LECTURE A12 - INTERACTION BETWEEN DIMENSIONS **Presenter : CD SCOTT**

1 INTRODUCTION

The designer and the road user see a road from totally different points of view. The designer sees the road as though from a considerable altitude but is nevertheless restricted to two dimensions at a time. He designs the horizontal alignment first, followed by the vertical and determines the cross-section as a separate exercise. In comparison, the driver sees the road from a very restricted altitude and hence sees very little of it at one time. However, the little that he does see is a dynamic picture in all three dimensions (length, width and height) simultaneously. A fourth and very important dimension that the designer needs to see and visualise in their mind at all stages in developing the design is the influence and interaction of drainage, road safety audit findings, road signs and markings, safety devices and traffic calming, all as covered in previous lectures.

A further important difference between the two points of view is that the designer sees a static picture. The driver, on the other hand has a dynamic view of the road, constantly changing his vantage point as he travels along it. He does not have much time to resolve any apparent inconsistency in the design because, unlike the designer, his attention must also focus on the activities of surrounding vehicles.

The designer must therefore train his eye to look at his drawings and visualise the three dimensions of the road and their changes as an integrated highway picture which corresponds with the driver's experience. Fortunately, the designer is also a driver, and most of this training can come from looking critically at roads while driving along them, consciously evaluating their designs with a view to spotting poor design features and then seeking methods to eliminate such features in his own future design efforts.

In this lecture, some poor design features which relate mainly to unexpected traps for the unwary designer (and thus the motorist) are considered. Possible methods of resolving these problems are also discussed. A key to discovering potential traps lies in always remembering that most design criteria and standards relate specifically to straight and level sections of road (e.g. stopping distances, sight distances), and these need adjustment when the line goes off the straight and level.

2 THE NEED TO CONSIDER INTERACTION BETWEEN DIMENSIONS

Here, “Dimensions” does not refer to measurements, but rather to the three dimensions in space along the X, Y and Z axes. The four major reasons why the designer has to consider the effect of interaction between the three dimensions of the road are:

- to ensure a clear message to the driver regarding what is expected of him
- aspects of safety
- the fundamental difference in the points of view
- aesthetic considerations

2.1 Clear messages to road users

When a driver has to react to a new road situation, he has a limited choice of courses of action open to him. He can change either the speed or the heading of his vehicle. These two options might give a theoretically infinite range of combinations between them, depending on the extent of change brought about in each. However they are limited in practice by the available friction, time and space. The designer must therefore provide signals giving timely warning to the driver regarding what and how much is required. As far as possible this should be done by allowing the driver to see in good time what lies ahead.

Any such signals should be provided sufficiently far in advance of the point at which the action is required so as to ensure that the driver has enough time to perceive and react to the situation presented him. A discreet little sign on the near side of a crest curve advising the driver that there is an intersection ahead when the intersection is, in fact, just on the other side of the crest and is also very busy is not an example of a clear signal to the driver.

2.2 Safety

The most pervasive element of safety is the ability to stop in time to avoid whatever obstruction may present itself. Stopping sight distance is based on the ability of a passenger car to stop while travelling in a straight line on a level road. A steep gradient can just about double the distance required for stopping. A horizontal curve will reduce the drivers' enthusiasm for sharp braking and so increase the stopping distance by a factor of 2 to 3. In terms of each individual “dimension” (related here to curvature or gradient), the road may well be according to the standards, but the interaction of the dimensions in combination results in a significantly under-designed facility.

Notwithstanding the driver's emotional condition when required to brake on a sharply curving steep downgrade, there are some practical features that bear closer consideration. Braking will place a disproportionate share of the total inertia of the vehicle on the outer front wheel. If this wheel or its tyre is in a poor condition, the probability of mechanical malfunction is heightened. Even without this potentially disastrous end to the exercise, there is only so much load available to generate friction with the road surface. With the bulk of this on the outer front wheel, the friction required at the back wheels to ensure that the vehicle does not break away, is sharply reduced. In fact, the inside rear wheel can lift off the road surface altogether. The possibility of spinning out of control or, in the case of an articulated vehicle, a jack-knife cannot be overlooked.

