Traffic and Accidents: Are The Risks Too High?

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Professor Michael G H Bell, Imperial College, in the Chair
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Professor Rod Kimber

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Abstract

Whereas it has been common practice to assume that behavioural change is the primary remedy for road accidents, in fact, big reductions can come from engineering the vehicle or the environment so as to remove the consequences of human error. Because of this, it makes little sense to speak of human error in isolation, and it is much better to tackle the human-vehicle-road system as an entity. This greatly increases the potential for progress.

The question how to reduce the risks associated with road travel is pursued using two categories: in the first by identifying risks associated with the human-vehicle-road system, counting ‘routine’ human error as an integral part, and in the second by identifying the risks associated with ‘non-routine’ human error, defined as inexperience error and error of ‘excess’ (drink-driving, speeding, and other aberrant behaviours). The relationships between the measured risk and the underlying behavioural influences (deriving from factors such as inexperience, blood alcohol level, relative speed) provide a basis for differentiating between the categories. Work on the quantification of risk with respect to behaviours and road and vehicle design is described within this framework.
Thank you Chairman. It is a pleasure to be here. Many thanks to Imperial College for inviting me to speak this evening and for hosting this event.

I plan to speak about road safety: in particular how we can get a better picture of where the risks lie, and what our general approach should be to reducing them.

What I want to argue is that whereas it has been common practice to assume that behavioural change is the primary remedy for road accidents, in fact, big reductions can come from engineering the vehicle or the environment so as to remove the consequences of human error. Because of this, it makes little sense to speak of human error in isolation, and it is much better to tackle the human-vehicle-road system as an entity. This greatly increases the potential for progress.

Introduction

In many senses, Road Safety has been one of the big success stories through the latter part of the 20th Century and into the 21st Century. But it is presentationally an uncomfortable subject because many people who are saved by safety measures don’t know about it, whereas the families of victims certainly do.

Although in relative terms they are rare, accidents are very real events. You can see from Figure 1 the types of forces involved, and they are large in relation to bio-mechanical strengths. Despite going into the windscreen backwards the child here would not have survived. People sometimes think they could restrain themselves in a crash by muscular effort alone, or for...
example hold a child safely on their lap in the back seat. To put this in context, consider what it would be like to dive off a three-story building onto a concrete pavement below. Attempting to use muscular restraint inside a crashing car is like trying to cushion the impact by doing a hand-stand just before you hit the pavement, head-down. It's not possible.

At the crassest level the national balance sheet looks roughly like this.

![Figure 2: The national (GB) balance sheet for travel and casualties](image)

<table>
<thead>
<tr>
<th>Road Travel</th>
<th>Road Casualties</th>
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<tr>
<td>Passenger miles pa</td>
<td>pa</td>
</tr>
<tr>
<td>450 bn</td>
<td>Deaths: 3,500</td>
</tr>
<tr>
<td></td>
<td>Serious injuries: 40,000</td>
</tr>
<tr>
<td></td>
<td>Slight injuries: 300,000+</td>
</tr>
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In principle, one might be tempted to argue that this isn’t bad: given that there is a huge amount of road travel, and, given that there are around 30m drivers who are not patently selected and trained as, for example, train drivers or airline pilots are, the numbers of accidents are surprisingly low. But the fact remains that in absolute terms these death and injury totals are simply too big for comfort. The other figure worth citing in this context is the lifetime risk for the individual of dying in a road accident. This is about 1 in 200 at present, which is high.

So there is a vivid contrast. From an individual’s point of view the ‘present’ or imminent risk (per hour of exposure for example) is usually very small. The overwhelming everyday experience of driving is that of arriving unharmed. But the integrated risk over significant time periods is high. As a result, the general appreciation of risk across the population is not very rational.

Figures 3 and 4 show what has been happening at the national level—first the number of accidents involving death and serious injury combined (Figure 3), and then with the numbers of fatal casualties shown separately (Figure 4).

There was a reduction in deaths and serious casualties of about 50% over the twenty years from 1980-2000. In the same period traffic rose by about 80%. However, what is more fundamental than the simple national totals is the risk—the frequency of accidents per unit of travel.

Figure 5 shows the time series for the risk of death or serious injury per billion vehicle kilometres. Characteristically its form has been close to a negative exponential with a 6% fall per year. The national total numbers of deaths and serious injuries are the product of this risk with the total traffic movement in billion vehicle kilometres per year (Figure 6).

Risk is not homogeneous. There are a number of forms of road travel: passenger and freight, car, lorry, bike, motorbike, pedestrian. There are a number of classes of road user: private, business; young, old; male, female. And there are a number of different road environments: town, country, high street, motorway. As a result there are many classes of risk, and generally they differ in size and impact. To take an extreme comparison, a child on a bike is about fifty times more at risk of death per mile travelled than when properly restrained in the back seat of a car.

