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Engineering judgment and road safety

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ABSTRACT

Decisions that highway and traffic engineers make significantly affect the safety of road users. The documents that guide highway and traffic engineering practice suggest that many of these decisions be made by 'engineering judgment'. One would like this judgment to be informed by evidence-based anticipation of their likely safety consequences and by a professional ability to balance safety against mobility and other dimensions of 'utility'. I show that these desiderata are largely unfulfilled. The many implications of this finding are discussed.

1. Introduction

> "Judgment is central to engineering … one who otherwise knows what engineers know but lacks engineering judgment may be an expert of sorts, a handy resource much like a reference book or database, but cannot be a competent engineer." (Davis, 2012)

Opinions may differ about the nature of this elixir that makes one into a competent engineer, but most would agree that engineering judgment is acquired largely through engineering experience and exposure to the findings and views of respected peers[1] . Can experience in engineering endow one with sound judgment about the road safety repercussions of engineering decisions? Can rubbing shoulders with respected peers do so? How can sound engineering judgment in matters of road safety be acquired? Does the training and the experience of highway and traffic engineers endow them with the knowledge needed to foresee the safety consequences of the judgments they make? Does it tell them how to trade road user safety against cost, mobility and other measures of performance?

These questions are motivated by the ease with which road design and operational decisions that affect life and limb can be made on opinions and beliefs[2] that are unsupported by evidence; they are prompted by the concern that one can adopt policies and procedures based on such beliefs and follow them for decades without the need for factual knowledge being recognized; they are aroused by the observation that when evidence runs counter to opinion the latter often wins the day. In Hauer (2019) I gave two examples[3] but there are, of course, many more[4] . The historical episode below may help to make the issues manifest.

2. A historical episode

In 1937 the American Association of State Highway Officials set up a Special Committee[5] the purpose of which was to formulate policies

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[1] See e.g. Coles (2002).

[2] There is not an agreed upon difference of meaning to the words 'opinion', 'belief' and 'judgment'. Although 'belief' may be more difficult to change than 'opinion' I will use them interchangeably as referring to something that everyone can have and requires no deliberation. The word 'judgment' will be reserved to something that requires thought, has more gravitas, and is invested with respectability as, e.g., in the phrase 'a person of judgment'.

[3] One was the decision to edgeline roads taken on the belief that doing so is bound to benefit safety. Even when evidence about the possible safety harm of edgelining later emerged, it did not trump the original belief. The other example was the ongoing saga of mandating some minimum retroreflectivity levels. Here inconvenient evidence was dismissed, disregarded, or twisted in order to make a pre-existing belief-based decision seem sensible.

[4] Here are a few I encountered recently: (a) Research shows that raised pavement markers often degrade safety and yet the contrary belief was sufficiently strong for several states to knowingly disregard this finding Yi Jiang (2006). (b) An intersection design with a built-in car-bicycle conflict was made into a national standard just because it was believed sensible. It is now used all over North America without its safety ever being examined (Hauer, 2016). The use of pedestrian countdown signals was made mandatory on the basis of the flimsiest of evidence (Federal Register, January 2, 2008, page 313.) Then there is the continued adherence to road design standards many of which "were developed without fully understanding the relationships that the design elements … have to safety performance." (ITE, 2015, page 2). I could go on but, unfortunately, piling example on example does little to convince a skeptic.

[5] The Special Committee on Administrative Design Policies.

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"toward the incorporation in practice of design features which will result in the maximum degree of safety and utility[6] *"* (AASHO, 1965, Preface). At the behest of this committee, between 1938 and 1944, seven policy brochures were developed, published, and later (in 1950) assembled into a book. The book became the main guidance for highway design engineering. Over the years it was revised, is now in its seventh edition, and referred to as the 'Green Book'. Authoring committees came and went, parameter values were modified, even the color of the book covers changed[7], but its conceptual foundations and within it the role of engineering judgment remained the same. This is why, in spite of its distant origin, the story is current.

One of the seven original policies was about sight-distance (AASHO, 1940a). How far along the road a driver can see is limited by its alignment, mainly by horizontal and vertical curves. To develop a sight-distance policy for incorporating "safety and utility" into the design of roads a technical committee was set up[8] . At that time, circa 1939, little was known about the causal link between sight-distance and crashes. How was a design policy that takes road user safety into consideration developed when the requisite evidence was missing?

Roads had to be built, guidance for their design had to be provided, and the making of assumptions and the exercise of judgment were unavoidable[9] . The committee opined that:

> "If safety is to be built into highways to the extent possible, it is vitally necessary that the road, at all points, be opened up to view for a sufficient distance to enable the driver to so control the speed of the vehicle as to avoid striking unexpected obstacles in its path" (AASHO, 1940a, page 1.)

That to be safe the driver must see far enough makes common sense. The need for judgment came in when one had to say how far is far enough. Considering that all 15 members of the committee were senior engineers, the judgments that went into the formulation of the sight-distance policy were of the engineering kind. To start on the path to quantification the committee clarified its intent by declaring that:

> "The …sight distance at every point on a highway should … be long enough to permit a vehicle traveling at the assumed design speed of the highway to stop before reaching a stationary object in the same lane." (AASHO, 1940a.)

At first blush this looks as uncompromisingly putting safety first, but embedded in the wording is an escape hatch: the 'assumed design speed'. That to design something one has to have some 'design value' in mind came to engineers naturally; bridges were designed to carry a design load, buildings to withstand a design earthquake, culverts to accommodate a design rainfall[10] . When the failure of an engineered system could endanger life, the code committees chose design values so that their exceedance be extremely rare. In road design this is not practical. The higher the design speed, the faster will drivers go, and the longer is the required sight-distance. If roads had to be designed for a speed that is exceeded only extremely rarely the required sight-distance would be so long that all roads would have to be nearly flat and straight - an impractical proposition[11] . A compromise between 'safety' and 'utility' had to be struck and the design speed was the instrument of the compromise. If you cannot fit a large radius curve into the landscape or make the intersection sight triangle long enough, then reduce the design speed.

The interpretation given to 'design speed' at that time (by another AASHO committee) was that it is the *"… speed that probably will be adopted by the faster group of drivers but not, necessarily, by the small percentage of reckless ones."* (AASHO, 1940b)[12] . As not only the small percentage of reckless drivers exceed the design speed, it is exceeded regularly, not very rarely. The compromise was that those traveling up to the design speed were to be assured of a safe stopping distance while those traveling faster might not see far enough to stop safely[13] .

The choice of the design speed and thereby of the balance between 'safety' and 'utility' requires the exercise of judgment. For the Committee this kind of judgment would have been unfamiliar. Engineers know materials, math, physics, chemistry, economics, etc. but there was little in their training, outlook, and experience to prepare them for considering death and injury as one of the regular by-products of an engineered system. Also, while the committee believed that sight-distance affects safety, at that time it was not known to what extent. How then could one judge what the right safety-utility balance might be?

One might expect engineers to try and find the right balance by some quantitative means such as cost-effect or cost-benefit analysis. But that would require explicit mention of so many deaths and injuries for so many dollars. Recall the public uproar surrounding the Ford Pinto affair (see e.g. Birsch and Fielder, 1994) in which engineers explicitly traded X fiery deaths for Y dollars spent on making a better fuel tank. No Department of Highways wanted such publicity. Besides, cost-benefit analyses in which death and injury are monetized became acceptable tools for governmental decision-making only decades later.

