Describing and Shaping Merging Behavior of Freeway Drivers

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This paper discusses the freeway merging behaviors observed in three types of design and draws conclusions about specific behaviors to be promoted, as well as those to be discouraged. Means of achieving these ends through traffic engineering and public education are discussed.

Freeways have proved to be much more forgiving of driving error and much less likely to induce errors than less expensive arterial highways. Drivers have not had much guidance in how to drive on freeways, and, in spite of many years of experience, no clear set of rules has been forthcoming. Moreover, designers are not always aware of what drivers do, and opinions of what drivers should do vary among those responsible for design, operation, and maintenance of freeway-quality roadways.

Before a behavior can be established as "best," "ideal," or "optimal," the variety and relative frequency of observed behaviors should be established. In addition, the best behavior should remain invariant through the expected range of variables such as volume of traffic, relative volumes of ramp and through traffic, vehicle mix, and driver familiarity.

It would be desirable to establish a set of "ideal paths" for each type of driving maneuver. Driver educators, enforcement agencies, safety groups, and design groups do not always have common working assumptions, and it is clear that driver behavior is not fully in accord with any one authority.

The present study of merging situations was part of a project entitled "Remedial Driving Techniques for Freeways and Interchanges" (1). Among the goals of the project were the specification of a set of proper and improper driving behaviors related to specific freeway segments and the recommendation of remedial treatments to eliminate or reduce the improper behaviors observed. Two features of the project must be made clear. First, the project was designed to be useful to the highway research community rather than directly to operating agencies at this time. Second, the orientation was strictly behavioral, i.e., it was intended to describe the behaviors observed and to make recommendations for specific driver behaviors.

The data were thus observational, rather than statistical, in order to describe the variety of events and behaviors that occur in traffic situations. Once the variety and relative frequency for each type have been established a determination of those behaviors to be encouraged and those to be discouraged can be attempted. Data on such factors as acceleration noise and headway distributions were not collected. Also, because of the importance of observing the typical range of behaviors that might occur, unobtrusive means were used to gather the data.

Ideal behavior does not necessarily imply ideal geometry or roadway design. While a great number of variations in design could be listed, this study was limited to three types of on-ramps that are typical of the variety of roads of the freeway type that are now in use.

Although accident records have been used as a basis for comparing characteristics, they cannot easily be used alone for identifying high-accident sites on freeways because of the relatively low accident rate and the inherent problems in pinpointing both the locations and the causes of freeway accidents. In addition, sites of a large number of minor accidents may never be identified because these incidents do not become part of the accident record. In fact, many of these minor accidents could have become major accidents, given small variations in the conditions or traffic at the time.

Related to this same problem are the definitions of erratic maneuvers, conflicts, critical incidents, driver errors, and a variety of other concepts related to traffic safety or driver behavior.

Three merging sites were selected by using relative accident records and other considerations such as proximity, the kind of design, engineering and administrative opinions of problems in the area, and the traffic mix. The first site had a fairly long parallel acceleration lane, the second had a very short taper for acceleration, and the third had an intermediate length taper for acceleration. While the length of the acceleration area is but one of the many variables that might be compared in

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entrance ramp design, the merge maneuver is likely to be strongly affected by the time available for the information processing and for the maneuvering and timing patterns dictated by this overall length.

PROPER AND IMPROPER MERGING MANEUVERS

It is generally agreed that the merge maneuver is basically a yield entrance into a stream of traffic and thus should be executed in a manner that does not interrupt or disrupt other traffic. Drivers of trucks and other large vehicles are restricted by the braking and acceleration capabilities of their vehicles during merging. The truck merge thus becomes a limiting case, which can serve as a rough model of the proper maneuver if a single optimal maneuver is to serve for virtually all traffic. Detailed models may have to be developed separately for vehicles with high and low acceleration and braking characteristics. For now, only one model will be discussed; it is based on cars and trucks with "average" performance.

