

A Critical Review of the Standards and Design Processes for Motorway Diverges in the UK

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This paper contains a critical review of design standards for motorway diverges in the UK over the last 40 years. These standards have been progressively updated at regular intervals and their evolving nature has been assessed. Most changes have been minor as a result of changes to traffic flow, driver behaviour or vehicle performance. A brief comparison has also been made between standards for diverges in the UK and those in other selected EU countries. This paper particularly focuses on the diverging flow-region diagram contained in the latest Government Standard TD22/92 'The Layout of Grade-Separated Junctions'. This diagram is used by traffic engineers as a tool in order to select the most appropriate diverge layout for a particular site. The historical background leading to its derivation is reviewed along with a discussion of comments made by five practicing traffic engineers as to its effectiveness and usage. These comments have been used along with other analysis to make recommendations as to how the diagram should be interpreted and how it could be improved.

Keywords: Design standard, Diverge, Diverging flow-region diagram, Layout and Exit

1. Introduction

A diverge is the area of a motorway or other major road where drivers can leave the main carriageway. An efficiently designed diverge will allow traffic to leave the mainline as easily and as quickly as possible, without disrupting other traffic wishing to continue on the mainline. The design process for motorway diverges was established in the 1970's, and has remained largely unchanged since then. In the meantime, traffic conditions and operations have changed significantly, and new diverge layouts have had to be introduced. This situation

has prompted the research described in this paper, which has concerned a critical review of standards and design procedures at motorway diverges

The latest UK standard, setting out the layout requirements for diverges, is entitled “The Layout of Grade-Separated Junctions” and is commonly known as TD22/92 (Department of Transport 1992a), which is currently being revised and updated. It recommends two basic designs of diverge layout; the Taper and the Parallel. These layouts are shown in Figure 1 along with some of the geometric parameters.

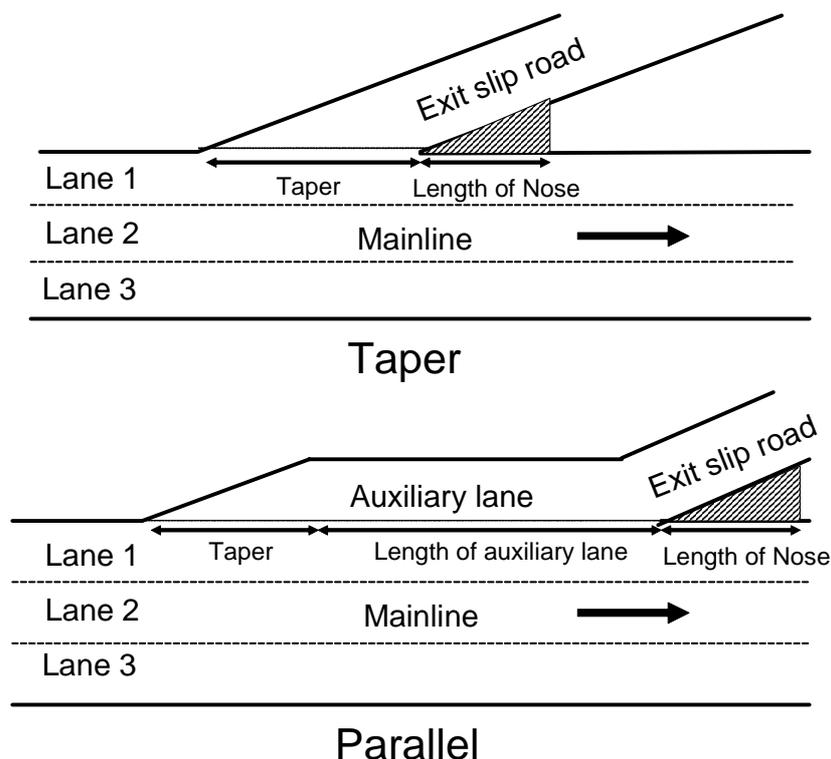


Figure 1. Two basic diverge designs in the UK

With the Taper diverge, drivers wishing to leave the motorway should stay in lane 1 prior to the diverge, and then move directly into the exit slip road. With the Parallel diverge, drivers wishing to leave the motorway should stay in lane 1 and then move into the auxiliary lane that feeds into the exit slip road. An auxiliary lane (sometimes called a parallel lane) provides extra capacity, reducing the risk of traffic blocking back onto the main carriageway. These two types of layout can be associated with a lane drop or double lane drop (Parallel only). A lane drop occurs when the number of lanes downstream of the diverge is less than the number of lanes upstream of the diverge. This is as a result of the inside mainline lane(s) feeding into the exit slip road. Lane drops are only usually provided when there is a high diverging proportion or when there is a high merging proportion requiring a lane gain upstream of the diverge. There may also be policy, layout or economic reasons for their use.

Following this introduction, section 2 describes how the UK standards have evolved over the last 40 years. The diverging flow-region diagram is introduced in section 3 with its research background reviewed in section 4. Section 5 contains a comparison of standards in other selected EU countries. A critical review of the diverging flow region diagram is contained in section 6 followed by conclusions and recommendations in section 7.

2. Evolution of standards for motorway diverges

The Romans introduced the idea of a national road system to Britain in the first century, in order for military purposes of conquest and linking important centres of trade. Similarities still exist between the main roads in existence in 200 AD and the present-day UK motorway network. Pressure for the construction of a system of motorways mounted as they were seen to be, potentially, a network of roads exclusively for motor traffic, designed for the needs of the country as a whole. This followed the construction of motorways in countries like the USA, Germany and Italy in the 1920's and 1930's. However, it was not until December 1958 that the first length of road constructed as a motorway was opened to the public. This was the 8 mile long Preston by-pass, part of the now M6 in Lancashire (Charlesworth 1984). Their purpose was to provide safe, fast and reliable communication between the main centres of the UK. They were to supplement the existing road network, providing access to the motorway at reasonable intervals via connecting roads.