The easiest way out was not to face the issue. The committee that wrote AASHO, 1940a elected not to say what the design speed is or how it should be chosen. The committee that authored AASHO, 1940b, only said that the design speed is that which is exceeded by a group of fast-but-not-reckless drivers but left that group unspecified and thereby the design speed indeterminate[14] . The only practical guidance given was that "the sight-distance at every point on a highway should be as long as possible" (AASHO, 1940a, page 24). That is, that the design speed

[6] 'Utility' is a useful all-purpose word intended to capture traits such as cost, mobility, security (perception of personal safety), environmental amenity, etc.

[7] From dark blue in 1954 to bright blue in 1965. Red in 1973 to dark green in 1984 then a lighter and in 2018 again a darker shade of green. In all these the titles still call it a 'Policy'.

[8] Under the name of the 'Operating Committee on Planning and Design Policies of the American Association of State Highway Officials'. The personnel of this committee was chosen by the Public Roads Administration, the precursor of the Federal Highway Administration.

[9] That decisions have to be made in the absence of sufficient evidence is more the rule than the exception. The ability to get things done, the readiness to make assumptions when evidence is sparse or missing, is the hallmark of engineering.

[10] The founding of highway design on an 'assumed design speed' disregarded an important distinction. Rainfalls do not change as a function culvert diameters and earthquakes do not depend on the design of foundations. Drivers, however, adapt to the road; the higher the design speed the faster they will tend to drive. This human trait – adaptation - complicates matters. But even with road user adaptation, regularities persist. Thus, e.g., the longer the curve radius or intersection sight triangle, the lesser tends to be the accident rate. From a large amount empirical research and for many interventions and countermeasures it follows that (a) adaptation is not perfect and (b) that road design and operational decisions do have safety consequences.

[11] The higher the design speed the longer is the distance to stop and the required sight distance. The longer is the required sight distance the larger must be the radius of the curve and the deeper into the hill must one dig. In sum, the higher the design speed the higher the cost.

[12] Later the definition was changed. In 1954 and 1965 it was said to be a 'maximum safe speed' and, in 2001, when it became evident that the designs speed is exceeded by a large proportion of drivers, this was changed to a 'logically chosen speed'. "Direct references to safety were removed from the current definition, but the same basic philosophy is still reflected in supplemental guidance related to design speed selection" (Porter et al., 2012, pages 40 and 41.)

[13] The design speed is neither the posted speed limit nor the advisory speed on curves; drivers cannot know what it is.

[14] Perhaps the committees were reluctant to specify the design speed not knowing the relationship between sight distance and safety; perhaps they did not want to make it obvious that by choosing a design speed money from DOH budgets is being traded against the life and limb of road users

should be as high as the local considerations of topography, geology, right of way, budget etc. allow.

And so the essence of the sight-distance committee's action was: (a) to make the design speed into a key concept governing the required sight-distance (and other elements of road design[15]); (b) not to say how the design speed is to be chosen and not to make it explicit that by choosing it road user safety is being balanced against costs; (c) to leave the choice of design speed to the judgment of the design engineers and their employers[16] .

Item (c) placed extraordinary and perhaps unrealistic expectations on the judgment of engineers. To get the safety-utility balance right they would have to judge how the choice of design speed affects road user safety and to somehow trade life and limb against dollars. Does their training and experience of engineers prepare them for this task? This, in a more general form, is the question aired in Section 3.5.

Once the committee postulated the existence of a design speed it could proceed to use of the traditional tools of engineering: Logic, Analysis[17], and Science. Logic: that those traveling up to the design speed should see far enough to stop safely. Analysis: that the stopping distance is made up two parts, the distance traveled during the 'Perception and Brake Reaction Time'[18] and the distance traversed from the onset of braking till stopping[19] . Science: using physics and math one could now write an equation with the required sight-distance a function of variables and parameters: the assumed Design Speed, the assumed 'Perception and Brake Reaction Time', and the assumed 'Tire-Pavement Friction Factor'. The parameter values are selected with data and practicality in mind; they cover most but not all circumstances. To apply the equation in to specific tasks a few more engineering judgments had to be made. Thus, e.g., to determine whether on a crest vertical curve one can see far enough the committee had to assume how high above the pavement is the driver's eye[20] and how high the obstacle to be avoided is[21] . The rest, again, was on the solid footing of formal science, here the analytic geometry of parabolas. Some of these assumptions were legitimate engineering judgments[22], others, however, may not pass the same muster[23] .

In sum, the charge of the committee was to devise a policy for sight distance that will incorporate into road design both 'safety' and 'utility'. The committee thought that safety will be served if drivers can see far enough so that, when necessary, they can safely stop. Logic, analysis, science and engineering judgment (about the value of some parameters) were used to cast this goal into equations. It was understood that given the realities of topography and cost it is not possible to provide sufficient sight distance to all drivers. The committee decided that there is to be a certain 'design speed' and that those driving faster may not see far enough to stop safely. The choice of the design speed and thereby of the balance between 'safety' and 'utility' was left to the judgment of the highway engineers and their employers. Can engineers live up to this expectation? At this point storytelling can end and the discussion of the arising issues can begin.

3. Issues arising

This historical anecdote seeds many questions. How do engineers consider the safety consequences of their choice of design speed? What do they know about how their choice will affect safety? What prepares them for mentally weighing injury and death against, say, the cost of land acquisition and earthwork? As I will show (in Section 3.4) concerns of this kind are not limited to the choice of design speed. Engineering judgment is used in many highway and traffic engineering decisions that affect road user safety. To prepare the ground it is best to begin by thinking about what engineering judgment is.

3.1. What makes a judgment into an engineering one

I said earlier that because the AASHO committee was made up of engineers the sight-distance policy it produced is a reflection of their engineering judgment. But the opening quote contradicts my assertion by saying that just being an engineer is not enough, that to have engineering judgment one also has to be 'competent'- in our case competent in road safety. I contradicted myself further by asserting later that even though all members of the committee were experienced engineers, not all their judgments do pass muster. This tangle calls for clarification.

Richard Feynman[24] gave vent to the scientist's impatience with the engineers at the Challenger inquiry saying: *"As far as I can tell, 'engineering judgment' means they're just going to make up numbers!" (*Feynman, 1993*)*. Many will disagree. The eminent geotechnical

[15] Minimum radius of horizontal curvature, banking (superelevation), side friction factor, curve widening, tangent to curve transitions, maximum grade and grade length, minimum length of vertical curve, etc.

[16] As Harwood et al. (2015) say: "… the AASHTO Green Book provides substantial flexibility in the choice of an appropriate design speed. As written … the choice of a design speed is left to the discretion of the designer." (page 7). Thus, e.g., for freeways AASHTO (2011) recommends minimum design speeds to be 50-70 mph (where the typical posted speed limit is 55-75 mph) and for local rural roads 30-50 mph (with typical posted speed limit of 20-45 mph). Some State design manuals specify the lowest allowable design speed. Thus, e.g., in Colorado on rural arterial roads the lower limit is 40 mph while on rural collector roads it is 20 mph.