A proper merge consists of observation, gap selection and gap pacing, the merge itself, and the assumption of the characteristics of the mainstream traffic. In the observation phase, the driver must establish a plan to take the vehicle into a gap in traffic without disrupting that traffic. The errors made in observation include (a) failure to monitor the mainstream traffic at all, (b) failure to monitor soon enough to provide sufficient time for selection and pacing of the gap, and (c) failure to observe other ramp vehicles ahead and behind.

Gap selection and gap pacing require realistic estimates of time, speed, and distance in terms of the vehicle's characteristics and other conditions. The gap selection errors include (a) planning to merge when there is no gap, expecting mainstream traffic to give way and create a gap; (b) selecting a gap that is too small, again requiring mainstream traffic to adjust during and after the merge; and (c) demanding an unusually large gap, unnecessarily delaying other ramp traffic and thwarting the expections of mainstream drivers, who expect a merge to be made when conditions are reasonable.

In the merging maneuver itself, the vehicle follows the planned path to enter the selected gap. Errors include (a) stopping on the ramp when gaps already exist that are sufficient for the merge; (b) driving unnecessarily slowly when gaps already exist; (c) entering the mainstream at too low a speed; (d) entering the mainstream at an unusual point, such as crossing the physical or painted gore or suddenly pulling in from the edge of the road beyond the edge line of the taper; (e) entering the mainstream at an unusually sharp angle, requiring sharp path-correction maneuvers that might disrupt other traffic or induce the loss of control; and (f) entering the mainstream before earlier ramp vehicles have begun their merge. Out-of-turn entries can be observed when the later ramp driver is more aggressive than the earlier driver. Trouble arises when the two vehicles attempt to merge into the same gap, which is not big enough for both of them, and the added complexity of multiple merges may overload the information capacity of the drivers involved.

There are also mainstream errors, which include (a) unnecessary application of the brake when a proper merge is being executed ahead; (b) lane changes into lane 1 (the shoulder lane) near the merge point; (c) lane changes into lane 2 or farther left without proper signaling or clearance; (d) straddling a lane line, edge line, or median line; and (e) sudden acceleration in lane 1 near the merge point.

Yielding

There are still problems in the definition of "proper" tactics in the ramp merging maneuver. It is generally accepted that a merging driver is required to yield to mainstream traffic by virtue of the fact that this involves entering one roadway from another roadway. Many states have chosen to make this explicit by installing yield signs along entrance ramps. The lack of agreement is illustrated by one recent judicial decision that the driver on the ramp has the right of way since he is to the right of the mainstream traffic. The Manual on Uniform Traffic Control Devices (MUTCD) says yield signs "may be used on an entering roadway without an adequate acceleration lane, but in a well-designed interchange, the sign would interfere with the free merging movement, and should not be used under those circumstances" (2).

In Pennsylvania the policy seems to conform to this, and yield signs are to be installed on "substandard" ramps or "when necessary" in the opinion of the district engineer (3). It appears that, in practice, the yield sign is used almost universally for entrance ramps, and Pennsylvania drivers probably expect to see it there.

As to the location of the yield sign, the MUTCD says it should be erected "at a point where the vehicle is to stop if necessary to yield the right of way." The manual also allows the use of a stop line for either a stop or a yield sign if the stopping position is not obvious. The point at which the driver is to stop is thus presumed to be the location of the yield sign itself. It is likely that a survey of drivers would reveal that this is not widely understood, and observation of behavior strongly implies this is so. Moreover, there is no assurance that the sign position is appropriate in every case, which leads drivers to rely on their own judgment as to where to stop. In the absence of specific guidelines, each agency responsible for traffic signs installs the sign as it judges proper. This leads to variations in locations at best and gross errors in placement at worst. Clearly, sign location could be improved in a number of instances. But if the driver is unaware of the definition of a proper merge and the meaning of the yield sign or hesitation point, the sign's location alone will not do much to improve driver behavior in the merge.

The lack of driver conformance to stop lines and marked crosswalks where signs are not installed indicates that, in general, the driving public feels that it is better qualified than anonymous traffic engineers and line-painting crews to judge the point at which it is necessary to stop. This feeling is justified in enough cases that little confidence is placed in the official markings and enforcement is, at best, difficult and spotty. This lack of confidence in stop-line placement might also be expected to carry over into a routine use of a line in conjunction with the yield sign, unless special provisions are made. Both the meaning of and confidence in traffic control devices must be established before conformance can be expected.