Ever since this first motorway was opened to the public in the UK in 1958, the standards for their construction have evolved over the years. Standards are technical specifications issued by Government in order to provide requirements for the design of new roads and junctions. These standards are mandatory for work on trunk roads or motorways in the UK and have been updated at regular intervals over the last 40 years, in particular to cope with the large increase in traffic flows. They have also needed to change in order to cater for new levels of vehicle and driver performance, as well as address any safety concerns. New standards are often just minor amendments to the existing standards. Some of the changes have been due to a need for further clarification, as the previous standard lacked the required detail or definition.

Standards may need to be 'relaxed' in order for a new road to be built in difficult circumstances e.g. very hilly terrain. Many standards contain a 'desired minimum' and an 'absolute minimum'. Behavioural studies have shown that there is a considerable margin below the desired minimum standards before safety is significantly reduced (Simpson and Kerman 1982). A relaxation from the desired minimum may be necessary if the economic or environmental cost cannot be justified. Departures (going beyond the absolute minimum) require authorisation from the Department's headquarters. Relaxations or departures should not compromise safety but may reduce driving comfort.

Table 1 lists the most important standards for motorway diverges to be published in the UK over the last 40 years. The Standard TD39/94 (Department of Transport 1994) recommends three layouts for major diverge layouts. These, however, are only suitable at major motorway-to-motorway interchanges with a mainline of at least 4 lanes.

Table 1. Selected UK standards for motorway diverges

Standard Title and Number	Government Department responsible	Year published
Layout of Roads in Rural Areas	Ministry of Transport	1968
Technical Memorandum on design flows for motorways and all-purpose roads (H6/74)	Department of the Environment	1974
Technical Memorandum on rural motorway to motorway interchanges – single lane links (H17/75)	Department of the Environment	1975
Technical Memorandum on design of rural motorway to motorway interchanges – merging and diverging lanes (H18/75)	Department of the Environment	1975
Highway Link Design (TD9/81)	Department of Transport	1981
Layout of Grade-Separated Junctions (TD22/86)	Department of Transport	1986
Layout of Grade-Separated Junctions (TD22/92 and TA48/92)	Department of Transport	1992
The Design of Major Intersections (TD39/94)	Department of Transport	1994

A comparison was made of the geometric parameters for motorway diverges recommended in H18/75, TD22/86 and TD22/92. Table 2 compares the principle diverge layout parameters for these Standards, illustrated in Figure 1. A blank entry denotes that no figure for that geometric parameter was provided in that particular Standard. It is assumed that the figure from the previous Standard would still be used in the updated Standard.

Table 2. Comparison of diverge layout parameters for three UK Standards

	H18/75	TD22/86	TD22/92
Length of taper (m) (Taper single/double link)	185	-	170 (1 lane) 185 (2 lanes)
Length of taper (m) (Parallel single/double link)	90 (1 lane) 185 (2 lanes)	-	75 (1 lane) 150 (2 lanes)
Length of taper (m) (Taper lane drop)	185	-	170
Length of taper (m) (Parallel lane drop)	90	-	75
Length of auxiliary lane (m)	200 (min)	200 (min)	200 (min) (up to 600m)
Length of Nose (m)	80 100 (lane drop)	80	80
Taper for Nose	1:15 min	1:15 min	1:15 min
Taper angle of diverging lane (Taper double link)	1:25	1:25	-
Taper angle of diverging lane (Parallel double link)	1:25	1:20	-
Taper angle of diverging lane (Taper lane drop)	1:50	1:45	-
Taper angle of diverging lane (Parallel lane drop)	1:25	1:20	-
Max total exit width (m)	9	9	9.6
Min loop radii (m)	-	75	75

These geometric parameters have showed a slight ‘tightening’ of values over time. The general tendency has been towards more compact designs with less generous values. Changes made have tended to be relatively minor and probably came about as a result of increased traffic flows, improved vehicle performance or changes in driver behaviour.

3. Introduction to the diverging flow-region diagram

In order for traffic engineers to choose the correct diverge layout for a specific site, the Standard TD22/92 provides traffic engineers with a diverging flow-region diagram, recommending the different diverge layouts for varying combinations of mainline and diverging flows (see Figure 2). The intersecting lines in the diagram form regions, which are given a letter A, B, C, D or E corresponding to one of the five diverging layouts. The traffic engineer needs to select the 30th highest combination of predicted hourly flows expected in the 15th year of operation. The 30th highest combination is used as it is assumed that there is very low seasonal variation on the motorway in the predicted hourly flows. The regions in the diagram are given a letter A, B, C, D or E. Figure 3 shows the appropriate diverge layout type for each of these regions with the exception of layout E (Mainline double lane drop at a Parallel diverge) which is not illustrated in TD22/92. However, layout E is the same as layout D but with 2 mainline lanes dropped at the diverge.

