The Traffic Safety Toolbox:

A Primer on Traffic Safety

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OVERVIEW

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The phrase "safe and efficient" pops up whenever an attempt is made to define the aims and goals of transportation engineering. Habit and rote make that phrase roll easily of our lips. Do we give more than lip service? It flows easily from our pens into articles of the constitution. But is it just an article of faith or a genuine foundation for practice?

We genuinely believe that what we do matters to safety; that under the guidance of professional standards, warrants, guidelines and practices, we build and operate safe roads. Why then do accidents occur with the regularity of a natural law on roads that are safe? If a safe road has accidents, in what sense is it then safe? Is this not just disguised sophistry, a ruse to impress others, a shield to protect our collective backside?

It is often tempting to carry the sophistry further by claiming that if an accident occurs on a road designed to be safe, it must be due to human error. Some claim that more than 95% of all accidents are so caused. If almost all accidents are caused by human error, what is there to be engineered? Should we abandon our goal of being the custodians of traffic safety and leave the field to be the playground of sociologists and psychologists? Is it not happening before our eyes that the engineer's role in safety is marginalized?

Perhaps we transportation engineers cannot act in good faith as the custodians of traffic safety because the goals of safety and efficiency are too often in conflict. One cannot pretend that what promotes speed (and thereby efficiency) also promotes safety. Perhaps this frequent conflict in goals inexorably leads to compromises that cannot be made by technical professionals who earn their living and professional self-esteem by attempting to reduce the time people spend on the road.

Some of these questions are weighty; others may ring artificial. It is important to separate the wheat from the chaff. In any case, these questions are unlikely to be raised in the substantive chapters of the primer and the danger exists that discussion may slide into the ritual of supporting whatever we are in the habit of doing. Therefore, I believe this overview should clarify matters and to create a realistic framework for the discussion of safety and transportation engineering.

WHAT WE DO MATTERS

Without a doubt, safety considerations are center-stage in highway and traffic engineering. Just recall how we shape the profile of a road to ensure that drivers can stop safely before colliding with an object on the road (on vertical curves) or avoid hitting vehicles emerging from intersections (sight triangles); how we bank the road to keep vehicles from sliding out (on horizontal curves); how we crown the pavement to drain it from water to reduce skidding; how we shape the roadside to protect drivers who have strayed; and how we separate conflicting traffic streams by medians, markings, signs and signals. The list could be made much longer. But this brief paragraph suffices to show how all-pervasive safety considerations are in our professional practice. That safety takes center-stage shows that we care as individuals and as a profession. But, does this demonstrate that what we do, matters to safety?

Consider for example the way we design crest curves. We strive to ensure by design that if there is some obstacle on the travelled way, the driver can see it in time to stop. This demonstrates concern. It would be unfair to design otherwise. But is it true that crest

curves with long sight distances are safer than crest curves with short sight distances? There is considerable doubt about this. From what little is known at this time, if there is a difference, it appears to be small. In this case, what we do so carefully in design, often at great cost, seems to matter little to safety.

When we select the change interval for a signal, we make sure that drivers can either stop safely or clear the intersection in time and that they can avoid being in violation of the law. This shows fairness and concern. But, it appears that when the intergreen is 10% longer than what fairness and law require, there are 25-60% fewer right-angle and rear-end accidents. Thus, in this case, what we do matters a great deal. But are we doing the right thing? Merely showing concern and ensuring fairness may not be equivalent to delivering the appropriate amount of safety.

When an intersection is converted from two-way to all-way stop control, accidents are reduced by more than 50%. When stop control reverts back to yield control, accidents more than double. In these cases, what we do,matters to safety. However, few traffic engineers willingly use all-way stops except when there is no funding for signals. They would also like to see fewer stop signs. Concern is not enough when safety and efficiency are in conflict.

These few examples suffice to conclude that what we do out of concern sometimes affects safety only marginally and at other times it matters very much. However, the same examples also suffice to show that concern about safety, however genuine, is insufficient. Our professional standards and warrants demonstrate a great deal of concern for safety, but these standards are too rarely based on a defensible knowledge of facts. I have elaborated on this theme elsewhere (Hauer, 1988).

Professionalism demands that we be able to anticipate the safety consequences of our actions. This anticipation must be based on knowledge of empirical fact, not heartfelt concern or fear of legal action.

This opens Pandora's box, and many worms are now wiggling into the daylight. In the next section I have to clear up two sources of confusion, paving the way to a realistic perception of our professional contribution to road safety.

WEEDING OUT CONFUSION AND OBFUSCATION

Accidents occur on crest curves with good sight distances, on horizontal curves with adequate superelevation, during intergreen times that meet the standard and at intersections with traffic control devices meeting the prevailing warrant. Yet I hear it said that a road designed to current standards is "safe". This is confusing. I also hear it said that if accidents still occur on such a "safe" road, they are "caused" by human error. This is obfuscation.