Merging Behavior

Although differences in opinion may exist, the following details of the merging maneuver are considered proper here. The driver approaches the ramp and assumes the recommended ramp speed. Continuing down the ramp, the driver observes through traffic to determine the probability of an available gap, the vehicle mix, the mainstream speed, and prospective lane changes by mainstream vehicles. At a point prior to the physical or painted gore, the driver has determined whether a gap exists or a wait will be necessary. If no wait is

necessary, i.e., a sufficiently wide and stable gap in traffic is available, the vehicle is accelerated gradually from ramp speed to approximately the speed of traffic in lane 1. After attaining speed and confirming that the gap remains and that the maneuver will not interfere with other vehicles, the driver crosses the boundary into lane 1. The boundary crossing is made in a gradual, continuous manner, with lateral movements sharp enough to make the entry obvious to other drivers but not so sharp as to require large lateral accelerations or large path-correcting steering upon entry to lane 1.

If the through traffic is likely to prevent a continuous merging motion, the driver either slows to wait for a slightly later gap or stops to wait for a gap to appear. The stop or the slowing is done in such a manner that the ramp driver has room remaining for acceleration to mainstream speed, has a sufficient view of through traffic, and can slow or stop at a point consistent with the expectations of drivers following the merging vehicle on the ramp. In many cases, it is appropriate for the vehicle to accelerate on the ramp to move ahead of slow-moving vehicles in lane 1. Unnecessary hesitation or stopping is avoided in the merging maneuver, and the path of entry is such that room remains for evasive actions in event of a miscalculation or unseen vehicle. This implies that the driver will not use the full paved taper routinely except when there is a very short acceleration area. A merge is not made unless the ramp is clear ahead, i.e., all previous ramp drivers either have merged or have made their point of merge obvious.

Since the combination stop-turn signal system used in the design of most American vehicles increases the likelihood of confusion of the turn signal with the stop signal and since the stop signal is of prime importance to the drivers following the merging vehicle, no turn signals are used in a merging maneuver until just before the actual crossing of the lane 1 boundary is anticipated. Entry into lane 2 or lanes farther left is made only after the path has been established in lane 1 and after signaling. No merging path crosses the physical gore, the painted gore, or any solid painted lines. A dashed line across the mouth of the acceleration area shows the area through which crossing is proper and places the responsibility to yield clearly on the merging driver throughout the merge maneuver.

The observational data are available in our final report (1). Obviously, not every detail of the merging maneuver can be analyzed from field observations with respect to accident-inducing qualities among its possible variations. The proper maneuver as described in this paper has been derived from logical analysis as well as from observations of specific interactions related to driver actions. The data are summarized briefly in the following discussions to the extent that they support or refute specific points.

STUDY SITES

The design of site A (Figure 1) is good according to modern standards for a partial cloverleaf without collector-distributor roadways (see, for example, Baerwald, 4). The parallel acceleration lane is 264 m (865 ft) from the physical gore to the end of the taper. The painted gore, 21 m (70 ft) long, and a taper of 67 m (220 ft) are included in this length. The yield sign is 15 m (50 ft) upstream of the physical gore. The ramp is on a downgrade and the view of it is reduced for eastbound through traffic by a left curve and a bridge structure for the crossroad grade separation.

The design of the ramp and its elevation above the through traffic give the ramp driver a good view of oncoming traffic for selection of gaps. The acceleration lane is long enough to allow almost any unimpeded vehicle to attain mainstream speed before merging into lane 1. The taper at the end of the acceleration lane to notify the driver of the remaining room for merging is obvious. There is a bridge that narrows the shoulder available for evasive maneuvers beyond the taper, but the total length of the acceleration area makes this a minor problem.