[17] Analysis is the process of breaking a complex topic into smaller parts in order to gain a better understanding of it.

[18] As its name indicates, this component too was thought off as made up of two parts: Perception Time and Brake Reaction Time. Some empirical evidence about both components was already available and the committee used it in coming to the conclusion that 2-3 seconds is OK for most drivers.

[19] The committee assumed that deceleration is constant and, using the then available empirical evidence, assumed a tire-wet pavement friction factor of 0.4-0.5. This value was later deemed too high and revised thereby prolonging the stopping distances (see e.g. Layton and Dixon, 2012, Table 4).

[20] *"The eyes of the average driver in a private passenger automobile are about 4 1/2 feet above the pavement. The eyes of the drivers of some low-hung makes of automobile are somewhat lower. … It is assumed therefore that the eyes of the driver are 4 1/2 feet above the pavement."* (AASHO, 1940a, page 17.)

[21] "*To be on the safe side of the surface the pavement should be visible to the driver the entire pavement of for the entire length of the non-passing sight distance but the necessity for it is questionable… small objects can generally be avoided the necessity stopping. Therefore, a height object 4 inches is assumed in determining non-passing sight distance*" (AASHO, 1940a, page 17.)

[22] Legitimate were judgments about the magnitude of the 'Perception and Brake Reaction' time, the 'Tire-Pavement Friction Factor', and the height of the driver's eye. These were based on a reasoned interpretation and integration of the then available evidence, allowances were made for missing variables (e.g. for inattention), for inherent variability, for differences between the laboratory and the field. To cover what was unknown a 'safety factor' was used.

[23] Thus, e.g., the committee said that *"To be on the safe side the surface of the pavement should be visible to the driver for the entire length of the non-passing sight distance, but the necessity for it is questionable … very small objects generally can be avoided without the necessity for stopping. Therefore, a height of object of 4 inches is assumed in determining non-passing sight distance."*(AASHO, 1940a, page 17.) The opinion about what objects can be safely avoided could perhaps be based on one's experience as driver but is not likely to have been rendered qua engineers. The real reason for choosing a 4" object height can perhaps be found in AASHO (1954) which says that: *"…. by increasing the height of object from 0" to 4" the required length of vertical curve is reduced by 40% … use of a greater object height …results in little additional economy."*(Pages 125-126). 'Economy' here refers to earthwork. The 4" object was selected because choosing a lower obstacle would be costly and the selection of a higher obstacle would not save much in construction cost. Since, at that time, nobody knew how many crashes are due to obstacles on the road, what kinds of obstacles these are, and what fraction of crashes would not have occurred had the crest curve been flatter, judgment was most likely based on what was known, namely the cost of construction.

[24] 1965 Nobel Prize in Physics

engineer Ralph B. Peck said *that "Almost all people in the practice of engineering would agree that successful practice requires a high degree of engineering judgment, but few would agree on the meaning of the word judgment itself."*(Peck, 1977, page 12). He thought that to the engineering scientist the exercise of judgment may seem to be a poor substitute for sophisticated analysis while to the practitioner it is often an impressive name for guessing. These views, Peck said, are misconceptions. In his view engineering judgment is *"a good sense of proportion"* (Page 12). That is, the engineer should be able to spot gross errors, to diagnose what the cause of a problem is, not to set unrealistic goals, etc.

Descriptions or definitions of engineering judgment are few. One definition says that engineering judgment is the *"evaluation of available pertinent information, and the application of appropriate principles, provisions, and practices …"*and that it *"shall be exercised by an engineer or by an individual working under the supervision of an engineer, through the application of procedures and criteria established by the engineer."* (FHWA, 2009, Section 1A. 13, definition 64). Of this definition I like the word 'evaluation', which, I think, means the mental integration of available evidence. What I do not like about the FHWA definition is that it is mum about the need for competence, that instead of evaluating 'available knowledge or evidence' it speaks of evaluating 'pertinent information' and 'appropriate principles' (who decides what is pertinent or appropriate?), and that it asserts that engineering judgment can be distilled into some list of 'procedures and criteria' that enables non-engineers to render engineering judgments[25] . Strigini (1996) speaking of risk and safety describes engineering judgment as *"informal inference from complex evidence"* and as *"integrating diverse evidence into an assessment of the safety or reliability of a product"*. The description I like best is by Baybutt (2018, page 206) who writes that engineering judgment is *"… the formation of opinions or decisions based on experience and knowledge gained as an engineer."* I like it best because it is brief and captures what is of essence. 'Just making up numbers', as in Feynman's biting comment, is not engineering judgment. Opinions not based on knowledge and evidence remain just that – opinions. For an opinion to qualify as engineering judgment it has to have a basis in 'knowledge' and 'evidence'.

Engineering judgment differs from other kinds of judgment (lay, medical, legal, etc.) for, otherwise, the adjective 'engineering' would have neither role nor meaning. Only engineers can have engineering judgment. One could differentiate further between engineering disciplines but it goes without saying that the judgment of, say, an electrical engineer does not count as an engineering judgment when the subject matter is, say, civil engineering[26] . If we do not differentiate amongst engineering disciplines it is, perhaps, because all share a certain commonality of disposition, a readiness to make and act on sensible assumptions in order to get things done.

The use of judgment was, is, and will be a key characteristic of engineering. Its exercise is a necessary response to circumstances that vary and to knowledge that is not perfect. Knowledge and practice change over time and so does the scope and content of the necessary engineering judgment. Thus, e.g., Kulhawy and Phoon (1996) describe how the nature of judgment in geotechnical engineering has changed from being based on precedent, observation, and experience to what was needed later when geotechnical design became based more on data, science, and risk analysis. Over time *"its role has become more focused on those design aspects that remained outside the scope of theoretical analyses."* (Page 30). A similar evolution and change should be expected in the content and scope of the engineering judgment for road safety.

Thus, to answer the question in the heading of this section, for a judgment to be of the engineering kind it must be made by an engineer whose competence is in the subject matter about which the judgment is rendered. Competence is rooted in knowledge, in the ability to identify and evaluate the available evidence and to integrate it into a judgment. To be competent in road safety the engineer has to know the facts needed to foresee the safety consequences of choices and decisions.

3.2. We 'dwell alone'[27]

Engineering judgments by highway and traffic engineers differ from those by most other engineers. In much of engineering design the occurrence of death and injury is the result of some unforeseen malfunction. If a mode of failure that could cause death or injury can be foreseen at design time, the relevant design values, procedures, codes, and policies ensure that fatal failures are exceedingly rare. Being unforeseen or exceedingly rare pushes the possibility of death and injury beyond the 'need-to-consider' horizon and frees the engineer from the obligation to account for future deaths and injuries in the design.

Not so in the design and operation of roads. The occurrence of death and injury on roads is not rare. Thus, e.g., death and injury on a mile of a rural freeway are about 10,000 times more frequent than what is the accepted standard for other 'safety critical systems'[28] . The authors of the sight-distance policy (AASHO, 1940a) disregarded this difference. As if death and injury on roads were exceedingly rare, they pushed crashes beyond the 'need-to-consider' horizon.