2.3 The difference in point of view

Reference has already been made to the bird's eye view enjoyed by the designer. A driver eye height of 1,05 metres corresponds more closely to a worm's eye view. An interchange can be quite easy to interpret when seen in its totality as a static entity, but the driver is treated to a series of glimpses of less than obvious lane changes, lane drops, off-ramps and on-ramps from which he is supposed to make logical decisions ensuring that he achieves the desired destination as opposed to some other. It is necessary to ensure that the driver can see sufficient of his immediate environment in addition to the obvious need for clear and unambiguous signing to make the correct decisions.

For navigational purposes we may legitimately rely on the use of road signs to assist drivers. Note however that signs should never be used to try and rectify or compensate for geometric design shortcomings. Signs are removed too often, and ignored too often, to allow that.

2.4 Aesthetics

The human eye is remarkably sensitive to departures from a smooth line. A plank looked at sideways on from the Olympian vantage point of the designer may appear reasonably straight and smooth. However, looking along its length from a close-up position will show clearly any bumps or nicks there may be along the edge. Similarly a driver's view of the road is end-on and correspondingly foreshortened. In terms of the analogy of the plank, the most unexpected bumps and holes and discontinuities may suddenly present themselves. The designer must therefore train himself to perceive the end-on appearance of his road from the square-on data presented to him by a plan-view, and must not lose sight of the fact that the plan-view data is itself incomplete, representing only two of the three dimensions. He can inadvertently build in seeming discontinuities in the three dimensional alignment that will be apparent and irritating to a driver, even though the elements and their combination meet the standards and can be traversed perfectly safely at the road's design speed.

The effect of these apparent discontinuities will be to create an un-aesthetic environment which will not be conducive to a relaxed attitude in the driver. A relaxed driver has reserve capacity to observe and respond to his immediate surrounding and is correspondingly less of a menace to his own safety and that of others around him. In short, aesthetics means more than just a pretty picture.

2.5 Interactions and Combinations

Besides the effect of <u>interaction</u> between changes along dimensions which bring about a change in the basic parameters (e.g. stopping sight distance on a downhill curve), attention must also be given to <u>combinations</u> of changing dimensions which do not have that interactive effect but which create particular difficulty in complying with all the normal "one-dimensional" standards. An example is an intersection with a stop condition (effectively a change, actually the termination, of the longitudinal dimension) being placed just after a crest vertical curve, which is a change in the vertical dimension. One does not have to set about changing/increasing minimum standards as in the case of the radius of a steep downhill curve, but rather just to ensure that all standards are fully complied with, particularly in applying decision sight distance where it may be necessary.

It is important to identify situations with a real interaction between dimensions because of the real need to be more generous with standards for them. When "unfortunate" combinations of changes along dimensions arise, the solution may be seen as simply the comprehensive application of all the normal one-dimension standards. Due to their importance and to the effect of the combinations of changing dimensions creating particular problems and a special need for designer awareness, a number of such cases are considered here.

3 PROBLEMS ARISING FROM INTERACTION

An inadequate consideration of the three dimensions of the road as a unit can give rise to a host of problems which fall into three categories, namely:

- reduction in safety
- optical illusion
- apparent discontinuities

3.1 Reduction in safety

Often a change in a road element will require a specific response from the driver. If this occurs at a point where he is not afforded much time to perceive and respond to the change, it is a problem. It is also one of the more typical problems that can arise from an interaction between the dimensions of the road. One changing element may form a concealing element which hides a change in another element. Such a concealing element could be a crest vertical curve or a horizontal curve in cut. In the latter case, the critical case is on a left-hand curve in a cutting, when a vehicle is in the lane closest to the cut face and its sight-distance is most severely affected. Who has not gone a bit too fast up a steep left-hand bend in cut and almost finished up under a slow-moving truck concealed in the bend?

An example of the “combination” problem is the location of a horizontal curve immediately beyond the crest of the vertical curve. The driver is suddenly presented with an entirely new vista (say after a long climb up a pass) and the likelihood is that his attention will be more on his environment than on the detail of the road design ahead. It is also a common tendency to “overdrive” vertical curves by a substantial margin so that the location of a horizontal curve immediately beyond a crest curve could be an open invitation for the vehicle to part company with the road. If the horizontal curve is at the end of a long straight and is anywhere near minimum radius, the invitation will, in all probability, be accepted.