Site B (Figure 2) has an S-turn approach with the only acceleration area consisting of a 46-m (150-ft) taper section and the painted gore area, giving 61 m (200 ft) from the nose of the physical gore to the end of the taper. The ramp is on a downgrade with good visibility of the traffic exiting immediately before this ramp and of the through traffic. Just beyond the end of the taper there is a small bridge that prevents the extension of the taper.

Site C (Figure 3) is almost identical to site B except that the acceleration area is somewhat longer. The taper and the painted gore area allow 96 m (315 ft) for attainment of mainstream speed. Visibility is good from the downgrade ramp.

Merging Behavior and Length of Acceleration Area

In order to bring about smoother interaction among vehicles in the area of a merge, a common model must be supplied to drivers so that they know what is expected of them and how to carry out the requirements of the model.

Site A

Since the acceleration area for site A appears adequate, the MUTCD would not recommend installation of a yield sign at all. This implies that the drivers know where to yield and how to accelerate so as to bring the vehicle to mainstream speed by the time it enters lane 1. This is a questionable assumption, especially in view of the variability of design of acceleration lanes currently encountered and the recognized inability of drivers to accurately estimate distances. The driver should have some signal to indicate where to hesitate, if necessary, so that sufficient acceleration room remains for each specific site.

Although the acceleration area of site A is 264 m (865 ft) long, only 38.9 percent of all vehicles made use of the last 181 m (595 ft) for acceleration before entering lane 1. The last 140 m (455 ft) was avoided by 86.6 percent, and the last 67 m (220 ft), the taper, was avoided by 97.3 percent of the drivers. Contrary to what might be predicted, less of the acceleration area is used when traffic volumes increase. Truck drivers tend to merge almost as early as car drivers but they are much less variable in their point of entry, implying more of a common, if not optimal, performance standard among them. In general, somewhat more of the acceleration lane should be used so that the variability of entry point into lane 1 is reduced.

The merging maneuver is executed with a variety of degrees of success in terms of smoothness and efficiency in traffic flow. At site A, 60.4 percent of the cars merged with a good speed profile, 2.1 percent slowed unnecessarily, and 0.5 percent stopped for no apparent reason. Unnecessary hesitations were more common among drivers who led a platoon of ramp vehicles than among those who either were alone on the ramp or were within a platoon. Assuming the same kinds of drivers were involved both in platoons and in lower traffic volumes, in which single vehicles were more likely, this could be interpreted as reaction to social pressure to conform to the mistaken idea that a safe merge requires a stop or slow entry. A similar trend by lead vehicles is seen

with the earlier entry into lane 1. Here this pressure leads to use of less of the available acceleration area. Earlier entry could also be interpreted as aggression in "staking a claim" to a position in lane 1. Whatever the reason, the effect is to increase the variability in merge maneuvers, to reduce the likelihood of smooth, high-speed merges, and ultimately to increase the perceptual load on interacting drivers.

Site B

For ramps of clearly inadequate design, such as that in site B, the hesitation point or yield point might be situated considerably earlier than the physical gore and may be arrived at through a compromise between providing adequate acceleration area and providing a sufficient view of mainstream traffic. In this case, the 61-m (200-ft) acceleration area would allow the attainment of only about 29 km/h (18 mph) for a semitrailer unit or approximately 64 km/h (40 mph) for a high-powered passenger car starting from a dead stop at the present yield sign. In the second half of the taper, the vehicle would begin to encroach on lane 1, requiring a longer gap in traffic for merging at such slow speeds.

Clearly the stop, if it is to be made, should be made back far enough to allow acceleration to reasonable speeds compared with the 88-km/h (55-mph) limit. According to the Traffic Engineering Handbook (4), about 122 m (400 ft) is required to accelerate from a dead stop to 48 km/h (30 mph) for small passenger cars and most single trucks and buses and to 85 km/h (53 mph) for high-powered automobiles. Moving the hesitation point farther back on the ramp will give some additional acceleration distance, but it is not possible to provide the 122 m (400 ft) desired. Other considerations, such as the angle of the ramp at that point and visibility of through traffic farther up the ramp for planning the merge, enter into the location of this hesitation point.