This was done by designing for an event that can cause death and injury but is anything but rare. While the committee said that seeing far enough to be able to safely stop is "vitally necessary", for road building to be practical they had to compromise. The compromise was to provide sufficient sight-distance only to those drivers who do not exceed the (unknown to them) design speed; those going faster are numerous and may not see far enough. Porter et al. (2012, Figure 5) report that most drivers exceed the design speed when it is less than about 47mph and more than some 15% still exceed design speeds as high as 55 mph. Morrall and Robinson (2003) report that many European countries and Australia choose the design speed to be that which will be exceeded by 15% of drivers. So, the exceedance of the design speed is certainly not a rare event. By designing for an event that may result in injury and death and is not exceedingly rare the committee strayed from the bulk of engineering design tradition.

The committee stipulated that there is to be a 'design value', the design speed, and then used Logic, Analysis, and Science to compute the required sight-distance. This left the desired impression that the usual

[25] I do not think that the exception made in FHWA (2009) holds water. Replacing a competent and experienced engineer by a non-engineer who follows 'procedures and criteria' denudes the notion of engineering judgement from its essence. A conclusion reached by following some protocol or checklist is almost an antithesis of the application of judgment.

[26] This is explicit in Codes of Ethics. Thus, e.g., the National Society of Professional Engineers code states that: "Engineers shall perform services only in the areas of their competence."

[27] *"For from the top of the rocks I see him, and from the hills I behold him: lo, the people shall dwell alone, and shall not be reckoned among the nations."* Book of Numbers, KJV, 23, 9.

[28] A 'Safety Critical Systems' is an engineered system where a malfunction may result in death or injury. The reliability standard for such systems is 1×10^{-9} per hour. On a rural freeway there were, on the average, 0.14 fatal and incapacitating injury accidents per mile per year (Mohammedshah and Kohls, 1994). This is the same as 1.6×10^{-5} such accidents per hour which, for one mile of freeway, is more than 6,000 times riskier. Considering all 43,000 miles of the Interstates as a safety critical system would make it exceed the reliability standard 258 million times. Perhaps in the future, when autonomous vehicles will replace fallible humans, the road system will be designed and operated with the same reliability aim as that of all other safety critical systems. Perhaps then highway designers and traffic engineers will rejoin the engineering fold. But at this time and in the foreseeable future incapacitating injuries are so frequent and their occurrence so directly influenced by the way roads are designed and operated that there can be no justification for thinking that engineers do not need to be consider them in their decisions.

time-honored engineering design tradition is followed. But that impression is false. The engineering design tradition works well when injury-producing events are exceedingly rare and therefore does not apply to the design and operation of roads. Because roads can be designed and operated to be safer or less safe[29] and injury is not exceedingly rare the engineer is not free to disregard the death and injury consequences of road design and operational decisions. Nor may the engineer assume that following a policy that was developed without a knowledge-based consideration of safety consequences will somehow make roads appropriately safe[30]. Emulating the form of an inapplicable tradition does not deliver the goods; it builds into roads an unpremeditated level of safety[31].

3.3. Codes of ethics

I noted that, with the existing road transport technology, injury and fatal crashes are not rare events and that this sets highway and traffic engineering apart from most other engineering disciplines. Being an engineering discipline that 'dwells alone' becomes evident when one compares the relevant codes of ethics.

Johnson et al. (2017) says that: *"…engineers have responsibilities that go well beyond what they owe to employers and clients. The most visible and concrete sign of this is the statements in engineering codes of ethics and professional conduct specifying that engineers should protect the health, safety, and welfare of the public. For example, the first canon of the National Society of Professional Engineers' (NSPE) Code of Ethics states that in the fulfillment of their professional duties, engineers shall "Hold paramount the safety, health, and welfare of the public" (*http://www.nspe.org/resources/ethics/code-ethics). Other engineering professional codes contain similar statements, though often the statements are nuanced in particular ways. The American Society of Civil Engineers' Code of Ethics, for example, commits its members to comply with principles of sustainable development in addition to holding paramount the safety, and welfare of the public (http://www.asce.org/Ethics/Code-of-Ethics/*)." (Page 85)*. In contrast, the canons of ethics for members of the Institute of Transportation Engineers (ITE) only says that *"The member will have due regard for the safety, health and welfare of the public in the performance of professional duties."* (Section 1).

Most engineers must hold safety 'paramount' but transportation engineers must only have 'due regard' for it. Paramount means more important than anything else. This is not a suitable term for transportation engineers. One cannot be holding safety paramount while building roads as we do and permitting traffic to move at the speeds which we permit and design for. But what then does having 'due regard' for safety mean? It is at this point that ethical considerations come in and become pressing.

What should the highway and traffic engineers do to have 'due regard' for the safety of the road user?[32] If they do have social responsibilities going *"well beyond what they owe employers and clients"* what are these? Examining the complexities of such questions Johnson concludes that the social responsibility of engineers is best rooted in the concept of 'accountability'; that is that engineers have an obligation to (have to be able to) justify their decisions and choices to the affected public. For highway and traffic engineers this obligation is largely latent. Road users as a group do not demand such an accounting[33]. What little demand for accounting there is takes the form of lawsuits in which individual road users ask to be compensated for their loss by the 'State'. In these litigations the question is not whether the engineer knew and considered what might be the safety consequences of her or his decision. In legal proceedings the question is only whether the engineer followed the current practice as embodied by documents such as the Green Book, the MUTCD, and their local versions. Even this very limited accountability provided by torts hinges on whether these documents appropriately safeguard road user safety. This question is aired next.

3.4. The concern

What a committee decided in 1940 would be of no concern today were it not that the main features of their approach and road design philosophy are still with us. In the latest edition of the Green Book (AASHTO, 2018), the fountainhead of all North American highway design standards, there still is the need to choose a 'design speed', there are the same equations (with somewhat different parameter values), and there is still the same notion that a road is OK even as a substantial proportion of drivers who exceed the unknown-to-them design speed, perhaps some 15% or more, do not see far enough to stop safely. The Green Book instructs the engineer to choose a design speed that is 'logical' and attains *"a desired combination of safety, mobility, and efficiency …."* (AASHTO, 2011, p. 2–54) but it does not say how to do so. Today as in 1940, the identification of the 'desired combination' is left to the engineer's judgment. Whether this is right, whether engineers can identify the desired combination by judgment, is at the root of my concern.

The concern would still be minor if engineering judgment was needed only for the choice of design speed. However, the story of how the sight-distance policy was forged narrated in Section 2 is but one illustration of how the need to know the safety consequences of engineering decisions was circumnavigated. The choice of design speed is but one of the many decisions in which engineering judgment is called upon to find the 'desired combination' of safety, mobility and efficiency. The concern is grave because most road design decisions (about alignment, cross-section elements, the roadside, intersections and other access points, etc.) affect road user safety, and all these highway design decisions and choices call for the exercise of engineering judgment.

The same applies to traffic engineering. Here the principal source of standards and guidance is the Manual on Uniform Traffic Control Devices (FHWA, 2009). Just like the Green Book, the MUTCD gives no

[29] I discussed this in Hauer (1993 and 1999).

