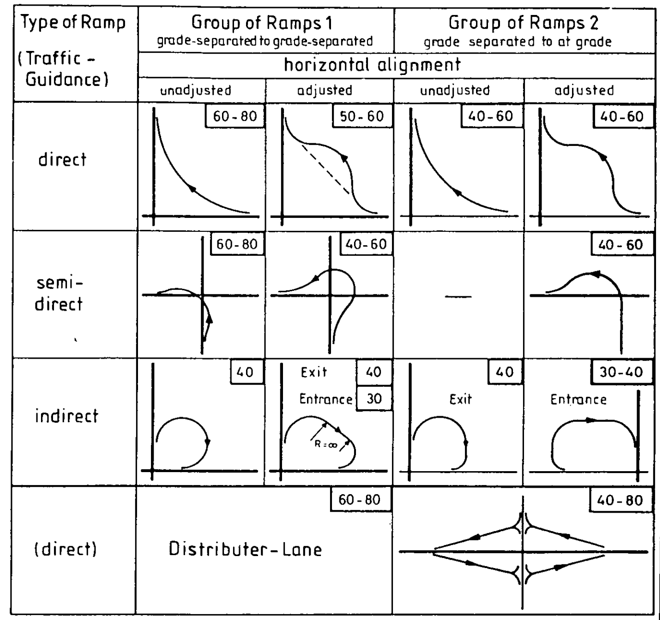

FIGURE 4 Types of ramps and recommended speeds (km/hr).

South Africa. It is not intended to be a legal document, and it is published mainly for the information and guidance of the officials of the Department of Transport, the Provincial Administration, and for consulting engineers engaged in the planning and design of national roads. The policies on highway design practice published by AASHTO, as amended and updated from time to time, are approved references for use in conjunction with the G2 manual. Where standards differ, the standards in the G2 manual apply.

Interchange Planning Considerations

Types

Selection of interchange type is affected by many factors including topography, proximity of other interchanges, speed traffic, local street system and cost. Interchange types are classified as local street interchanges or access interchanges that are designed for stop conditions on one or more turning movements and freeway-to-freeway interchanges or major interchanges that are designed for free-flow conditions on al turning movements.

Spacing and Signposting

To ensure a high level of service for the foreseeable future the spacing between interchanges on national freeways shal be 8 km or more. Any closer spacing requires the approva of the director of the Division of National Roads. All inter changes must be properly signposted in accordance with th South African Road Traffic Signs Manual.

Lane Balance and Width

Design traffic volumes and capacities will determine the num ber of lanes required. This number may be increased or de

TABLE 7 Limiting Values for Design Parameters

Design Parameter		Design Speed V_d [km/h]					
		30	40	50	60	70	80
Minimum Radius of Curve	R [m]	25	50	80	130	190	280
Maximum Upgrade	+ s [%]	5,0					
Maximum Downgrade	- s [%]	6,0					
Minimum Crest Vertical Radius	R_c [m]	500	1000	1500	2000	2800	4000
Minimum Sag Vertical Radius	R_s [m]	250	500	750	1000	1400	2000
Minimum Superelevation Rate	e_{min} [%]	2,5					
Maximum Superelevation Rate	e_{max} [%]	6,0					
Minimum Stopping Sight Distance	SSD [m]	25	30	40	60	85	115

creased in some sections to ease operation. The following lane balance principles should be followed:

- The basic number of lanes beyond the merging area hould be the sum of all merging traffic lanes minus one.
- The basic number of lanes before the diverging area should e the sum of all diverging traffic lanes minus one.
- No carriageway may be reduced by more than one lane t a time.
- All traffic lanes including auxiliary lanes must be 3.7 m vide.

Design Speed of Crossroad

n rural areas, the design speed of the existing crossroad must e used. This should preferably not be less than 100 km/hr. n suburban areas, the design speed of the crossroad must be aken as 10 km/hr in excess of the existing speed limit on that rossroad or 80 km/hr, whichever is greater. Control of access nust be enforced on the crossroad at least 160 m beyond the amp intersections.