On this site, cars and trucks were almost equally likely to run off the road—3.3 percent. This indicates excessive information loading of the driver or inadequate use of available information. Up to 27 percent of the ramp vehicles came to a complete stop, with the most common stopping points being in the painted gore area or the taper itself. Overall, 56.1 percent of all vehicles either stopped or slowed drastically. Obviously, stops that late in the merge, and even slow driving in these areas, would prevent a proper, full-speed merge. Drivers again tended to enter the mainstream as quickly as possible without necessarily attaining maximum possible speed. For example, even with the very short acceleration area on this site, 18.9 percent of the drivers had already merged before they entered the 46-m (150-ft) taper area by crossing the gore or the gore paint.

Poor geometrics can be compensated for to some extent by greater driver skill in gathering and using the information that is available. Monitoring of through traffic was not done early enough by some drivers. There was a tendency for drivers who monitored late, i.e., near the painted gore or beyond, to stop or to make slow approaches in their merges. This seems to indicate lack of skill or confidence, since the late monitoring of traffic does not allow time for merge preparation, especially on a short ramp like this one. The smoother, high-speed merges were made by those who did their observations farther up the ramp and then committed themselves to merges before the painted gore area was reached. The data showed a tendency for drivers who monitored to make smooth merges, while those who were not observed to monitor mainstream traffic seemed to make fewer good merges. This result was not statistically significant, however. About 10 percent of all the drivers at site B were not observed to monitor at all. Clearly, some means of increasing early monitoring and planning of the merges is important when the merging maneuver is tightly constrained.

Site C

While the acceleration distance is inadequate at site C according to modern standards, the driver, making use of all the available length for acceleration, can approach the criteria for a proper merge maneuver. The observational data from sites B and C confirm that the additional 35 m (115 ft) in the acceleration area of site C was of considerable advantage. Whereas 3.3 percent of all single or lead vehicles ran off the edge of the pavement during merging at site B, only 0.5 percent did so at site C. Ironically, the last 32 m (105 ft) of the acceleration area at site C was virtually unused. About 37 percent of all drivers observed at site C entered lane 1 while 64 m (210 ft) of the acceleration area still remained, and only 51 of the 1432 vehicles observed (3.6 percent) drove on the last 32 m (105 ft) of the acceleration area. The extra 35 m (115 ft) at this site seems to be required by most drivers but only as insurance, for use exclusively if sudden need should arise.

It will come as no surprise to most readers that truck drivers are more aggressive in merging. However, their behavior as a group at all three sites implies a common, relatively well-defined model of the proper behavior. Both the vehicle's characteristics and the truck driver's attitude tend to make this model less flexible, and car drivers who do not conform to the truck driver's expectations are vulnerable. A common expectation as to speed profiles, hesitation points, and lane 1 entry points, based roughly on the truck driver's model, seems most conducive to smooth total operation.

Approaches to Remediation

Because site B is the most restricted by its design, the remedial treatments are most critical for this site. The same treatments should be applicable to all or most merges, however, for consistency in driver expectation.

First, the observation of through traffic is required for planning and executing a smooth merge. A clear, obvious observation area must be provided. This may require posting signs in some cases to encourage early observation. It may also require the paving or special treatment of small shoulder areas since even well-maintained grass can reduce the view of through traffic in many older designs. A tutorial sign may be desirable where the observation distance is good but the acceleration area is short. It would be located up the ramp as for as possible and would advise drivers to CHECK HERE FOR FRWY TRAFFIC. This might increase the preview and merge-planning time. At this time techniques for placing such tutorial signs have not been evaluated specifically for the remedial treatment of any site. Driver awareness of the need to observe early will have to be achieved through education in the proper merging concepts, although this need would seem to be self-evident.