Another example is the location of an intersection immediately beyond a crest curve. This is a particularly dangerous example of dimensional interaction. Because of the vertical curvature of the road, road markings will not be visible and the intersecting road surface may also be obscured. The only indication of the existence of the intersection may be its stop sign. This is hardly good enough. The designer may well think that the driver has got enough space to stop once the stop sign appears in view, if the vertical curvature is designed with stopping sight distance in mind. Unfortunately, this need not necessarily be the case because of the presence of a stopped queue of vehicles which may absorb much of the space thought to be available. A more comprehensive design analysis may be necessary in this tricky situation, as discussed below.

When an intersection is located beyond a horizontal curve in cut the problem may be more severe. The driver is being distracted by a continuing change of vista and, at the same time is required to negotiate the curve. The intersection is a third element demanding his attention simultaneously with the other elements referred to. The problem is considered more severe because of the reduction in the rate of deceleration which the driver is prepared to bring to bear in the curve, for coming to a stop at the intersection. The possibility of a stopped queue absorbing some of the required stopping distance remains as an exacerbating feature, as would a down-grade. There is no substitute for the proper separation of alignment changes and thus the provision of space for driver decisions and actions. The road changes require proper visibility and distance between them, and that will then ensure sufficient time-separation between successive driver decisions and actions.

The stage illusionist routinely causes an object which is plainly in sight to become "invisible" by misdirection of his audience's attention. A designer might unintentionally achieve the same result by concealing a message to drivers within some visual clutter or at a point where the driver's attention is drawn away from the road. Any traffic officer can attest to the frequency of tail-end collisions along roads next to popular beach fronts. A particularly striking road feature, such as a major bridge, can achieve much the same result.

Another way that features requiring a driver response are disguised is by hiding them within other features. The designer suffering a rush of architectural blood to the head can, by the cunning use of different radii of curvature for the edges of a carriageway conceal a lane drop within the length of a horizontal curve. The warning that the driver then has that the two lanes at the start of the curve become one at its end may just be when the vehicle alongside is suddenly much nearer than it had been previously. The driver is then not only required to attend to negotiating the curve but must also execute a merging manoeuvre which may also require a speed change on the curve.

3.2 Optical illusion

The intention at all times should be to ensure that the driver does what is expected of him when it is expected. Illusion can actually be used to "trick" or mislead drivers into performing the correct action. In this context, illusion can be a useful item in the designer's armoury. An example is COSBI (control of speed by illusion). Unwanted illusions can however deceive the driver into a course of action which is unanticipated by others or unsafe or both.

The "wrong" illusion can be created by the combination of a road element with an external element or by interaction between the dimensions of the road. An example of the former is the location of a road in a particular direction alongside a row of trees. Consider a road running roughly south-west along the southern side of the row of trees, in the late afternoon. The trees cause a regular interruption to the light falling across the road and onto a car travelling south-westward. A following car could get the impression that the leading vehicle is signalling an intention to turn right. The trailing driver thus proceeds to overtake on the left resulting in, at the very least, two very surprised drivers with more serious consequences also a possibility.

More often the illusion arises from interaction between road dimensions. A horizontal curve located on a sag curve looks sharper than it really is, especially when the topography gives an almost plan-like view from a distance. Distracted drivers have been known to drive off the inside edge of the road as a result. When located on a crest curve the horizontal curve appears to have a larger radius than it actually has, encouraging a false sense of security dispelled only by sharply striking a cut face or a guardrail.

If a horizontal curve commences at a distance of about 60 metres beyond the start of a vertical curve, the superelevation development can create the impression of a straight grade by the outer edge rising relative to the centreline which is actually dropping away. The vertical curve is thus only perceived as such some way along its length and consequently appears much more severe than it really. The superelevation development on the inside of the curve causes this road edge to drop away very sharply heightening the illusion of a vertical curve which is more an instantaneous change of gradient than a curve. The driver is of course half scared to death by all this and is in the market for an unpredictable reaction.

3.3 Apparent discontinuities

This refers to combinations of changing dimensions resulting in kinks or breaks in the alignment of the road edges whereby the aesthetic harmony of the road is destroyed. The combination of horizontal and vertical curvature, (the last-mentioned of the illusions discussed above) is also a special case of this problem. Regardless of where on a vertical curve the superelevation development commences, the effect will always be of a break in an otherwise smooth curve, unless special care is taken. (refer to the profiles, pages 8 & 9).