Both assertions, about roads being "safe" and accidents being caused by human error, are comforting. First, they shift attention and responsibility from those who build and operate roads to those who use them. Second, they explain away the paradox of accidents occurring on roads that are said to be "safe". Because of their superficial plausibility and because these assertions are used by those who wish to impress without doing, and aim to justify the symbolic delivery of road safety as a substitute for the real thing, this double-headed hydra has to be slain.

Both assertions derive from an incoherent notion of "cause". Let us not be diverted by metaphysics. When I kick a ball and it flies away, I do not hesitate to call the kick "cause" and the trajectory of the ball "effect". While road accidents are perhaps more complex events, one should not deny that they are the result of some causal chain. Consider the following causal chain.

Suppose I decide to stop suddenly because the signal has turned amber and someone rear-ends my car. Surely I could have either gone through amber or been less abrupt in braking. This could have prevented the unfortunate occurrence. Similarly, the driver behind me could have followed less closely. While neither one of us did something outrageous, between the two of us we must admit to having "caused" the accident. Such an admission is natural but premature. It is natural because people tend to seek cause in the immediate antecedents of events; because the two drivers have each other on scene to blame for "causing" the accident and because the concepts "cause", "blame" and "fault" are hopelessly

intertwined in our mind. It is also natural because the police officer will officially determine who "caused" the accident by charging the driver behind me with "following too closely".

The operative principle I used in admitting to have been (partly) the cause of this accident was the speculation that had I behaved slightly differently, the accident event might not have occurred. The police officer used the same principle in thinking that the other driver caused the accident: The driver could (should) have followed less closely. By "cause" we mean something which, had it been different, would have an effect on the eventual outcome. This concept of "cause" invites us to extend the causal chain to remoter events which might have averted the occurrence of my accident.

For example, the signal could have been "actuated," changing to amber mostly when there are no vehicles in the "dilemma zone". Alternatively, even if signals are not actuated, they could be so coordinated that in most cycles amber comes on before the platoon of arriving vehicles enters the dilemma zone. Is the decision of the traffic engineer not to install an actuated signal also a "cause"? Of course it is! Had the signal been actuated, I might not have had to face the need to make a sudden maneuver. Is the practice of traffic engineers not to take safety into account when signals are coordinated not a "cause"? Again, the answer is yes. In some sense the traffic engineer's decisions are a more weighty "cause" than mine because they are a causal factor in *all* accidents which occur at that intersection under similar circumstances. Furthermore, the engineer's decisions are a matter of deliberation, while I and the other driver feature in the causal chain against our will and because of a decision we had to make in haste.

Suppose now that in his or her deliberations the traffic engineer has used some "guidelines" about when to install actuated signals or relied on some software for signal coordination and that road safety considerations did not influence the formulation of the guidelines nor the writing of the software (as is true in most cases). Many traffic engineers then proceed to use the same guidelines or software to make decisions about many intersections at which accidents such as mine do and will occur. Thus, the "guidelines" and the "software" are a very weighty "cause" indeed! They are part of the causal chain of many accidents at many intersections.

It follows that it is just lax language, bad habit or laziness of mind to use the word "cause" for what is easy to see and is proximate in time to the crash event. It is logically unsound and therefore unprofessional to speak of an accident as if it had a single cause and, in particular, to point to the two drivers as being that single cause. This is why the claim that accidents are caused by human error is not only devoid of meaning, it is incorrect and often (intentionally) misleading.

Above all, to call the proximate event (something the driver did or did not do a few seconds before the crash) by the name "cause" is useless as a guide to action. When a non-swimmer without a life jacket falls overboard and drowns, the "cause" of death is listed as asphyxiation. This is, of course, the proximate event which starved the brain of oxygen as a result of which clinical death has occurred. However, the fact that the person never learned to swim, fell overboard, did not wear a life jacket, etc., is surely the more relevant causal factor when one is interested in water safety. The event offering opportunity for effective intervention is of interest, not the event closest in time to the crash.

In our context, the concept of "cause" has meaning only if we think by it something which, had it been done differently, would have affected the eventual outcome. Altering the features of a road and controlling its traffic will usually affect the probability of accident occurrence, its severity or both. It will do so by altering the circumstances in which the road users find themselves or by affecting their behavior. So there is no reality and no usefulness to the dichotomy: roads as a cause versus human factors as a cause. There is just a causal chain in which the road, its environment, markings and signs affect what road users do.