Ramp Design

- Off ramps at access interchanges must be long enough or nust be widened to provide sufficient storage for vehicles so hat interference with through traffic is avoided.
- A traffic lane width of 4 m is specified for ramps at terchanges.
- The maximum grade on ramps should be 8 percent, but percent is preferred. A 3 percent maximum grade to the mp intersection shall be used.
- Ramp intersections must be placed to meet the crossroad where the grade on the latter does not exceed 3 percent.
- The design speeds of ramps depend on the design speed of the national road and should not be less than those specified below:

National Roads (km/hr)	*Ramp (km/hr)*
60	30
80	40
100 and above	50

- In general, a design speed of 40 km/hr is considered desirable for loops.
- The design speeds for directional ramps depend on the design speed of the national road and should not be less than those specified below:

National Roads (km/hr)	*Ramp (km/hr)*
60	55
80	65
100	75
120	85
140	95

- Diamond ramps should be designed for a speed of at least 80 km/h in the vicinity of the nose, but only 30 km/h to 40 km/h near the intersection with the cross-road.
- The minimum radii for the reference lines of ramps are specified below:

Design Speed (km/hr)	*Minimum Radius (m)*
20	30
40	45
50	70
60	110
70	160
80	210

Notes on Local Practice in South Africa

- Diamonds, because they are the type expected by motorists, are preferred for access interchanges. Parclo interchanges can be used, but generally only where physical conditions so dictate; Parclo A interchanges are preferred.
- "Crossroad over" is preferred because of assistance with deceleration and acceleration and better visibility.
- Quadrants are landscaped to make accidental departures from ramps safer and to eliminate guardrail for sight distance reasons.
- Diamonds don't include left signals until traffic dictates addition of signals.
- A number of full cloverleaf interchanges exist as system interchanges, but new interchanges of this type will not be built because of the weave problems they generate. A loop in the minor flowing direction would be used today. However, few system interchanges are built in the current funding situation.
- Only one double diamond (3-level diamond) exists in a location where space was restricted.
- No single-point diamonds have been built, but one is being considered as an additional interchange on the existing freeway between Johannesburg and Pretoria.

INTERCHANGE PLANNING AND DESIGN IN SWITZERLAND

The information presented in this section is based on *Intersections, Part SNV 640263, Principles*; *Part SNV 640265, Types*; *Part SNV 640266, Elements*, prepared by the Swiss Association of Road Specialists, 1972.

The planning and design of interchanges in Switzerland is based on an extensive amount of information on the following factors:

- Geographical, physical, and political data [e.g., geology, topography, border lines (state, county, etc.)];
- Land use (e.g., zoning, existing facilities, utilities, structural lines, access control, population data);
- Traffic (e.g., traffic analysis, existing road network, mass transportation system, pedestrian facilities);
- Existing projects (e.g., general access projects, projects for the road network); and
- Funding (e.g., existing funds from federal, state, county, municipality, land acquisition, construction, maintenance and operation costs).

Types and Classification

An interchange is characterized by connecting road types (freeways, arterials, connectors, collectors, local roads), number and type of lanes per leg, permissible traffic movements, number of levels, urban or rural area, type of traffic regulation, pedestrian and bicycle traffic, and operation of mass transportation.

The type of intersection depends on the type of connecting roads. Types of roads that connect intersections are shown in Figure 5. As the figure shows, there are eight intersection types: Types 1, 2, and 3 for at-grade intersections; 4, 5, and

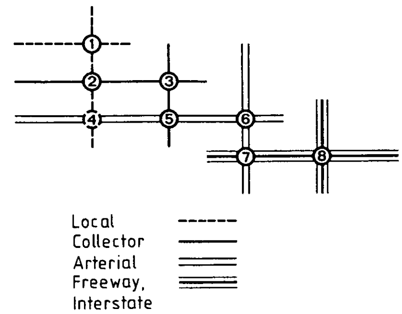

FIGURE 5 Numbering of intersection types with regard to connecting road types in Switzerland.

6 for at-grade or grade-separated intersections; and 7 and 8 for grade-separated intersections. Type 8 can be designed for more than two-level structures. Type 4 is avoided. For grade-separated intersections, the traffic lane arrangements for Types 7 and 8 are proposed in the Swiss guidelines (Figures 6 and 7).

Important operational features of intersection Types 5–8 are presented in Table 8. The information is limited to design speeds, number of lanes, acceleration and deceleration lanes, and entering traffic volume, as related to various intersection and road types.

Lane Widths

- The lane width depends on the type of lane, such as through or ramp lane, type of road, and location of the intersection/interchange.

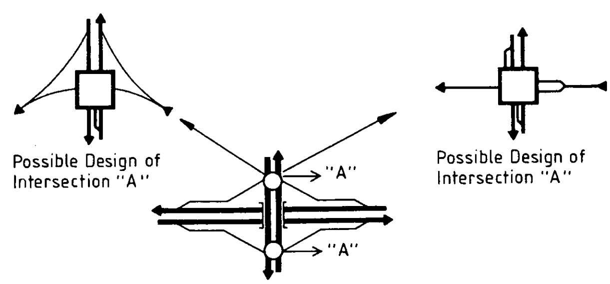

FIGURE 6 Traffic lane arrangement for interchange Type 7.