Second, the hesitation point should be marked. Education of drivers alone will probably not achieve proper stopping or slowing points in view of the variety of lengths, grades, geometries, and conditions of visibility that will continue to be encountered. The yield sign has, in theory, served this purpose, but its location is not fully thought out in routine use. The concept of where to slow and how to merge must be instilled by driver and public education. However, the "yield-point" concept

might be established for marking an optimum distance in advance of the acceleration lane for any necessary hesitation. The ramp driver is supposed to have enough information at this yield point so that either stopping or slowing can be used as needed or a steady acceleration can be maintained to approximately the speed of through traffic and, at the same time, the vehicle can remain relatively independent of preceding ramp vehicles. To reduce the time pressure on drivers, it is desirable to separate the vehicle-following task from the merging task and also to encourage early monitoring for planning the merge maneuver and merging at lane 1 speed.

Third, the entry path should be defined more completely, especially for substandard ramps. Solid lines can be used to indicate no-crossing areas. Education and well-devised enforcement activities will be needed to get this implemented. The gore paint marking can be extended to reduce the incidence of sharp angle entries. Short, broad dashed lines across the mouth of the acceleration area will remind the through driver of the possibility of merging traffic and will make the entry into lane 1 by a merging vehicle obvious, emphasizing the driver's responsibility to yield. The dashed line denotes the area in which crossing is expected and indicates that crossing near the gore and in the last part of the taper is to be avoided. Part of the taper (most of it where the acceleration area is reasonably long) is to be kept for evasive actions only; it is not now routinely used, and its use should be discouraged further to reduce the variability among drivers. Even with very short acceleration areas, the majority of drivers avoid the last part of the available taper or acceleration lane. This should be recognized, and, though somewhat greater use of the available acceleration area is to be encouraged, the reservation of the final portion for emergencies only should be marked as such with a solid line separating it from lane 1.

Yield Points

The yield-point concept has many components that have to mesh properly. The prescribed behaviors must be possible and natural (if not automatic) but probably somewhat different from those now commonly observed. Drivers who wish to merge must first ascertain that the ramp is clear ahead. Only then can they decide whether there is a gap available for their merge. If there is none, they must delay by slowing or stopping. Marking the delay point is the new element—the point should be far enough forward that the merge information is available before acceleration to the merging speed is begun and far enough back that prior vehicles on the ramp have already committed themselves to a merging maneuver, eliminating both the possibility of collision and the need to continue to observe them. For ramps that must hold several vehicles waiting to merge, the empty section between the yield point and the merge point should not be long. It must allow acceleration time, stopping distance for an aborted merge if the driver feels he was unwise in choosing a gap, and a good view of mainstream traffic to provide the merge-planning information.

Figure 4 shows the yield-point concept applied to site B. The treatment consists of additional striping, reloca-

Figure 1. Site A: adequate accleration area.

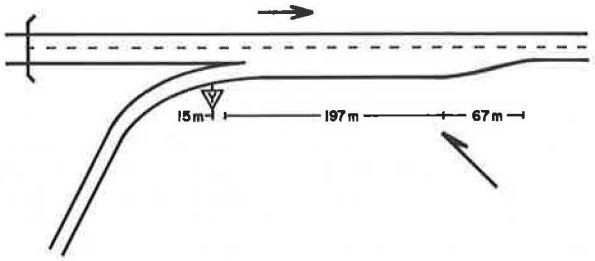


Figure 2. Site B: extremely short acceleration area.

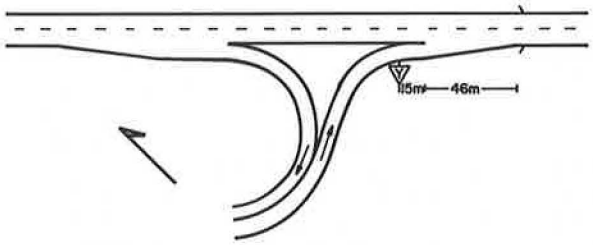


Figure 3. Site C: short acceleration area.

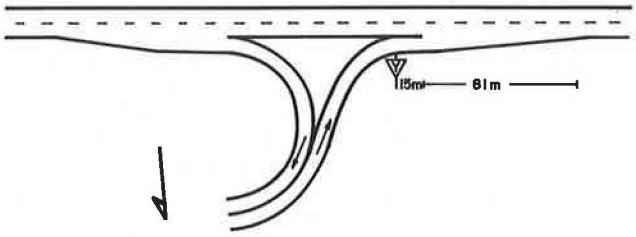


Figure 4. Yield-point concept applied to the worst case design.