[30] Nowadays it is customary to distinguish between 'substantive' and 'nominal' safety. Substantive is "… that aspect of safety which derives from the count of accidents and their severity" while 'nominal' is "…that aspect of safety which is related to conformance with standards, warrants and design procedures" (Hauer, 1993, p. 6).

[31] To follow form without content is 'pseudo engineering' in the same sense as Feynman spoke of 'pseudoscience': *"In the South Seas there is a cargo cult of people. During the war they saw airplanes land with lots of good materials, and they want the same thing to happen now. So they've arranged to imitate things like runways, to put fires along the sides of the runways, to make a wooden hut for a man to sit in, with two wooden pieces on his head like headphones and bars of bamboo sticking out like antennas—he's the controller—and they wait for the airplanes to land. They're doing everything right. The form is perfect. It looks exactly the way it looked before. But it doesn't work. No airplanes land. So I call these things cargo cult science, because they follow all the apparent precepts and forms of scientific investigation, but they're missing something essential, because the planes don't land."* From RP. Feynman: Some remarks on science, pseudoscience, and learning how to not fool yourself. Caltech's 1974 commencement address.

[32] In the 'Country Report' for the U.S. Hasson et al. (2015) pointedly say that *"Design professionals are faced with many questions for which there may be no clear answers"* and ask: *"How do we balance safety against other community, environmental, economic, or mobility values? How do we determine where compromise is reasonable and if it is possible to trade safety against these? How do we know if the owning agency is at risk for making such tradeoffs? How can one select the preferred solution?"* (Page 7).

[33] Perhaps because they tend to believe that because crashes are almost always the consequence by someone's misdeed they can only be prevented or ameliorated by measures to improve the skills and behavior of road users. This, of course, is not true. Nodding off while driving is indeed a misdeed but the chance of rolling down the slope can be reduced by a lane departure warning system or rumble strip, and mostly prevented by a guardrail.

information about the safety consequences of the choices and decisions the engineer has to make. In traffic engineering the need to balance safety and mobility is center-stage and the MUTCD puts the onus to find that balance on engineering judgment explicitly and frequently[34] . Many of these calls for the application of engineering judgment have safety consequences. To illustrate, Section 2B.04 says that *"Engineering judgment should be used to establish intersection control"* (Page 50). Whether traffic control is by Yield signs, Two-Way Stop, All-Way Stop, Signal (with all the possible variations of phasing and timing) affects road user safety[35] . Similarly, Section 3B.07 says that *"Edge line markings should not be placed where an engineering study or engineering judgment indicates that providing them is likely to decrease safety."*(Page 371).

To form a judgment about what the 'desired combination' of safety and 'utility' might be the highway and traffic engineer would have to be clear about:

a) How a choice or decision is likely to affect safety (and 'utility');
b) How to trade life and limb against 'utility'[36] .

And so the concern in the title of this section is not about the sight-distance policy coined many decades ago. The concern is that engineers make many decisions that affect road user safety, that in making these decisions they need to find a 'desired combination' of safety and 'utility', that the task of finding the desired combination is entrusted to their engineering judgment, and that to judge what the desired combination requires the competencies in (a) and (b) which most highway and traffic engineers may not sufficiently possess. Whether they do, is discussed next.

3.5. On acquiring engineering judgment for decisions affecting road safety

Engineering judgment is acquired in two ways: from 'experience gained as an engineer' and from 'knowledge gained as an engineer' (Baybutt, 2018). For decisions that affect the safety of road users, engineers need to form two kinds of judgment: a judgment about what are going to be the *safety* consequences of their choice and judgement about what is the right balance between safety and 'utility'. This suggests the following two-by-two section structure:

Engineering Judgment	From experience	From knowledge
About the safety consequences of choices	3.5.1	3.5.2
About the balance between safety and 'utility'	3.5.3	3.5.4

3.5.1. Judgment about safety effect gained from experience

Engineering judgment is called upon when there are several options of which one needs to be chosen. Using earlier examples, the choice may be of the design speed for a curve, the decision whether to signalize an intersection or leave it stop-controlled, the option to edgeline or not to edgeline a road, etc. Judgment is gained choice-by-choice, decision by decision. To gain in judgment one must know what the consequences of that choice or decision were. When the decision was one that affected road user safety then, to learn from it, one must know how their safety was affected.

To know how an implemented decision affected road user safety is difficult. An engineer may choose the design speed for many curves but will not know how different their safety would have been had a different speed been chosen. An engineer may change the traffic control at many intersections, but without investing time in counting 'before' and 'after' traffic conflicts he or she will not be able to assess how their safety has changed. An engineer may decide not to edgeline a certain road segment thinking that doing so would harm safety, but will never find out whether this was the right decision. Without knowing how one's choices and decisions have affected road user safety there can be no learning from personal experience, no gain to one's engineering judgment[37] .

The engineer could resort to the use of surrogates[38] . One could measure how speed or traffic flow was affected, how conflict frequency has changed, how sight-distance was altered, how marking visibility was modified, etc. Then, assuming that it is known how a change in the surrogate affects safety, one could infer what the safety consequence of a choice or decision was and thereby improve one's engineering judgment.

Unfortunately this path to enlightenment is both uncommon and limited. It is uncommon because only rarely does the engineer collect the required before-and-after-the-change surrogate data. It is limited because inferences of this kind are possible only when there is a change or difference to observe; when the choice does not involve change or difference (e.g. when a design speed is chosen or when the decision is not to change traffic control or not to edgeline a road), the possibility to compare surrogates does not exist. Another limitation is that few surrogates have a known relationship to safety. One may fairly confidently assume that reducing mean speed by 'X' reduces crashes of a given severity by 'Y'. One can make a similar assumption about the safety consequence of a change in traffic flow. However, whether traffic conflicts and crashes go hand-in-hand depends on what one decides is a 'conflict'[39] . How close the relationship between sight-distance and safety is, depends on circumstances[40] . That increasing the visibility road markings always enhances safety is in doubt. An additional difficulty is that surrogates seldom change singly, that people adapt to

[34] 'Engineering judgment' is mentioned in the MUTCD some 150 times. Its importance to practitioners is well illustrated by the following episode. The 2003 edition the MUTCD said that no matter what guidance for the design and application of traffic control devices it contains, these *"…should not be considered a substitute for engineering judgment"*. The FHWA changed this unlimited freedom in the 2009 edition saying that *"Standard statements shall not be modified or compromised based on engineering judgment or engineering study."* This created an uproar. The AASHTO Board of Directors and the National Committee on Uniform Traffic Control Devices requested that the new language be removed and the 2003 language used. This forced the FHWA issue an 'Official Interpretation' (Lindley, 2010) which tries to accommodate the concerns expressed, promises to consider proposals for revised language for future editions, and recognizes that *"…the use of engineering judgment and studies is a fundamental tenet of the application of traffic control devices."*.

[35] The MUTCD lists five factors to be considered by the engineer in choosing the appropriate traffic control. Surprisingly, the expected safety consequences of the choice is not one of them.

[36] Cost, mobility, perception of personal safety, environmental amenity, etc.