Choices made by transportation engineers feature prominently in the causal chain of most accidents. These choices are made long before the accident event. Perhaps this is why our work has evaded public scrutiny. But, we

should not evade our professional responsibility. Within limits, highway traffic engineers can make roads safer or less safe. We must know the safety repercussions of our choices.

KINDS OF SAFETY

I have used the words "safety" and "safe" as if their meanings are clear. Most people would agree that the safety of some road or intersection is related to the number of accidents (crashes) and their severity expected to occur per unit of time or exposure. If so, since in addition to the engineer and the environment the road user is always in the causal chain preceding accidents, no road or intersection can be said to be "safe". All facilities must be expected to have a non-zero number of accidents per unit of time.

What then can we possibly mean when we say that a road built to current standards is "safe"? Instead of discarding this concept as useless, it may be better to salvage what is important in it. I do so by creating a distinction between two kind of safety. I will call that aspect of safety which derives from the count of accidents and their severity as *substantive safety*. Substantive safety is a matter of degree. A road is never "safe"; it can only be safer or less safe. In contrast, that aspect which is related to conformance with standards, warrants and design procedures I will call *nominal safety*. A road or intersection can be nominally safe, meaning that it conforms to current standards, warrants and design guidelines. Earlier I used examples and reasoning to show that nominal safety may be only weakly related to substantive safety (as on crest curves) and that it is unclear whether what is nominally safe accords with some socially desirable level of substantive safety (as in the case of the intergreen or the multiway stops).

I take it as common ground that for transportation engineers, substantive safety is an important measure of performance. Is there anything of import to salvage about nominal safety? There are at least two aspects of nominal safety that need to be preserved. First, our designs must enable road users to behave legally. Second, our designs must not create situations with which a significant minority of road users cannot cope.

An examination of the current standards, warrants and design procedures would reveal a degree of fuzziness; both substantive and nominal safety seem to play a role. Nevertheless, so it seems, most have been written with considerations of nominal safety in mind. Typically, one imagined some way in which "failure" — accidents — could occur. On a crest curve we imagine a collision with obstacles. At unsignalized rural intersections, we think accidents might occur when a vehicle decides to pull out of the side road and the driver cannot see far enough, so that an oncoming main road vehicle cannot stop safely. In signalized intersections we think accidents occur when two vehicles of conflicting streams can concurrently occupy the same spot.

After imagining how failure occurs, step two was to ascertain what are the properties of the elements involved: reaction time, walking speed, design or approach speed, available friction, comfortable deceleration rate and the like. At this stage some compromises need to be made because it is impractical to cater to the fastest vehicle or the slowest pedestrian. The next step is a rigorous analysis in which, using the "properties" selected in step two, we determined how to design so that "failure" does not occur.

The tradition from which this approach derives must have been that of civil engineering. There, the concept of "failure" is often self evident: a beam breaks, a column buckles, a culvert floods. Another characteristic of this tradition is that the interacting elements are inanimate; their properties, once determined, remain unchanged. However, the same can not be said about transportation. First, failure is some times a matter of not being able to behave legally, at other times not being able to cope with a situation. Also, failure is usually a matter of degree. Only drivers with a reaction time less than one second can behave legally, only pedestrians walking faster than 4 ft. per second can reach the middle of the far lane. Second, unlike steel or concrete, people's properties are not fixed constants. When they do not see far enough they lift their foot from the gas pedal and pay more attention. When it rains they slow down. Driving is a self-paced task. For these two reasons the civil engineer-

ing tradition leading to the definition of what is nominally safe is open to question.

But there is more to this than tradition and training. Although concern about legal liability gained prominence over the years, it was always there. Concern about nominal safety and the writing of standards cannot be divorced from concern about liability.

We and lawyers live in two different worlds. They judge adequacy with reference to what is accepted professional practice. It tends to be a black and white world; a shoulder may be deemed substandard even if it is only an inch less than what the standards specify. We who write the standards are humbled by the realization of how imperfect our knowledge is and what important role is played by unsupported judgment in the formulation of standards. Our world comes in shades of grey. We are trained to think of cost and effect and perhaps would like to see standards based on empirical fact. But cost and effect arguments make the defendant vulnerable in court. The safe haven offered by nominal safety is just too inviting. Concern about nominal safety is in ascendance in a litigatious society, the delivery of substantive safety suffers.

Still, when speaking of safety, most of us have in mind accidents—that is, substantive safety. At the same time one has to admit that professional practice is driven mostly by nominal safety considerations. The two are not the same. In my opinion, our work at this time ought to be guided by both kinds of safety. It ought to satisfy the requirements of nominal safety, so that most road users can behave as the law requires and that few find themselves in a tight spot when behaving reasonably. However, it also ought to be guided by considerations of substantive safety. This is only imperfectly done. Many professionals like to think that what is nominally safe automatically ensures the appropriate level in substantive safety. This is simply not true.