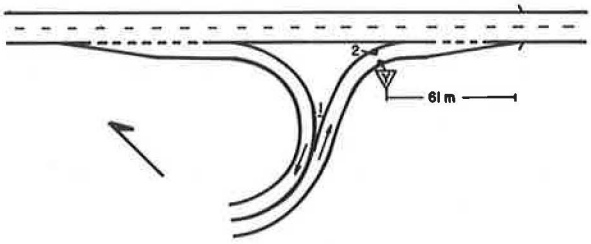


Figure 5. Yield-point concept applied to an adequate design.

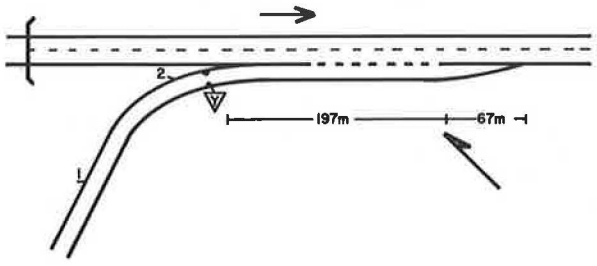
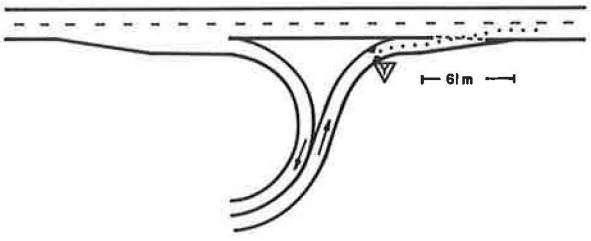


Figure 6. Yield-point markings and merge-path marks where a single path is acceptable.



tion of the yield sign, addition of the suggested yield-point triangular pavement markings, and two tutorial signs to help inform the driver of the proper merge tactics.

The striping of the gore makes the gore appear wider at the physical nose, and it extends farther into the acceleration lane to encourage small-angle entrance into lane 1. "Elephant tracks" (short, broad dashed lines delineating the edge of lane 1) are used to make crossing of the lane 1 boundary clear to both merging and through drivers. The striping also extends back from the taper. This area is not often used by drivers, and this fact is recognized by reserving the area for emergency use only.

Relocating the yield sign is intended to aid in several ways. First, it marks the point for stopping or slow driving if a wait is necessary so that the remaining acceleration area is as long as possible. Second, it more strongly discourages out-of-turn merges or merges across the gore. It also encourages monitoring of mainstream traffic for a reasonable preview. From this position the driver can look for traffic by turning about 120 deg, as opposed to 170 deg from the present location of the yield sign.

Since the merge-point markings are unknown to the driving public, some posting of tutorial signs is advisable. Sign 1 bears the legend, YIELD POINT AHEAD—CONTINUE IF CLEAR. Without further explanation, drivers probably would look for something special but would not stop unnecessarily because the familiar yield sign is present. The markings indicate a boundary, while the CONTINUE IF CLEAR message shows that this boundary can be crossed if gaps are available. Sign 2 reads YIELD POINT—ENTER FRWY AT SPEED OF TRAFFIC. This emphasizes the separation point of the planning (waiting) phase from the acceleration phase of a merge maneuver. It also makes it clear that drivers should not enter slowly and must plan to accelerate before crossing into lane 1.

Although site A has a long acceleration area, the same basic treatment as that illustrated for site B can be used. Figure 5 shows the details. Even with the extended gore striping and solid line out from the taper, a considerable range of crossing points into lane 1 is provided. Narrowing of the lane near the gore will channel vehicles more directly into the acceleration area rather than into lane 1. The yield point remains at the location of the present yield sign, and distinctive triangular pavement markings are also added to reduce the chance of out-of-turn merges and to encourage earlier monitoring of through traffic.