In general, the scale of this problem depends on the distance at which the driver can see the offending element. It may also be a problem internal to one dimension only and hence outside the scope of this lecture. A short length of sag curve at the foot of a long downgrade creating the infamous "broken plank" effect is a case in point.

4 RESOLUTION OF PROBLEMS CREATED BY INTERACTION

Much has already been said about intersections following closely after a crest vertical curve. This is not strictly a problem of interaction as much as one of the combinations of two features which simply require that sufficient sight distance be provided. Depending on topographic detail, the required sight distance may have to be achieved by reducing the operating speed on the side road so as to reduce the required sight distance. Typically, a small-radius horizontal curve could be used on the approach, at a position where it is clearly visible. The end of the curve should then be placed so as to allow a straight approach to the intersection, of length somewhat greater than the stopping sight distance for the design speed of the curve.

The best warning that a driver can be given of an impending change of direction is to commence the horizontal curve at or prior to the commencement of the vertical curve. Seeing that the road can be traversed in both directions it follows that the vertical curve should be contained within the horizontal.

A common aesthetic problem is that caused by super-elevation development. It must be noted that the development of super-elevation provides two possible kinks in the smooth flow of the road edge, both on a straight grade and also on a vertical curve. If there is an unfavourable overlap, i.e. where the horizontal curve is within the vertical, the appearance of a kinked edge is heightened. This can possibly be reduced by rotating the road around a line other than its centreline, (as is commonly done on interchange ramp design). It is also important to design super-elevation in two stages, in which the drawing of calculated edge lines is followed by a graphical smoothing process. This is illustrated in two diagrams at the end of this paper, which show for two different alignment cases, a plan, a calculated set of profiles and a smoothed set of profiles. It is always necessary to check and ensure that the final amount of super-elevation after smoothing of the initial calculated profile is still suitable at all points along the profile.

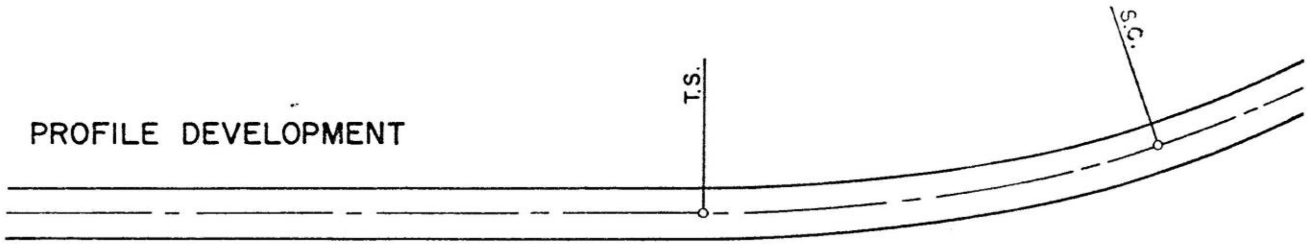
In very restricted circumstances, the designer may find himself forced into a sub-minimum situation. It has been said that a combination of horizontal and vertical curvature will add to the available sight distance over a crest curve by virtue of the presence of the super-elevation which raises the eye-height of a driver on the outside of the curve. It may thus be theoretically possible to steal a little on the minimum K-value of the vertical curve. However, there can be a directional effect, and the super-elevation runoff in the opposite direction (on the inside of the curve) may well shorten the available sight distance, so great care is needed in trying to use such unusual design devices. It is certainly not wise to apply any degree of "theft" to the radius of the horizontal curvature.

It is always preferable and often essential, when confronted with adverse combinations of horizontal and vertical alignment, to avoid the use of minimum radii for horizontal curvature. One must ensure that the driver is not unnecessarily surprised by a change in circumstances, and that he retains adequate vehicle control and manoeuvrability where downward gradients have an impact on the driving comfort within horizontal curves. A general aim would be to try to add about 50 % to the minimum radius specified for the design speed. However, steeper downgrades in combination with horizontal curves require that the designer be even more generous with the stopping sight distance he provides, and three times the minimum radius may be a worthwhile goal.