SAFETY VERSUS SECURITY

I think the distinction between nominal and substantive safety is an important one. Both should affect what we do. However, another kind of safety already affects what we do, and yet we either fail to recognize it or are loathe to mention it. Much of what we do is because people wish to feel safe.

Catering to people's desire to feel safe creates a certain amount of tension. Some think that engineers are here to deal only with the substantive aspects of safety—accidents and their severity. But the reality is that we are in the employ of people and their wishes must count. And, let us admit, they do count frequently and appropriately. Thus, e.g., we paint crosswalks to give pedestrians a feeling that there is a piece of the road where they are protected. There is some evidence that this feeling of security is false; that by painting two white lines the number of accidents to pedestrians is increased. But we still paint crosswalks. I will stick with the convention that substantive safety is manifest in the occurrence of accidents and their harm and will refer to people's subjective perception of safety as "security."

To illustrate, let the abscissa of A in Figure 1 describe the pedestrian safety if crosswalks at intersections are not marked and the ordinate of A measure the pedestrians' feeling of security under such conditions. Let A^1 represent the state of affairs after crosswalks have been painted. Pedestrians now feel protected by the two lines of paint on the pavement and therefore their security has increased. However, their risk of being run over has increased (at least in accord with what has been found in San Diego by Herms, 1972). Perhaps pedestrians have been lulled into a false sense of security.

In the same representation, consider a publicity campaign on television that shows the mangled bodies of accident victims, or the placing of demolished cars in the center of roundabouts, and of posting the number of persons injured alongside many road sections. This kind of campaign is not uncommon. Let B represent the state of affairs before the campaign and B^1 be the safety and security after the campaign has run its course. Road users now feel less safe and the number of accidents may have dropped ever so slightly. Neither the shift from A to A^1 nor B to B^1 is a clear-cut improvement. A clear-cut improvement is only if the change is one from C "before" to C^1 "after". A clear-cut fiasco is a change from D to D^1. Real-life interventions may be of the A, B, C or D kind.

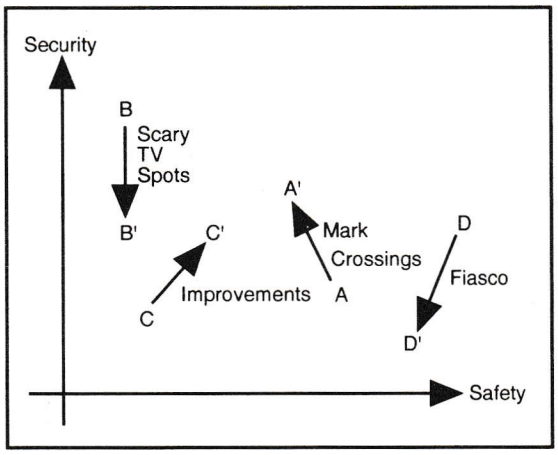

Figure 1 Possible changes in Safety and Security.

A shift in attitude seems desirable. What we do affects both substantive safety and also feelings of security. Both are important and need to be considered.

CLOSURE

What makes someone a professional? A professional must possess some specialized knowledge to which non-professionals cannot lay claim. Our claim to professionalism in road safety is weak because our substantive professional knowledge in this field is underdeveloped. We have painstakingly developed standards and warrants to guide nominal safety considerations. Our knowledge of substantive safety consequences is lagging behind.

This book will, of necessity, describe where we now stand. It is important from time to time to summarize what are recognized as good safety practices. But this book should be sold with a big lump (not grain) of salt. The challenge is to ensure that the next edition be based on more sound, empirical and defensible knowledge. It can be done, because we are the custodians of constantly accumulating professional experience. But, the change in direction will not come about by itself.

I intended to stop here. However, a reviewer asked for "more detail on what needs to be done" to enhance our professionalism in road safety. I tackled this question at some length in 1988. Those desiring detail can find it in the reference section. Therefore I will limit myself to a few unkind comments.

Progress to knowledge-based professionalism is not much impeded by insufficient money for research; much research is and has been funded. Progress is perhaps slowed by objective difficulties, such as when one cannot do large controlled experiments. However, other disciplines manage to make progress in face of worse obstacles. It is not even a question of poor methods, although much of what we now regard as fact has been produced by amateurs and is little more than folklore. Still, adequate methods to learn from the kind of data we can get already exist. Lack of progress is mainly a reflection of lack of resolve.

The profession and its institutions seems to be content to let loose on the road system engineers who have not received training in road safety at the undergraduate level, and allow them to build roads and control traffic without requiring the acquisition of knowledge in road safety during their career. If knowledge is not in demand, it will not come into being. With resolve, the Institute of Transportation Engineers can bring about change.

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