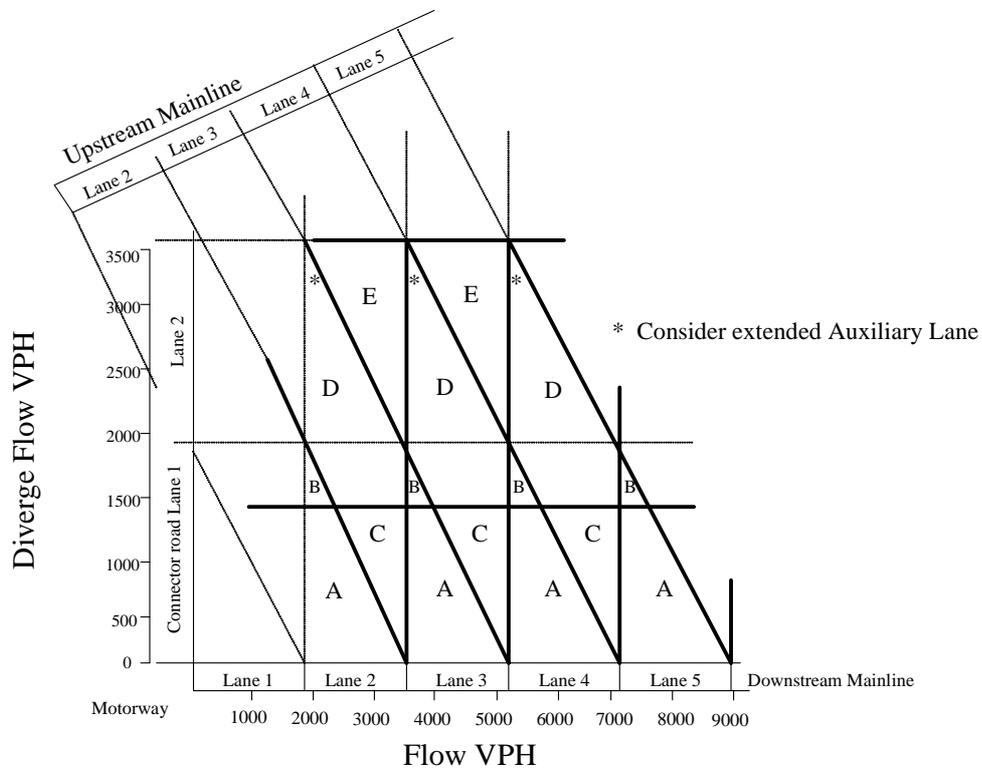


Figure 2. The diverging flow-region diagram from TD22/92

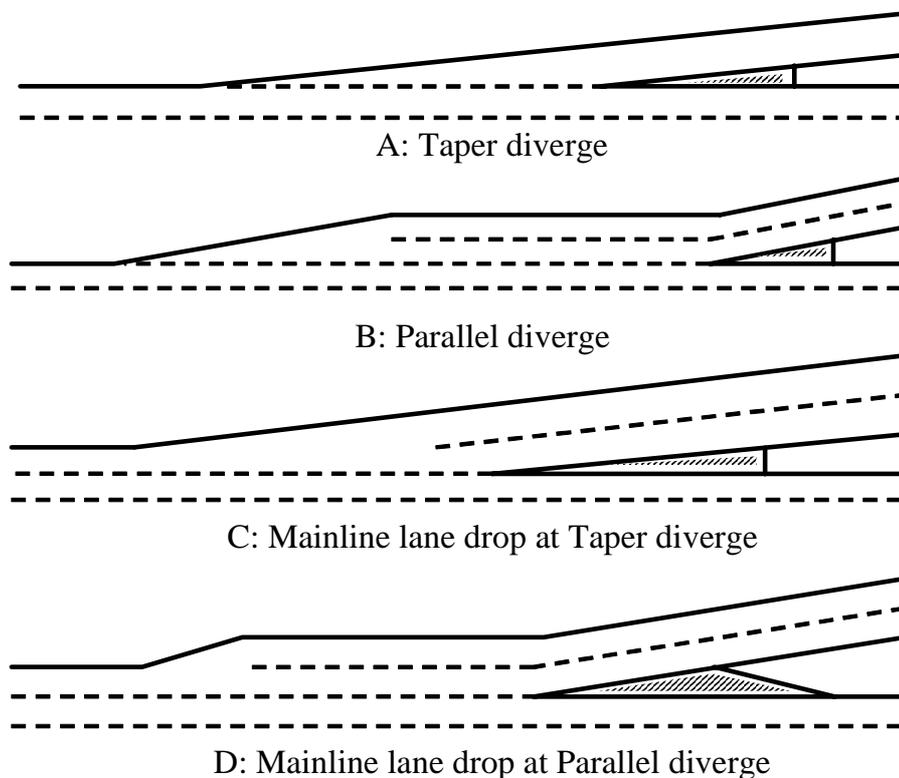


Figure 3. The diverge layout types associated with the diverging flow-region diagram

The diverging and mainline downstream mainline flows used in the diverging flow-region diagram are maximum design working flows and are based upon a standard traffic composition and gradient. The standard composition is defined to be 15% HGVs and up to 1% uphill. Correction factors apply to non standard traffic compositions and gradients, which are shown in Table 3. The research that these figures are based on is unclear but the correction factors seemed to have been simplified for use by traffic engineers due to their linear progression in multiples of five percent. The factors also represent a combined figure for the mainline gradient and HGV percentage. They do not take into account the length over which the gradient is applied, although the Standard recommends that a Parallel diverge should replace a Taper diverge if the mainline has an uphill gradient of $>3\%$ (or a downhill gradient of $<-3\%$) for longer than 1.5km prior to the start of the exit.

Table 3. Correction factors (%) within TD22/92

%HGVs	Mainline gradient	
	< 2%	> 2%
5	-	+ 10
10	-	+ 15
15	-	+ 20
20	+ 5	+ 25

4. Research background to the diverging flow-region diagram

Design standards for motorways in the UK and elsewhere have been greatly influenced by research in the USA. A number of roads of motorway type, with grade-separation and interchanges, were built in the USA in the 1930's. These early motorways became an excellent resource for observation and research purposes. Two important publications followed in the 1960's that were the basis for future American Association of State Highway Officials (AASHO) design policies. These were "The Highway Capacity Manual" (Highway Research Board 1965) and "A Policy on Geometric Design of Rural Highways" (American Association of State Highway Officials 1965).