[37] The problem is that crashes are rare and their count of crashes is subject to random fluctuations. This is why, the 'safety' of a unit (a curve, an intersection, a road, a driver, an age cohort) is defined as the *expected* crash frequency by severity would be if it was possible for all causal influences to remain unchanged. Expected values can be estimated but cannot be directly observed. For detail see Hauer (1997, Section 3.2) and Hauer (2015, Section 1.1). In this reality it takes an expertly conducted and expensive special-purpose research study to estimate the safety effect of some action and even then only the average effect over many road miles or intersections can be reliably estimated.

[38] Safety surrogates are phenomena that are causally related to safety and can be sufficiently reliably observed.

[39] Some commonly used 'conflicts' are brake application, evasive maneuver, time to collision and post encroachment time. The correlation between these and the count of crashes varies.

[40] To the authors of (AASHO, 1940a, 1940b) the existence of a causal relationship must have seemed self-evident. But Harwood and Bauer, 2015 find that on crest curves sight distance is unrelated to safety except when there are driveways, intersections or other features that may cause vehicles to slow down or stops. Eccles et al. (2017) find that "Early studies of intersection sight distance found that removing sight obstructions reduced crashes as much as 30 to 67 percent. … .More recent studies have found that increased ISD results in more moderate crash reductions … and perhaps even adverse effects. … an expert panel determined that improving limited sight distance in each quadrant of the intersection can reduce total crashes by 5 to 17 percent." (page 5).

change in complex ways, and therefore the final outcome is at times unexpected and difficult to anticipate.

The fact that differences and changes in safety are not directly observable, that engineers only rarely observe surrogates, that they can be observed only when there was a change, that trustworthy safety-surrogate relationships are few, and that only seldom does only one surrogate change while all others remain constant, makes learning about the safety consequences of choices and decisions from personal experience difficult. For all these reasons I conclude that *no significant gain to engineering judgment about the safety consequences of choices and decisions comes from experience gained as an engineer*[41] .

3.5.2. Judgment about safety effect gained from knowledge

The other possibility for developing engineering judgment about the safety consequences of choices and decisions is from knowledge gained as an engineer. Such knowledge can be gained before graduation, and later in practice.

Before graduation civil engineers typically have one semester of highway engineering and one of traffic engineering. In the highway design course they mostly study the approach and procedures of the Green Book[42] . Since the Green Book does not provide information about the safety consequences of design choices and decisions students will be familiar only with speculative notions of safety akin to that in the story told in Section 2. In the traffic engineering course students will spend almost all their time on issues related to traffic flow, speed, capacity, delay, traffic control, etc. Most likely nothing will be said about the safety consequences of the choices and decisions that a traffic engineer has to make.

The upshot is that rookie engineers walk into practice not knowing how their actions will affect the safety of others. What they are taught engenders the belief that the interest of road user safety is served by following the procedures and spirit of Green Book and the MUTCD; that the rest is the road users' responsibility. This is the wrong belief to have to begin with, and it is likely reinforced by practice. In this reality, possession of factual knowledge about the road safety consequences of their choices and decisions can come only from study and training after graduation.

The need for training in road safety was recognized around the turn of this century[43] . At that time there was some fresh thinking and support for the notion that road safety management should be evidence-based[44] . The thinking was that the transition to evidence-based road safety management requires a knowledgeable workforce[45] . A task force was set up at the Transportation Research Board and it initiated work about what are the required core competencies for such a workforce (Jovanis and Gross, 2006). A model curriculum for the core competencies was developed (Cambridge Systematics, 2010), and taught a few times. The task was taken up by the Road Safety Academy at the UNC Highway Safety Research Center. A textbook was written (Carter, 2017) and once or twice a year a distance learning course is offered to about 25 participants. A new and current initiative by the Institute of Transportation Engineers is to provide certification as a Road Safety Professional for those who will pass a written examination.

All these activities were and are aimed at professionals with special interest or responsibility in road safety management. They were not aimed at the 100,000 or so highway and traffic engineers now in U.S. practice; engineers whose judgments, choices and decisions affect road user safety. The absence of suitable large scale training in evidence-based road safety for highway and traffic engineers was a lacuna even when adherence to the standards and warrants of the Green Book and the MUTCD was the dominant norm. Now that the dominance diminished, attitudes have changed, and engineering choices and decisions need to be informed by their road user safety consequences, the absence of training in road safety is an obvious gap.

That during the past two decades attitudes have changed and evidence-based practice is more in vogue can be gleaned from the pages of ITE (2015); it speaks explicitly and unequivocally of the need to design and operate roads with 'substantive', not 'nominal' safety in mind[46] . Working with substantive safety requires engineering judgment to be based on knowledge. ITE (2015, Section 9.2.3) enumerates the demands placed on such engineering judgment. It says that the engineer must use appropriate and reliable sources of knowledge; that the engineer must fully understand the methodology used in measuring quantitative safety; that there is to be an analysis that cannot contain errors, use incomplete data, or misapply formulae; that results that are counterintuitive should not be automatically thought incorrect but should be subjected to rigorous verification; that only that judgment which satisfies the aforementioned conditions is sound engineering judgment.

In sum, engineering judgment about road safety consequences of choices and decisions can be acquired neither from personal experience nor from the beliefs acquired by training in and practice based on the Green Book and the MUTCD. The only source of sound engineering judgment is the study of the available evidence. Two observations follow:

> First, that highway and traffic engineers who did not study and do not know what the available evidence says about the road safety consequences of their decisions can have opinions and beliefs in that matter but they cannot possess the requisite engineering judgment.
> Second, a large-scale and evidence-based training program has to be developed and made a requirement for engineers whose decisions and choices affect road user safety.

3.5.3. Judgment about balancing safety and 'utility' gained from experience

Nearly every engineering choice and decision that affects road user safety also has 'utility'[47] consequences. Therefore, in balancing safety and 'utility', highway and traffic engineers have a great deal of practical experience. This balancing is by a subliminal process in which an incomplete awareness of the various consequences is mixed in with a

[41] Except, of course, if that experience is that of studying the safety consequences of engineering choices and decisions.

[42] I retired from teaching civil engineers in 1997 and know only what was true at that time. But a survey of undergraduate and graduate programs in civil engineering offered at U.S. universities (Jovanis and Gross, 2006) confirms my own experience.

[43] In 2002 a 'Highway Safety Workforce Planning Workshop' was convened in San Antonio, Texas.

[44] Around 1997 the FHWA took the first steps to assemble the necessary information for developing a software (the Interactive Highway Safety Design Model, FHWA, 2018) that would enable engineers to predict the safety of design alternatives. The public release of the IHSDM software was in 2003. The reader may find it surprising that till then engineers did not and could not know how alternative road designs differ in crash frequency and severity. Around the same time (in 1999) another initiative materialized. A workshop was held to determine "…the need for and nature of" a document on the subject of "predicting the highway safety impacts of highway design and operation" (AASHTO, 2010, page xxiii). This document, the Highway Safety Manual, also for the first time in history assembled much of the requisite knowledge. (The second edition of the HSM is now in preparation.) The third important step to support the transition to evidence-based road design and operation was the establishment (circa 2009) of the Crash Modification Factors Clearinghouse. This online service provides continuously updated information about what research found to be the safety effect of decisions, choices and countermeasures. It can be accessed at www.cmfclearinghouse.org.