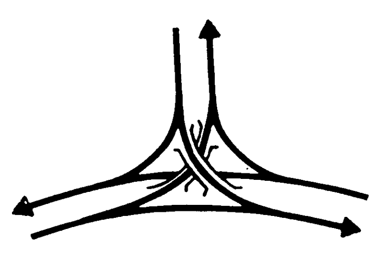

FIGURE 7 Traffic lane arrangement for interchange Type 8.

• As a general rule, and unlike open roadway sections, the through lanes within intersection areas should remain unchanged.

• Entrance and exit lanes, as well as acceleration and deceleration lanes, can be narrow.

• In curved sections, the principles of road-widening apply, as in the case of normal roadway curves.

• When bicycle volume exceeds 100 bicycles per hour, the lane widths within the intersection area should be widened by as much as 0.5 to 1.0 m, or extra bicycle lanes should be added.

• The lane widths for through lanes and ramp lanes, with or without shoulders, in intersection/interchange areas are presented in Table 9.

INTERCHANGE PLANNING AND DESIGN IN OTHER EUROPEAN COUNTRIES

Greece

Greece is a typical country in which official technical norms, standards, or guidelines for intersection and interchange design do not exist; work is currently under way to formulate guidelines in the near future.

Intersections and interchanges are planned, designed, and constructed on the basis of AASHTO guidelines (*A Policy on Geometric Design of Highways and Streets*) and the German Guidelines. The following interchange types are often used:

- Diamond (most favorable),
- Parclo,
- Trumpet,
- Cloverleaf, and
- Modified and mixture of the above-mentioned types.

As is the case in France and Italy, interchanges in Greece have tollbooth stations. As a result, provisions must be made on entrance ramps. In turn, certain modifications and mixtures of the different types of interchanges discussed in this study are often used.

Ireland

Interchange design standards in Ireland generally follow the procedures adopted in the United Kingdom and detailed in the United Kingdom Department of Transport Standard TD 22/86. A number of changes are made to suit traffic levels and driver behavior in Ireland.

TABLE 8 Design Criteria for Intersection Types 5-8 in Switzerland

Intersection Type	5		6		7		8	
Road Type Design	SS	HVS	HVS	HVS	HVS	HLS	HLS	HLS
Speed (km/h)	50-80	60-120	60-120		60-120	80-120	80-120	
No. of Lanes	2	2/4	2/4		2/4	≥4	≥4	
Acceleration/ Dec. Lanes						X	X	
Entering Traffic Volume (pcu/h)	500-3500		1000-4000		>1500		>2000	

Legend: SS = Collector; HVS = Arterial; HLS = Freeway/Interstate; and PCU/H = Passenger Car Units per Hour.

TABLE 9 Lane Widths in Intersection and Interchange Areas

Lanes	Freeway		Arterials		Collectors		Local	
	ST	MIN	ST	MIN	ST	MIN	ST	MIN
Through Lanes	4.00	3.50	3.75	3.00	3.50	3.00	3.00	2.75
Ramp Lane WTPS	5.00	4.50	5.00	4.50	5.00	4.50	4.00	4.00
Ramp Lane WPS	4.00	3.50	5.00	4.50	5.00	4.50	4.00	4.00
Paved Shoulder	2.50	2.50	NO PAVED SHOULDERS REQUIRED					

NOTE: Lane widths are in meters.

Legend: ST = Standard; MIN = Minimum; WTPS = Without Paved Shoulder; and WPS = With Paved Shoulder.

Interchanges are provided at all junctions on motorways and at major junctions on certain nonmotorway roads. They are generally either grade-separated roundabouts or grade-separated diamond types (possibly with small roundabouts at the ramp/minor road intersections). The actual layout chosen is determined by taking into account costs, topography, and traffic flows.

General Design Parameters

The design speed for the motorway is 120 km/hr. For connecting ramps, it is 60 to 80 km/hr, and it varies with size for roundabouts.

The minimum radius for normal roads is as follows:

$$R = \{V^2/[127(s + f)]\}$$

where

R = minimum radius (m),
V = design speed (km/hr),
s = superelevation rate (m/m) (max = 0.07), and
f = side friction factor (0.15 for 60 km/hr, 0.14 for 80 km/hr.