Much of the research background to the diverging flow-region diagram, however, was carried out in the 1970's in the form of various motorway merging trials. Due to the high dependence on the USA for data on merging and diverging behaviour, a study was initiated in the UK at four urban motorway merge sites in 1972 (Berresford and Seddon 1972; Seddon 1976). Traffic flows at the sites were high enough to cause congestion at certain times of the day. Data was collected using time-lapsed cinematography. This enabled equations to be produced by multiple linear regression to calculate the upstream lane 1 flow. After numerous attempts, the most acceptable regression for the inside lane flow was:

$$Q_i = 493 + 0.36Q_u - 0.14Q_r - 19G - 183N \text{ where} \quad (1)$$

Q_i is the upstream inside lane flow

Q_u is the total upstream flow

Q_r is the slip road flow

G is the relative gradient (slip road grade – motorway grade, uphill positive)

N is the number of motorway lanes (either 2 or 3)

Equation (1) was based on 67 three-minute observation periods at four different sites. Statistical tests gave an R^2 value of 0.85. Subsequent t-tests indicated that Q_u was significant at the 1% level with all other variables significant at the 0.1% level. The equation shows a dependence of the inside lane flow on the slip road flow, indicating that many mainline vehicles move into the outer lanes to allow easier access for merging vehicles as well as minimising their own journey time. The equation also showed the dependency of the inside lane flow on relative gradient, showing that with good visibility (uphill gradient and downhill slip road), there would be a higher inside lane flow. These equations provide a knowledge of the inside lane capacity rather than a working design value which is more important in the design process. Nomographs accompanied the equations to make calculating the inside lane flow easier. Figure 4 shows a nomograph to help to calculate the inside lane flow.

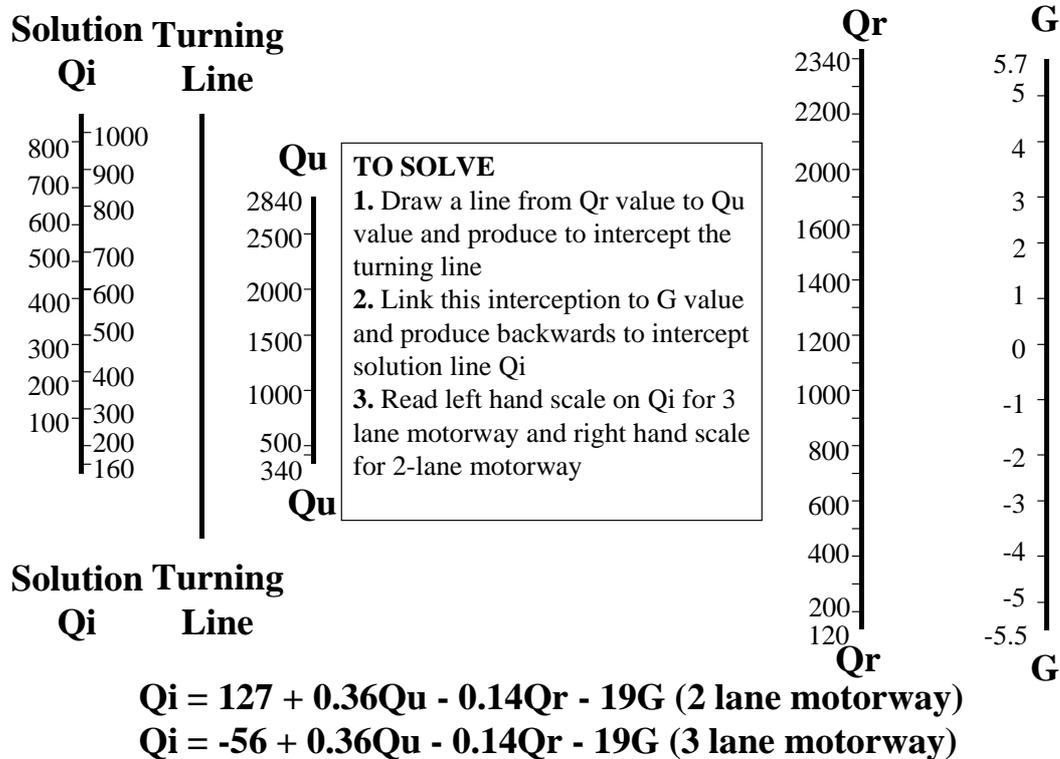


Figure 4. A nomograph to help to calculate the inside lane flow Q_i (from Berresford and Seddon 1972)

The study continued in 1973 so that the number of merging sites being analysed could be increased (Sneddon 1976). The formula for the inside lane flow was revised and included a slip road gradient term which was a better fit to the UK sites than the one in the Highway Capacity Manual (Highway Research Board 1965). A new set of nomographs accompanied the revised equation. Once calculated, the merging and the total downstream flow could be assessed as to their suitability for particular levels of service (a term used in the Highway Capacity Manual to assess the operating conditions of a particular stretch of road) or limiting flows.

Building on this research which introduced the concept of limiting merging and downstream flows, Warwickshire Sub-Unit of the Midland Road Construction Unit produced a new set of motorway merge design flow-region diagrams for a Department of the Environment Working Party. These were based on practices in the USA as described in the Highway Capacity Manual, showing maximum traffic flow levels for different levels of service. They suggested much higher flow levels than those recommended in the previous Standard “Layout of Roads in Rural Areas” published in 1968. The diagrams were modified by TRL (Burrow 1976) and then incorporated into Technical Memorandum H18/75 (Department of the Environment 1975), which gave advice regarding the design of merging and diverging layouts.

A derivation of the merging flow limits (which made up the merging flow-region diagram) were provided one 'level' at a time. The merging diagram was derived as follows (Burrow 1976):

1. The mainline upstream is limited to a flow of 1600 veh/hr per lane.
2. The entry flow on the slip road is limited to 1200 veh/hr for a single link and 3200 veh/hr for a two-lane link.
3. The downstream flow must not exceed 1600 veh/hr per lane.
4. The entry flow should not exceed the upstream mainline flow.

A design flow of 1600 veh/hr was seen as the maximum working flow (upper limit of the range of flows used for rural motorway design purposes) operating just above the limit for level of service D (approaching unstable flow). This was different to the capacity, defined to be the highest level of flow operating just above the limit for level of service E (unstable flow).