It has already been stated that lane drops should not be concealed in horizontal curves. They must always be clearly visible and emphasised by an abrupt change of the edge line (using a kink). Although not previously mentioned, a lane drop immediately beyond a vertical curve is an another example of not providing the driver with sufficient advance notice of a required action. In a rural environment, the lane drop is very often a case of terminating a climbing lane. The lane drop should be sufficiently far beyond the crest to allow the vehicles that have been using the climbing lane to accelerate to a speed more closely matching that of the through lane and furthermore, the location of the lane drop should be such that its presence is very clear to all road users.

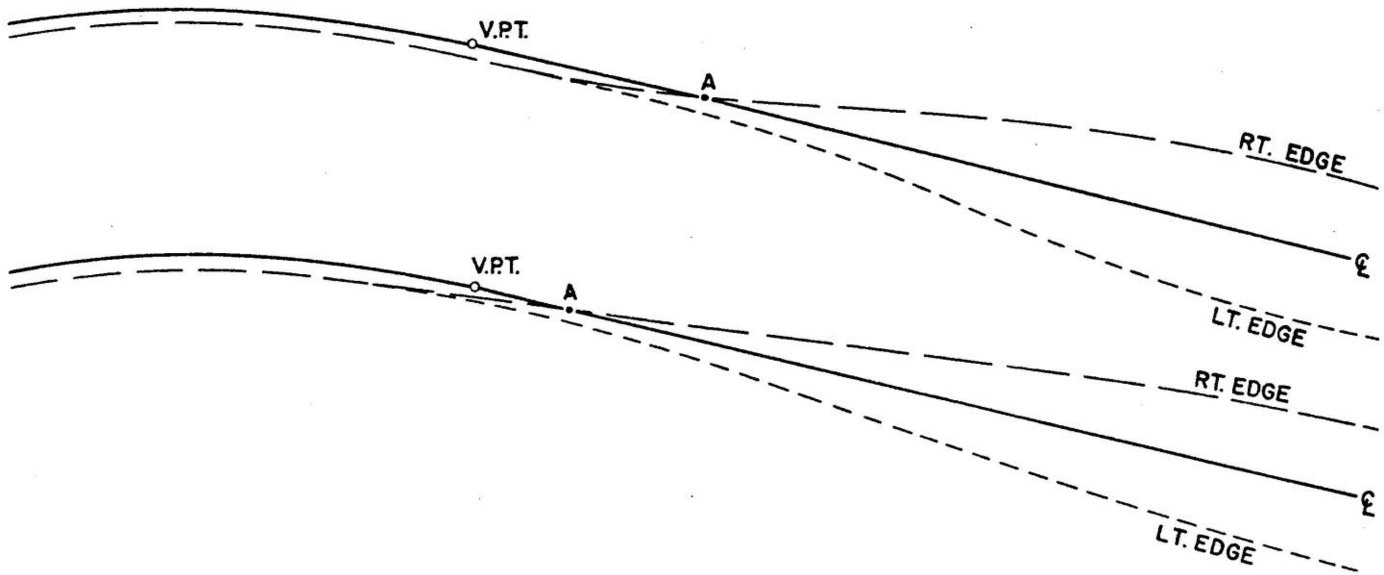
Much discussion above, particularly on aesthetics, has been aimed at kinks. It referred to their general undesirability on a continuous line, and to measures that can be adopted to avoid them. Nonetheless the need to convey clear messages to drivers very often requires that a kink be introduced into the alignment deliberately. For example, a deliberate discontinuity will highlight the fact that an off-ramp is a road leaving the freeway and is not a continuation of the freeway itself.