The minimum sight distance for normal roads is as follows:

$$SD = 0.56\ V + [V^2/(254\ cf)]$$

where

SD = sight distance (m),
V = design speed (km/hr), and
cf = coefficient of friction (0.34 for 60 km/hr, 0.32 for 80 km/hr).

The minimum longitudinal gradient for normal roads is 0.3 percent with curbs; no minimum applies if there are no curbs.

The maximum longitudinal gradient is 4 percent if the ramp carries a large volume of heavy trucks, up to 8 percent if a grade assists a change in speed, and up to 10 percent on minor, low-volume ramps.

The cross-section width on one-lane ramps is 1.5 m for the left shoulder, 4.0 m for the carriageway, and 0.5 m for the right shoulder. On two-lane ramps, the width is 1.5 m for the left shoulder, 7.5 m for the carriageway, and 0.5 m for the right shoulder.

Norway

Selection of Intersection Type

Grade-separated intersections (interchanges) should be considered outside urban areas when annual average daily traffic (AADT) exceeds 10,000. On some national routes, the limit is 5,000 AADT. Intersections on motorways shall always be grade-separated. Intersections on roads reserved for motor vehicles shall normally be grade-separated. In general, these are two-lane roads with two-way traffic (called Motorway B, even though there is only one lane in each direction).

Three types of interchanges are recommended: trumpet, diamond, and parclo. Mixtures of these types may also be used. To avoid conflicts between vehicles and pedestrians and cyclists along the secondary road, a parclo intersection with both ramps on the same side of the secondary road may be used.

Design

Today, it is essential to have auxiliary lanes of high standard in Norway. Deceleration lanes should always be used. When the speed limit of the primary road is 70 km/hr or higher, parallel deceleration lanes are recommended. Normally, acceleration lanes should be built. An acceleration lane should always exist and be of the same width as the through traffic lane (but not more than 3.5 m), with a short taper at the end. In Norway, this traffic situation is regulated with merging signs so that vehicles on the acceleration lane have the same right as the vehicles on the through traffic lane. However, the driver of the accelerating vehicle should adjust the speed to the speed level of the through traffic. With high standard on the auxiliary lanes, the standard of the ramps can be moderate.

Most Norwegian interchanges have at-grade intersections between ramps and the secondary road. Traditionally, these parts of the interchanges have the highest accident rates and can also cause capacity problems. The new guidelines recommend the use of roundabouts as a standard solution in the connection between ramps and secondary road on each side of the primary road. Roundabouts are safe; they provide high capacity and are often flexible for variations in traffic. It is interesting to note that even guidelines for interchanges in tunnels exist in Norway.

SUMMARY

To achieve the objective of this study, the authors reviewed, analyzed, and evaluated norms, standards, and guidelines for interchange design in Australia, Austria, Germany, South Africa, Switzerland, and others. For Greece, Ireland, and Norway, only abbreviated versions were discussed here to avoid repetition. For the countries under study, the following topics were investigated: (a) interchange planning considerations or principles of interchange design, including information on location and spacing, lane balance, safety, capacity and the like and (b) interchange types, such as freeway-to-freeway interchanges (often called system interchanges) and freeway-to-minor road interchanges (often called mixed or service interchanges).

As a result of this study, the following conclusions can be drawn. With respect to system interchanges (see Figures 1–3), the types of three-leg interchanges given high priority in nearly all the countries under study were the trumpet and Y and T types.

The four-leg interchanges given high priority were full cloverleaf, cloverleaf with semidirectional ramps, and semi- and full-directional types. It should be noted that, contrary to U.S. experiences, all types of cloverleaf interchanges are considered favorable solutions, as long as the weaving traffic volumes are not extremely high.

The following types of mixed interchanges were in use: conventional-, split-, single-point-, and half-diamonds; Parclo A, Parclo B, and Parclo A-B; bridged roundabout; one quadrant; and modified types, such as half-diamond and quarter-cloverleaf.

The following also were found in the study: design standards, including design and operating speed, horizontal and vertical alignment, and cross-section design for ramps; information on local practice; and information on traffic safety.

Because of space and time constraints, information on entrance, exit, acceleration, and deceleration ramps, as well as information on weaving lanes, sight distance considerations, equipment, signing, and the like, was not discussed in detail here.

The variability of approaches to interchange design in the countries under study, along with the experiences gained in the United States, should provide a basis for any future attempts to improve and extend existing norms, standards, and guidelines in the various countries of the world. In closing, future research on interchange design should take into account the differences in design philosophies as well as similarities between the countries under study as well as other countries, such as France, Great Britain, and Japan.

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