There were also additional merging limits derived from the Highway Capacity Manual to give a merging level of service comparable to that for the mainline flows. These limits were combined and used for up to 3 lanes upstream with 1 or 2 slip lane entries, in order to derive the merging flow-region diagram. The diverging flow-region diagram was derived in a similar way by replacing the phrase "upstream of the merge" with "downstream of the diverge". This may seem questionable, as the concepts behind merging and diverging are very different; merging involves joining a traffic stream, which involves gap acceptance and possible adjustments by the drivers on the mainline whereas the decisions/manoeuvres involved at a diverge where traffic leaves a traffic stream are quite different.

The diagram was to be used in the early stages of design to see which layout was likely to be most appropriate for the given downstream mainline and diverging flows. Within a given region of the diverging flow-region diagram, a tick indicated which of the nine diverging layout configurations were suitable (see Table 4). A method of compensating for variations in the traffic composition and for the effect of gradients was also included. Comparisons made with recorded flow measurements showed that the new design flows were realistic. Figure 5 shows the diverging flow-region diagram from H18/75 with the motorway scale added from TD22/86 (Department of Transport 1986). TD22/86 was the first Standard that assigned a different maximum capacity for a lane on an all-purpose road than that on a motorway.

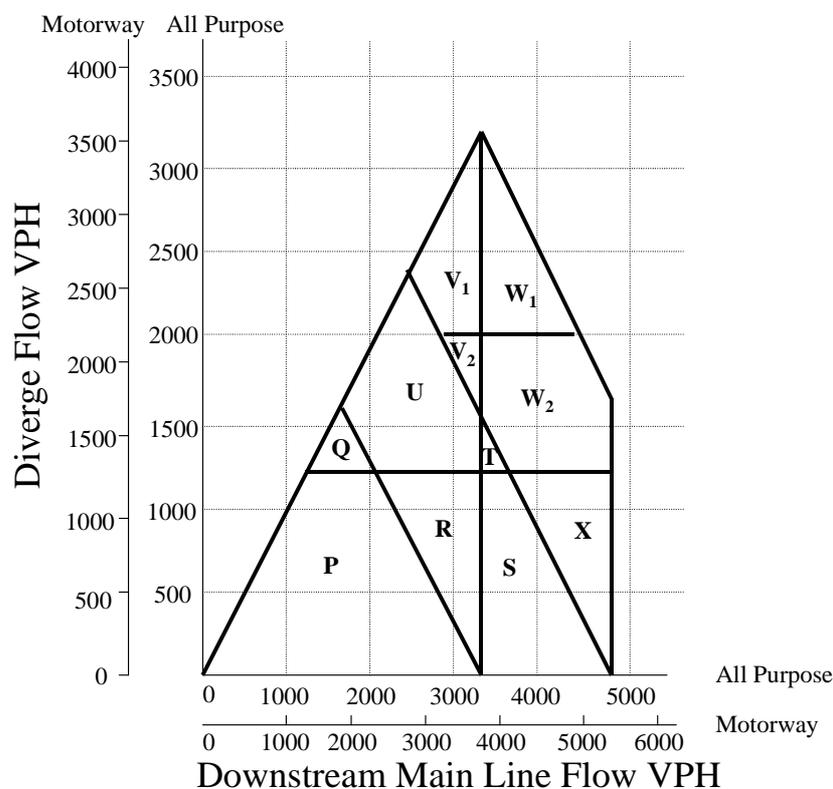


Figure 5. Diverging flow-region diagram from H18/75 (motorway scale added from TD22/86)

Table 4. Diverging lane types applicable to flow-regions in Figure 5

Diverging lane types		1	2	3	4	5	6	7	8	9
Number of lanes	Upstream mainline	2	2	3	3	3	4	3	4	4
	Link (slip lane)	1	2	1	2	2	2	1	1	2
	Downstream mainline	2	2	3	2	3	3	2	3	2
Flow Region	P	√	√	√	√	√	√	√	√	√
	Q	X	√	X	√	√	√	X	X	√
	R	X	X	√	√	√	√	√	√	√
	S	X	X	√	X	√	√	X	√	X
	T	X	X	X	X	√	√	X	X	X
	U	X	X	X	√	√	√	X	X	√
	V	X	X	X	X	X	√	X	X	√
	W	X	X	X	X	X	√	X	X	X
	X	X	X	X	X	X	√	X	√	X

About 5 years after the publication of TD22/86, it became clear that it had to be revised to cope with greater traffic flows and more proficient merging and diverging behaviour. The latest Departmental Standard TD22/92, published in 1992 (Department of Transport 1992a), sets out the design standards for methodology for the geometric layout of grade-separated junctions on trunk roads. The diverging diagram now catered for 5 mainline lanes as opposed to only 3 lanes in H18/75 and TD22/86. Also, the diverging diagram recommended diverge layout types (e.g. Taper, Parallel) as opposed to diverge layout configurations (i.e. number of

upstream lanes, number of slip lanes and the number of downstream lanes) as in H18/75 and TD22/86.

5. Comparison between different selected European countries' Standards

A comparative look at standards for motorway diverges in other selected European Union countries revealed that the use of a diverging flow-region diagram was unique to the UK. The only exception to this was the Republic of Ireland, which has used an amended version of the UK standard TD22/92 since January 2001. This has been done by the use of an Addendum (National Roads Authority 2000) in order that the Standard suits Irish conditions and practice. Standards in the other selected countries took into account many factors when deciding when to install a Taper or a Parallel layout. These included traffic flows, safety issues, topography, highway classification and the economic cost. The length of the auxiliary lane was determined by factors such as the distance required for de-acceleration after the vehicle has left the mainline, which is dependent on the design speed of the mainline and slip road.

A recent study for the European Union compared some of the recommended geometric parameters for motorway diverges in selected EU countries (Steinbrecher 1994). Table 5 shows some of these recommended geometric parameters for selected EU countries.