[45] See e.g. Hauer (2002).

[46] Nominal safety is the adherence to standards and warrants such as those in the Green Book and the MUTCD while substantive safety is measured by the expected number of crashes and their severity; see also footnote 30.

[47] 'Utility' stands for consequences in cost, mobility, security (perception of personal safety), environmental amenity, etc.

personal perception of the prevailing professional practices and traditions[48] and, occasionally, with external pressures[49] . To learn from such an experience one would have to know whether the safety-'utility' balance struck was right or wrong. But no opportunity for such feedback exists. Therefore no matter how often an engineer trades safety for 'utility' there is no gain to judgment.

3.5.4. Judgment about balancing safety and 'utility' gained from knowledge

If experience does not build engineering judgment for balancing safety and 'utility', could it perhaps be acquired by study? To answer I have to be clear about what knowledge could nurture this kind of judgment.

One possibility is to assume that existing standards, warrants and practices, being the reflection and result of deliberations by a succession of committees, are the embodiment of the right balance. Were this so the engineer's judgment about how to balance safety and 'utility' could be improved by the study of current practice and of documents such as the Green Book and the MUTCD. However, as I argued throughout this paper and particularly in Section 3.5.2, current standards, warrants and practices are the carriers of 'nominal', not of 'substantive' safety. Neither an individual nor a committee can appropriately balance road user safety and 'utility' without evidence about how a decision will affect road user safety. Only those elements of current practice that are based on the precepts of 'substantive' safety, those that use evidence about the effect of decisions on road user safety and are not burdened by attitudes of the past[50], can serve as knowledge for the purpose of study and development of sound engineering judgment.

Another possibility is to assume that the right safety-'utility' balance can be identified by some quantitative means such as a cost-benefit analysis[51] . If so then to nurture and enrich the engineer's ability to judge what the right safety-'utility' balance is would require the study of the results of such cost-benefit analyses done in a variety of circumstances. That opportunity for such study does not now exist is evident. Nor is it clear that quantitative tools such as a cost-benefit analysis can capture the many non-market consequences and local considerations.

Neither the study of documents describing current practice nor the study of documented cost-benefit analyses seems to be a viable source of knowledge for building engineering judgment about how to balance safety and 'utility'. This is a quandary. As I wrote in Section 3.2, in most of engineering injury is rendered very rare by design so that one need not be explicit about trading health for 'utility'. When the need to do so cannot be avoided, formal means such as risk analysis are available. Only highway and traffic engineers have to trade injury for mobility and other aspects of 'utility', only they must do so frequently, and only they are required to do so on the basis of engineering judgment. All this whilst neither their training nor their professional DNA prepares them for the task.

3.5.5. On engineering judgment for balancing safety and 'Utility'. Summary

In the preceding four subsections I discussed in some detail why the competencies for balancing safety and 'utility' are difficult to acquire. Here I summarize and draw conclusions.

Judgment is acquired by experience and by study. To learn from experience one must know what the consequences of one's decisions were. To acquire judgment by study the opportunity to do so must exist and be used. For highway and traffic engineers neither condition is met.

In Section 3.4 I gave voice to the concern that judgment about the 'desired combination' of safety and 'utility' requires competencies which engineers may not sufficiently possess. The concern is now substantiated. Neither by study nor by experience do individual engineers acquire the competencies necessary to judge what the right balance of road user safety and 'utility' should be. And yet current professional practice asks them to do so. One must ask: What are the ethical ramifications of exercising judgment that is based on beliefs for which there is insufficient evidence?

3.6. The ethics of belief

Members of the AASHO committees had to write a road design policy for sight distance. They did not know how sight distance affects safety but thought, sensibly, that drivers should see far enough to safely stop for an obstacle in their path. However, as it would be too costly to provide sufficiently long sight distances for all, the committee said that a 'design speed' is to be chosen; those traveling faster, and they are many, may not see far enough to safely stop. This is how the design speed became the carrier of the cost versus safety compromise. But the AASHO committees elected not to say how the design speed is to be chosen; they left this choice to the judgment of the individual design engineers who were even less qualified to judge how the choice of a design speed will affect safety than the members of the AASHO committees. The AASHO committees acted on insufficient evidence. Was this morally wrong?

All US roads are designed by the Green Book and its local variants. All editions of the Green book, including the current one, adopted the idea that a design speed has to be chosen and left this choice to the design engineer's judgment. Many other road design choices that affect road user safety and are also left to the judgment of the design engineer. Highway design engineers, by and large, do not know what the road safety consequences of their decisions are. The same goes for traffic engineers. Is all this morally wrong?

Philosophers continue to wrestle with such questions[52] but I can do no better than to quote Clifford (1977) who opens his still timely[53] essay by a story:

> "A shipowner was about to send to sea an emigrant-ship. He knew that she was old, and not overwell built at the first; that she had seen many seas and climes, and often had needed repairs. Doubts had been suggested to him that possibly she was not seaworthy. These doubts preyed upon his mind, and made him unhappy; he thought that perhaps he ought to have her thoroughly overhauled and refitted, even though this should put him at great expense. Before the ship sailed, however, he succeeded in overcoming these melancholy reflections. He said to himself that she had gone safely through so many voyages and weathered so many storms that it was idle to suppose she would not come safely home from this trip also. He would put his trust in Providence, which could hardly fail to protect all these unhappy families that were leaving their fatherland to seek for better times elsewhere. He would dismiss from his mind all ungenerous suspicions about the honesty of builders and

[48] Engineers are usually well aware of costs and, by training and practice, of delay and travel time. Less easy to quantify, and therefore perhaps less prominent, are safety, security, environmental amenity and similar consequences.

[49] This process of forming an opinion may or may not deserve to be called engineering judgment.

[50] In the past the consideration of automobile mobility tended to eclipse environmental, societal and safety considerations. The traffic engineer was "… Detroit's man in the council chambers" (Schneider, 1971, page 47) whose role is to keep traffic moving and to ensure the growth in automobile use.

[51] Here I am on thin ice. I doubt that econometric estimates of the value of life and injury are any good. (Hauer, 2011a; Hauer, 2011b, and Elvik, 2018). If we are right then how good can the computed balance be?

[52] For a review see 'The Ethic of Belief' by Andrew Chignell in the Stanford Encyclopedia of Philosophy online (https://plato.stanford.edu/entries/ethics-belief/

[53] Uribe (2018) says that "…reality has caught up with Clifford. His once seemingly exaggerated claim that 'it is wrong always, everywhere, and for anyone, to believe anything upon insufficient evidence' is no longer hyperbole but a technical reality".

contractors. In such ways he acquired a sincere and comfortable conviction that his vessel was thoroughly safe and seaworthy; he watched her departure with a light heart, and benevolent wishes for the success of the exiles in their strange new home that was to be; and he got his insurance-money when she went down in mid-ocean and told no tales.

What shall we say of him? Surely this, that he was verily guilty of the death of those men. It is admitted that he did sincerely believe in the soundness of his ship; but the sincerity of his conviction can in no wise help him, because he had no right to believe on such evidence as was before him. He had acquired his belief not by honestly earning it in patient investigation, but by stifling his doubts. And although in the end he may have felt so sure about it that he could not think otherwise, yet inasmuch as he had knowingly and willingly worked himself into that frame of mind, he must be held responsible for it."