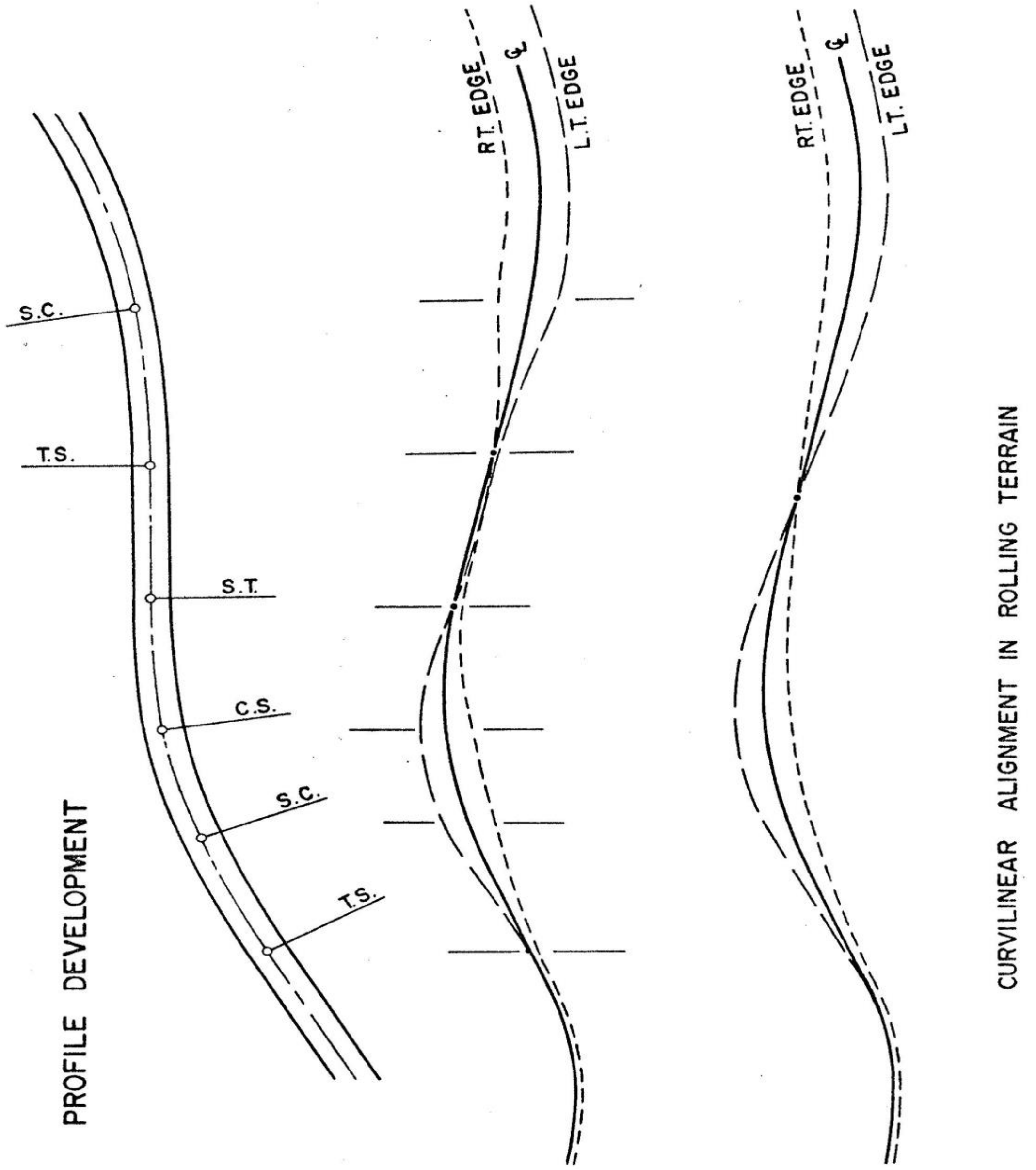
An "architectural" approach to the design of an interchange off-ramp on the outside of a horizontal curve might be to treat the ramp edge as a tangent to the curve and to create the separation between the ramp and the through lanes by using the curvature of the latter. The unfamiliar driver, particularly at night or in bad weather, will invariably perceive the tangential ramp edge as the end of the freeway curve, and go down the ramp thinking that he is still on the freeway – then at a speed of 120 km/h, when the stop sign for the cross road ramp terminal pops up....surprise!



PROFILE DEVELOPMENT

CREST VERTICAL CURVE NEAR END OF HORIZONTAL CURVE




PROFILE DEVELOPMENT
S.C.
T.S.
S.T.
C.S.
S.C.
T.S.
RT. EDGE
L.T. EDGE
RT. EDGE
LT. EDGE
CURVILINEAR ALIGNMENT IN ROLLING TERRAIN