Table 5. Recommended geometric parameters for selected EU countries

Country	Diverge type (Taper/Parallel)	Length of auxiliary lane (m)	Length of taper (m)
Germany	Parallel	190	60
France	Parallel ⁽¹⁾	>1000	250
	Taper		150
UK	Parallel ⁽¹⁾	200 (min)	75
	Taper		150
Netherlands	Parallel	150	100
Portugal	Parallel ⁽¹⁾	>400	75
	Taper		110
Belgium	Parallel	80	120
Ireland	Parallel ⁽¹⁾	145	75
	Taper		
Denmark	Taper	-	100
Spain	Parallel	220	-

⁽¹⁾ In the case of a two-lane exit slip road.

Parallel layouts are recommended for all exits in Germany, The Netherlands, Belgium and Spain. However, in the UK, Ireland and France, auxiliary lanes are only recommended for two lane exit slip roads. In Portugal, Taper and Parallel layouts are recommended although in practice Parallel layouts are used. Denmark is the only country that does not recommend Parallel diverges as a standard layout. However, the Danish guidelines do provide for a sufficient length for drivers to de-accelerate in before reaching the minimum curve radius. The geometric values for the UK are generally within the range of values for the other selected EU countries. The length of the auxiliary lane is generally above 145m with the

exception of Belgium whose standard is 80m. However, the recommended length of taper in Belgium for the Parallel layout is the highest with the exception of France.

Safety is a major consideration in the production of design standards for motorway diverges; little reliable evidence has been found in the literature of a link between design standards and safety for motorway diverges. It is not altogether surprising therefore that variations in both the design process and recommended geometric parameters exist between the various EU countries.

6. Critical review of the diverging flow-region diagram

6.1 Introduction

This section provides a critical review of the UK diverging flow-region diagram which includes the following:

- Checking that the diverging flow-region diagram is logical.
- Recommending improvements to the diagram itself which include comments from five practicing traffic engineers.

This review focuses on the detail of the diagram and whether its concept is logical.

6.2 Checking the logic of the flow-region diagrams

The recommended layouts, for various downstream mainline and diverging flows within the diverging flow-region diagram, were checked to see if they progress in a logical way. This was shown to be the case by:

1. Increasing the downstream mainline flow with a constant diverging flow - the configuration for the diverge changes by adding an extra upstream lane and then adding an extra downstream lane. This process is repeated as the downstream mainline flow is increased (e.g. 2-1-2 to 3-1-2 to 3-1-3 to 4-1-3 where the configuration is in the form of upstream mainline lanes-slip lanes-downstream mainline lanes). This seems logical because as the downstream mainline flow increases (with the diverging flow constant), more capacity is needed both upstream and downstream of the diverge. The Taper diverge is only recommended when the diverging flow does not exceed the capacity of one slip lane.

2. Increasing the diverging flow with a constant downstream mainline flow - the configuration changes by adding an extra upstream mainline lane and then adding an extra exit slip lane. Again this process is repeated as the diverging flow increases (e.g. 2-1-2 to 3-1-2 to 3-2-2 to 4-2-2). This seems logical because as the diverging flow increases (with the downstream mainline flow constant), more capacity is needed both upstream of the diverge and on the exit slip road. As the diverging flow increases, the layout recommended in the diagram provides more and more capacity for exiting drivers. As the diverging flow exceeds the capacity of one slip lane, it is recommended that a Taper layout is replaced by a Parallel layout which provides more capacity at the exit. As the diverging flow increases further, a Parallel lane drop is recommended with the possibility of increasing the length of the

auxiliary lane if necessary. For very high diverging flows, a Parallel double lane drop can be installed.

6.3 Possible improvements to the diverging flow-region diagram

The views of five traffic engineers who use the diagram on a regular basis were sought, during the spring of 2001, in order to investigate its strengths and weaknesses, and how it could be improved. The engineers were Stephen Pollock (Road Services, Northern Ireland), Martin Price (Mott Macdonald), Mike Slinn (MVA), John Border (Arup) and Bob Marlow (WS Atkins). The diagram was now being used almost exclusively as a design tool for an evaluation of existing motorway diverges, rather than for newly proposed diverges.

Improvements that could be carried out easily and quickly were identified and were mainly presentational in nature. The following comments about the diverging flow-region diagram, however, focus on improvements that may require further research. These were:

- **Adopting a more realistic design flow value**

Some traffic engineers use a maximum working design flow of 2000 veh/hr per lane for a motorway rather than the lower figure of 1800 veh/hr in TD22/92. This figure of 1800 veh/hr was increased from 1600 veh/hr in TD22/86 (Department of Transport 1986) and has remained unchanged for almost 20 years. Increased levels of vehicle and driver performance have increased the capacity of a motorway lane to about 2300 veh/hr (Hounsell et al 1994). The scale on the diagram could easily be modified to adopt a more realistic design flow based on current maximum working flows. However, if the design flow value is increased, the provision of the number of lanes will be less generous for a given set of mainline and diverging flows resulting in a more critical choice (with less spare capacity) for the traffic engineer.

- **Providing additional advice in border line decisions**

When plotting data points on the diagram, it is quite common to find that some will appear on the border of two or three different regions of the diagram. This is a particular problem when the data point is within a region designated for a type 'B' diverge (Parallel diverge) as these regions are clearly smaller than the error margin of the traffic flow data commonly used. Traffic data recommending region 'B' may lead to the traffic engineer having to consider the six adjacent regions in the diagram to check if they could provide more suitable layouts. Given the changing nature of traffic flows over time, a layout in a particular region needs to be easily adaptable in order to convert it into the layout recommended for the adjacent region(s) in the diagram.