Clifford is the iconic representative of strict Evidentialism and believes that one earns the moral right to believe something only if the belief is based on evidence obtained by 'patient investigation'. Moderate Evidentialists allow exceptions. They would agree with Clifford when a belief leads to action that has morally significant consequences (e.g. the choice of a design speed) but will allow the legitimacy of belief for which there is no evidence when not much is at stake. On the whole, however, *"Evidentialism of some sort is far and away the dominant ethic of belief among early modern and contemporary philosophers alike"*. (Chignell, 2018)

Also relevant to engineering judgment and the transition of highway and traffic engineering from 'nominal' to 'substantive' safety[54] is Clifford's closing salvo:

"If a man, holding a belief which he was taught in childhood or persuaded of afterwards, keeps down and pushes away any doubts which arise about it in his mind, purposely avoids the reading of books and the company of men that call into question or discuss it, and regards as impious those questions which cannot easily be asked without disturbing it–the life of that man is onelong sin against mankind."

Anything I could add would lessen.

3.7. Judgment versus protocol

In Section 3.4 I expressed concern about most engineers not having sufficient competencies for forming judgments about decisions that affect road user safety. In Section 3.5 I argued that the concern is justified. In Section 3.6 I questioned the ethics of forming judgments on insufficient evidence. Taken together these strands of reasoning could lead one think that, where road safety is involved, it is best not to rely on the judgment, that in making decisions affecting life and limb evidence-based rules and protocol should play a greater role. Would that be the right conclusion?

What is the right mixture of evidence-based protocol and professional judgment is the subject of lively debate in other disciplines. Thus, e.g., arguing against *"… some current ideologies in health care regarding the primacy of evidence-based practice and the application of protocol"* Coles (2002, abstract) says that*"… professional practice fundamentally involves the practitioner in making judgments"*. He worries that *"practitioners are being constrained (by the media, politicians, and some members of their professions) to engage in forms of practice that diminish the role of reflective and deliberative judgment …. That such a course of action is not in society's best interests.* "(Page 8).

Dunne (2005) sees the same issue as the emergent dominance of 'technical rationality' which is in *"… inherent opposition to practitioners' knowledge"* over 'practical rationality' which is able to *"yield concrete, context-sensitive judgments."* Technical rationality *"… puts a premium on 'objectivity'. … The ideal to which technical rationality aspires, one might say, is a practitioner-proof mode of practice."* Practical rationality, in contrast, relies on judgment which Dunne defines as*"the cultivated capacity to make calls resourcefully and reliably in all the complex situations that they address."*

Dunne concedes that technical rationality is attractive because*the "…objectivity that it adheres to seems to make it proof against intrusions of the merely subjective. … The prediction that it enables and the control that it guarantees provide unambiguous criteria for establishing accountability and assessing success…."*Furthermore, that *"…technical rationality seems to accord with the fabric of the material"* and that it "*…is most at home with the activity of production or fabrication, where there are materials* …."

But what about practices such as transportation engineering that do not deal only with materials but in which prominently *"include volatile constellations of human passions and motivation"*? Dunne asks whether attempts to impose technical rationality *"on the very different reality of human practices spring from a considered understanding of this reality itself, or from an* a priori *enthusiasm (even obsession) to have in these areas the same kind of standardisation and control which, partly through technical rationality, we have in our dealings with some aspects of the material universe?"* But Dunne does not say wherefrom does his practitioner or policy maker, those whose subject matter are 'human passions and motivation', draw the wisdom and the cultivated capacity to make the decisions. Nor does Dunne offer any assurance that attempts to impose technical rationality in such situations would not, on the whole, serve society better.

At the beginning of this section I asked whether in view of the identified shortcomings of engineering judgment it might be best to rely on judgment less and trust protocol more. Of course, reliance on protocol also has weak spots. In road safety, center-stage are "*human passions and motivation*". The predictions which protocol can provide reflect all the difficulties of predicting human responses as individuals and in groups. In addition, the circumstances to which decisions apply usually differ significantly from these from which the data at the basis of evidence-based protocol were obtained. To illustrate, while periodic motor vehicle inspection was found to be ineffective in Norway the Italian representative to the EU judged that it would be effective in Italy.

Still, one must keep in mind that engineering judgment about the road safety consequences of decision cannot be extracted from individual experience; it can only come from the study of the same evidence that is (should be) used to create evidence-based protocols. It follows that the collective wisdom of protocols should be primary. The main role of judgment by individuals is to adapt the protocol to specific circumstances. Doing so requires more than thorough familiarity with the extant evidence. As Dunne says, "*Judgement is more than the possession of general knowledge, just because it is the ability to actuate this knowledge with relevance, appropriateness, or sensitivity to context."*

So far I considered the roles of judgment and of protocol when the task is to predict what are likely to be the safety consequences of decisions. When it comes to the other task, that of balancing safety against 'utility', the considerations are similar. Here one has to compare the ability of judgment versus that of protocol to identify the right safety-'utility' balance. The conclusion, however, is different. As I do not see what endows a highway or traffic engineers with a 'cultivated capacity' to trade safety against 'utility' I think it better to rely on protocols formulated by properly constituted committees[55] . It was wrong for the

[54] See Section3.5.2.

[55] What makes for a properly constituted committee to formulate protocols for use by professionals is an important question that merits a thorough and separate discussion. Some principles, however, are self-evident. First, if the protocol affects road user safety, road users should have an influential say. Second, the committee should be insulated from the influence of commercial

AASHO committee in 1940 to assign the task of balancing safety against 'utility' to individual engineers as it is wrong today for the Green Book and the MUTCD to do the same.

4. A brief closure

The gist of the argument is this: Professional practice requires highway and traffic engineers to use their judgment for making decisions that affect the safety of road users. One would like this judgment to be informed by knowledge of what the safety consequences of engineering decisions are likely to be, and by an unbiased ability to balance safety against mobility and other dimensions of 'utility'. These desiderata are largely unfulfilled.

Highway and traffic engineers graduate without knowing what the safety consequences of their decisions will be and their subsequent practical experience does not tell them what they were. This is why, without specialized training, engineers cannot have good judgment about how what they do will affect the safety of road users.

Engineers know how to quantify the money cost and mobility consequences of their decisions. Safety consequences, however, are seldom quantified and are judged mostly in the light of conformity with standards and warrants. This is an inadequate foundation for forming a judgment about how to balance safety and 'utility'.

Two conclusions follow. First, that one should not ask engineers to do what they cannot professionally do. It is the job of the 'protocol' setting committees to know what the relevant safety consequences are and to balance evidence-based consideration of road user safety against 'utility'[56] . Second, standards and warrants apply 'on the average' and in specified conditions. It is the job of individual engineers to use judgment to adapt these to local circumstances. This task requires continuing familiarity with available evidence and specialized training.

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(*footnote continued*)
interests. Third, the committee should have members who well know the extant evidence, understand its strengths and limits, and can explain it to others.

[56] That in the 1940s the AASHO committees failed in this respect is understandable. That the subsequent committees issuing the Green Book and the MUTCD failed and fail is less so.