While the gore itself could signal the yield point when the acceleration area is adequate and the use of signs could be reserved for inadequate designs as recommended by MUTCD, a single standard marking seems advisable for reducing the driver's need to process information. Until entrance ramps have a single design standard, it seems necessary to mark all entrance ramps to guide the driver in the execution of a smooth, more uniform maneuver.

Site C is between sites A and B in the degree of restriction of the merge points. In this case the range offered is short, but it is not reduced to the single path seen in site B.

Merge Paths

One further possible remedial treatment is suggested where the geometry or design reduces the choice of acceptable merge paths so that there is essentially a single path. Figure 6 shows the recommended track delineated so that it becomes obvious where the traffic engineers expect merging vehicles to travel. This delineation with merge-path marks should be quite compelling for drivers, since it provides an obvious indication of where the center of the vehicle is to go. When viewed directly ahead as the ramp drivers see it, the marks are perceived as a strong line. Since the marks begin well up the ramp, where there is no question of multilane tracks, the function of the merge-path marks is clearly identified as different from that of lane boundaries.

When the merge-path marks are viewed from an angle, as they are by through drivers, the marks fail to form as strong a line, but their meaning will soon become obvious: Merging traffic will enter here. The "elephant tracks" across the entrance are in the direction of travel for through drivers, so they are perceived as a strong boundary line. The opposite is true from the angle of the merging driver: The path marks determine a strong line and the dashed entrance markings present a weaker boundary, since they are seen from an angle.

Merge-path marks are not necessarily the most practical remedial treatment for a merge site because the yield-point concept is more directly related to current practice. The optimum symbol shape, size, and spacing for path marks must also be investigated. Although site B exemplifies the type of situation that requires one best path, the path marks may also be useful in better designs (such as site A) to reduce the variation among drivers in path choice. While no single ideal path can be shown to be critical in the sense of determining accident frequency, the path marks should encourage better merging performance through a gentle tutorial remainder of the recommended merge tactics. Reduced variability in the behavior of merging drivers decreases the uncertainty for all drivers.

SHAPING MERGING BEHAVIOR

Changing a driver's behavior in any situation also involves changing the expectations of other drivers. For example, drivers have always had the option of stopping farther back on a ramp to allow more room for acceleration. In many cases, a driver will be hesitant to stop at the "proper" point because no one else does. Following ramp drivers might not expect a stop at that point and might run into the stopping vehicle or might go around the stopping vehicle, perhaps assuming that the engine has stalled. If the hesitation point must be moved back from the current yield-sign or gore location to allow room for smooth merging, the point should be marked and other drivers should be prepared for stops at this point by advance warning signs and by prior education.

Erecting special signs only on substandard entrance ramps has the advantage of "custom" treatment, which reduces the likelihood that they will be used routinely to form a standard that does not really apply. Driver confidence in signs has been eroded by the use of signs for the wrong reasons, e.g., ease of law enforcement or problems of liability rather than as driver aids. Where drivers are required to make decisions and commit their vehicles to high-speed merges, they must have confidence in the signs that shape their paths and speeds.

Achieving smoother operations in merging is obviously too broad a job for driver educators alone. Contributions from traffic engineering are essential, especially when costs prohibit reconstruction of inadequate designs. Posting tutorial signs to educate drivers and to shape their behavior to allow smoother interactions in the system may be useful. Legislation and legal expertise are also required to make enforcement more of a rehabilitative and corrective force and less of a puni-

tive one. The laws and codes must be consistent with the requirements of the transportation system as it actually functions. For example, the wording of the Uniform Vehicle Code (5), Section 11-403(c), implies that stopping at a yield sign is always prudent to avoid liability in case of an accident during merging, as though, having stopped, the merging driver can enter the mainstream blindly.

Until drivers know what is expected of them and until they are aided in making judgments that are known to be difficult, there is little hope of bringing about a common, efficient set of behaviors in the merge situation. The recommended tactics must be based not only on what some authority finds most desirable but also on what drivers are willing and able to do under specific circumstances. While the highest design standards are conducive to smooth merging operation, behavior can be shaped to reasonably accommodate less than ideal conditions through an integrated program of education, engineering, maintenance, and enforcement.

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