Converting some layout types to another layout type may not be possible if the acquiring of land is needed due to the problems of cost, availability of land (if part of the hard shoulder is not to be used) and environmental concerns (e.g. converting a Taper into a Parallel). It is therefore important when designing a Taper diverge that consideration is given to the ease at which it could be converted into a Parallel diverge in the future, if an increase in diverging flows required it. More advice in the Standard concerning borderline situations would help the traffic engineer.

- **Providing additional advice where the recommended layout is impractical**

At some sites, the recommended number of upstream, downstream and exit lanes may be impractical due to restrictions on land take, environmental considerations or economic reasons. It would be useful if the Standard provided additional advice concerning the best layout possible given certain practical limitations at the site.

As the diagram is mainly used to re-assess existing diverge layouts, it can be difficult to know how to plot points where the provision does not match the demand. For example, there may be a diverge with a predicted downstream mainline flow of 2500 veh/hr on an existing 3-lane motorway, or where 3 lanes needs to be provided for other reasons.

- **Providing additional advice about the use of lane drops**

Layout types 'C', 'D' and 'E' involve dropping a lane(s) at the diverge, with the lane(s) normally gained again at the merge. Lane drops are only usually provided when there is a high diverging proportion or when there is a high merging proportion requiring a lane gain upstream of the diverge. There may also be policy, layout or economic reasons for their use. Additional advice in the Standard concerning the use of lane drop type diverges would help engineers decide if their use is appropriate for a particular exit. The incorrect use of a lane drop type diverge could cause problems both for mainline and diverging traffic.

- **Extending the diagram so it can cater for mainlines of more than 5 lanes**

With the proposed widening of the M25 and other motorways, the diagram could be extended to cater for a mainline of more than 5 lanes. The diagram can be easily extended to cater for more lanes. However, diverging behaviour can become very problematic with mainlines of 6 or more lanes due to the increase of the number of lane changes necessary and the subsequent "turbulence" which it creates. Alternative diverge layouts may need to be considered which can cope more adequately with these situations. One possible solution suggested is a left/right diverge layout which allows vehicles to leave the mainline from the inside lane to slip lane 1 and the outside lane to slip lane 2 (Stanton 1992). Lane changing would be reduced but there would be extra structural costs as well as potential operating problems. Drivers would have to become familiar with the new signing, layout and road markings for it to be considered a feasible option.

- **Modifying the diagram to include the new "tiger-tail" Ghost Island diverge**

Since the production of the diagram, a lot of research work has been carried out at the TRL into the effectiveness of the new "tiger-tail" Ghost Island diverge layout, with or without a lane drop (see Figure 6). They have been shown to be successful at three UK motorway diverges in reducing the number of potentially dangerous last minute lane changes, as well as regulating the traffic flow into two orderly streams of traffic (Wedlock et al 2001). In addition, the new Ghost Island layout at the M3/M27 near Southampton received a favourable response from drivers in a questionnaire survey in terms of smoother flow, a reduction in last minute lane changes and easier access to the M3 (Wall 2004). They are particularly recommended where there is a high diverging proportion (i.e. above 40%), poor lane discipline, a high number of potentially dangerous last minute lane changes and a need to increase the capacity of the exit (Highways Agency 1998). The diagram could be redrawn to provide regions where the Ghost Island diverge (with or without a lane drop) would be the

recommended diverge type. This could be done by replacing the Parallel diverges in a similar way as in the merging flow-region diagram, also contained also in TD22/92.

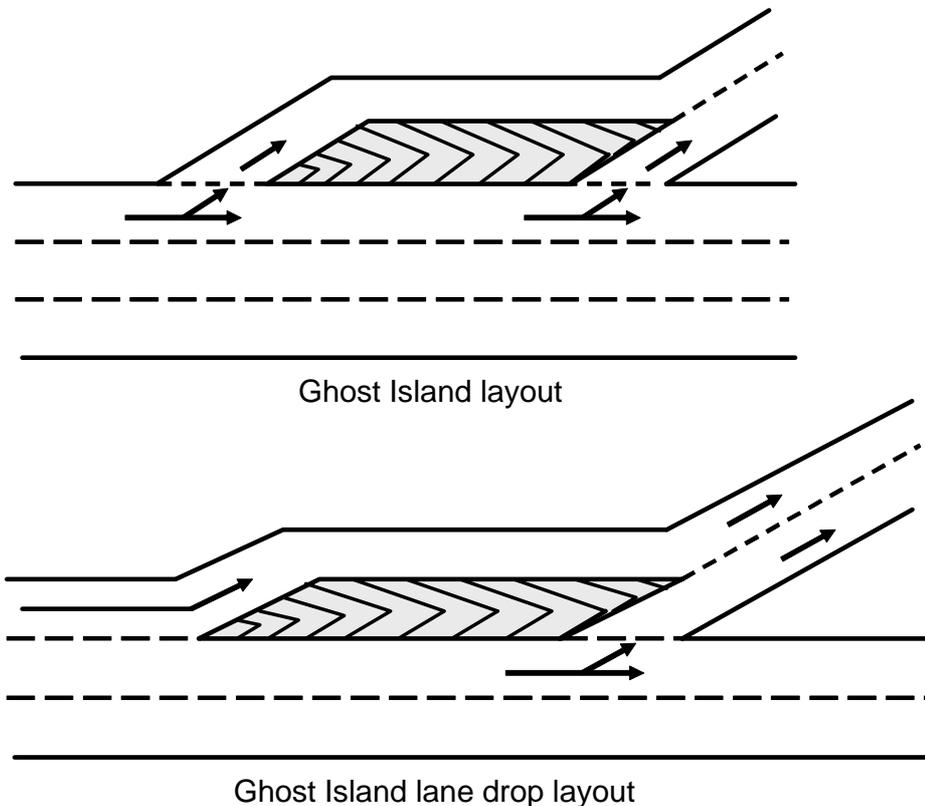


Figure 6. Schematic diagram showing the Ghost Island diverge layouts

- **Providing advice regarding the length of the auxiliary lane**

TD22/92 states that the auxiliary lane in the Parallel layout should be a minimum of 200m and up to 600m if necessary. More exact advice is given to traffic engineers in the USA as to what the desired deceleration length should be based on the design speed and average running speed of the motorway as well as the design speed and average running speed of the exit curve (Koepke 1993). Further advice such as this would aid traffic engineers in the UK select the most suitable auxiliary lane length for a particular junction.

- **Checking the assumed capacity of the auxiliary lane**

The Taper Diverge (layout A) is used only where the diverging flow is less than or equal to 1350 veh/hr on motorways. The parallel diverge (layout B) uses an auxiliary lane as an addition to the Taper Diverge and is used where the diverging flow is between 1350 veh/hr and 1800 veh/hr on motorways. This suggests that the auxiliary lane can cater for an additional 450 veh/hr independent of its length (which is normally a minimum of 200m). There may need to be more research carried out to calculate the extra capacity the auxiliary lane provides (with different lengths of auxiliary lane) as well as its affect on queuing traffic from the exit.

6.4 Discussion

The diverging flow-region diagram is a useful tool for providing a preliminary indication of which diverge layout is most suitable for a given set of downstream mainline and diverging flows. These flows are also corrected for gradients and HGV percentage within the traffic composition. However, according to the diagram, these are the only factors which affect the capacity of the diverge and the subsequent choice of layout. The selection process is therefore made mainly from a traffic flow perspective. There are also operational, behavioural and safety issues that also need to be carefully assessed. Driving behaviour is also considered to have an affect on capacity. Diverge layouts which experience frequent lane changes in the exiting vicinity can operate less efficiently and therefore below expected capacity. In addition, the capacity of the diverge is dependent on the capacity of the junction at the end of the slip road. It is therefore important that this junction (roundabout, signal-controlled or priority) is designed in the most efficient way in order to disperse queuing slip road traffic quickly and therefore reduce delays and exit blocking. The installation of an auxiliary lane at diverges where exit blocking may be likely is important as it reduces this risk considerably.

The use of a flow-region diagram is not unique to the selection of diverges and merges. In the Departmental Standard TD42/95 entitled “Geometric Design of Major/Minor Junctions” (Department of Transport 1995), traffic engineers are recommended to use a flow-region diagram in the selection of the type of major/minor priority junction to install. With a low minor flow, a simple priority junction is recommended but with a high minor flow, a roundabout is recommended.

The Standard states that the diagram “gives the starting point for junction choice ... but other factors need to be considered before a final decision is made” (Department of Transport 1995). This is an important principle for the diverging flow-region diagram, which is a useful tool but can never be used to make the final decision exclusively. The traffic engineer needs to use his/her common sense and experience along with additional advice or guidance that could be provided in the standards, particularly in borderline situations or where the diverging flow is variable and/or expected to rise noticeably in the future. The use of the diagram would normally be followed by producing a more detailed design (deciding upon the various geometric parameters) which would be supported by using the macroscopic simulation computer program ARCADY (for roundabouts) or PICADY (for priority junctions). The geometric parameters are typically adjusted in order to obtain a RFC (Ratio of Flow to Capacity) value of no higher than 0.85.

In using the diverging flow-region diagram, traffic engineers can only select the layout and not alter any of the geometric parameters associated with that layout (with the exception of the auxiliary lane which must be at least 200m in length). In practice, these geometric parameters (such as taper length, angle of slip road to mainline and length of auxiliary lane) may well affect the capacity of the diverge and research confirming the most suitable values would be beneficial. There is the advantage of having a consistent design for diverges across a motorway or dual-carriageway network in terms of driver familiarity and therefore safety, but this can reduce the flexibility of the traffic engineer to try and cope with varying traffic levels. The use of a suitable microscopic model could also be beneficial in confirming the

most suitable diverge layout in terms of capacity, journey times and lane changes, particularly in borderline situations (where the data point borders several flow-regions) or where the diverging flow is very variable. The model would need to have been extensively calibrated and validated with real data and use proven car following and lane changing logic (Wall 2004).

7. Conclusions and recommendations

The conclusions and recommendations have been made with regard to the standards and more specifically the diverging flow-region diagram. They are as follows:

1. The standards for motorway diverges have been regularly updated over the last 40 years, in order to cater for new levels of traffic flows, vehicle performance and driver behaviour. The geometric parameters have showed a slight 'tightening' of values over time, with the tendency towards more compact designs with less generous values.
2. Safety is a major consideration in the production of geometric standards. However, little reliable evidence has been found in the literature of a link between design standards and safety for motorway diverges.
3. The diverging flow-region diagram has been critically reviewed with the following four conclusions made. They are that:
 - The diverging flow-region diagram provides traffic engineers with a useful design tool in order to make a preliminary assessment of the most suitable layout.
 - The recommended layouts, for various downstream mainline and diverging flows within the diagram, seemed to progress in a logical way.
 - Improvements could be made to the diagram immediately to make it a more effective tool for traffic engineers.
 - Some of the assumptions made in the construction of the diagram could be explained and justified in more detail.
4. It is recommended that:
 - The flow-regions of the diverging diagram be adapted to include the Ghost Island diverge (with and without a lane drop). This would provide new diverge layout designs which could improve both capacity and driver behaviour.
 - A suitable microscopic model could be used to confirm the choice of layout, particularly in borderline situations or where the diverging flow is very variable. They can also be used to model the junction at the end of the slip road and therefore assess the likelihood of exit blocking (Wall 2004).
 - When designing a diverge layout (particular a Taper design) that consideration is given to the ease at which it could be converted into a layout with increased capacity, if an increase in diverging flows required it.

- Further research into the effect that the geometric parameters (such as taper length and angle of slip road to the mainline), proportion of HGVs and gradient (both uphill percentage and the length for which it is applied) has on capacity.

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