I am not going to veer off into a mass of statistics, though there are a few key ones that I’ll talk about. What I plan to do this evening is to consider, in broad terms, what types of risk there are in using the roads, and how risk can be reduced.
The first question might seem to be: what should we reduce it to? It would be implausible, both economically and physically, to go for zero risk within nearly half a billion passenger miles of road travel per year. So what level would be reasonable?

We might be tempted to think that it should be equal to that for the traditionally ‘safe’ forms of travel—rail, for example. But because road risk is so much higher than rail risk at present (per passenger mile), and because road safety carries not insignificant costs, it makes more sense to consider what steps towards lower risk are feasible, rather than to worry about exactly what the end point should be. This becomes more than ever apparent when one looks at the current investment context for safety across modes. There are huge disparities between investment levels per life saved. For road and rail the official position is that it is worth investing £1.2m per life saved on the roads and £3.5m per life saved on rail, although the new safety systems for rail are expected to cost £10m or more per life saved. In contrast, a recent survey of senior local authority officials (at the previous County Surveyor level) elicited the clear view that working upwards from present investment levels they could, if they had the money available, save lives by local road engineering at the rate of one life per £100,000 of extra investment. There is thus a ratio of up to a hundred in the ‘allowable’ cost of saving a life. Prima facie, the interpretation of the difference in how much we are prepared in practice to invest to save life on road and rail is that it is worth allowing a hundred people to die on the roads in order to save one life on the railways.

This type of argument has not yet persuaded anyone to attempt an explicit rebalancing of investment in transport safety between road and rail, however. Although it might in future help to tilt the funding a little away from the present relativities, it is unlikely to move it to full parity.

Why is there such an imbalance? Part of the reason is that rail is a controlled and ‘closed’ system where passengers in effect sign over the responsibility for their personal risk to the operator. For practical purposes, therefore, specific failures, even if they are rare, are never seen as acceptable. In contrast there seems to be an extraordinary penalty on traffic for being in an ‘open’ engineering system.

The result is that we cannot yet get a sensible answer to the question of how many road accidents per year would be ‘reasonable’ in economic terms. That is, we cannot say what would be a ‘rational’ rate—a rate above which the reduction in death or injury per £1 invested in safety would be greater than for other modes, and below which it would be less. One can arrive at that conclusion quite simply, just by looking at road and rail travel, let alone by making any wider comparison of risk. That is why I am not going to attempt to juggle with parity arguments at a quantitative level.

Instead, I am going to probe where the big risks come from, and try to get a better framework for understanding how to reduce them. What I will argue is that we should move towards a less open system in engineering terms.

The need to understand cause

The first question to address is what lies beneath the national trends? I do not mean what the disaggregate trends are, but what are the general ‘causes’ of accidents? You would be surprised how difficult it is to answer such a simple question. Unlike in air or rail crashes, there is rarely a detailed forensic investigation of road accidents. Whilst road deaths are nowadays getting more detailed attention, for most road accidents there are at best incomplete witness accounts, and in some cases a pretty crude opinion by the police attending the scene, after the event.
The old causal picture; driver error as predominant

In early on-the-spot accident studies (where expert teams get to the accident scene as quickly as possible by using a fast response vehicle, and attempt to reconstruct what actually happened before the evidence has disappeared) the usual approach was to classify the apparent causes into failures of the driver, failures of the vehicle and failures of the road. More than one type of failure could be present in a given accident.

Figure 7 shows the concept: three partially overlapping sets of causes. Researchers are sometimes a bit cagey about using the word ‘cause’. Sometimes they say ‘principal factor’—but that does not matter too much for the moment. When the numbers were arrived at by classifying the data subjectively, the sets looked like those in Figure 8. In those terms, the picture to emerge was that driver error dominated. It was said to be present in 95% of all accidents and the main factor in more than two thirds of them.

Now, it is certainly true to say that, more-or-less always, the accident could have been prevented by the driver doing something differently, at some stage. For example, pure vehicle failure, like a wheel unexpectedly dropping off, or sudden brake failure, is rare. The issue with this picture is whether it really helps in any material sense. The causal chains leading to an accident might in principle be interrupted at a number of points. The picture focused so much attention on driver behaviour that interventions with potentially greater effect were easily overlooked. Moreover, driver behaviour is such a wide category that it is easy to populate it by default when the evidence is incomplete, for want of any better explanation.

Because of the predominance of driver failure in these classifications, the main priority for a long time was thought to be to put the driver right, that is to concentrate on measures to change driver behaviour so as to eliminate the failures. This view, in which the focus of attention was correcting driver behaviour as a first priority rather than re-engineering other parts of the driver-vehicle-road system, began to change in the mid-1980s in Britain; but it has been a long haul and a belief in the primacy of driver error still remains predominant in too much of the thinking, particularly abroad. I do not think this approach served us at all well. It arose out of weak categorisation and out of confusion in the concept of ‘cause’.

A better model—the ‘system’ model, where (driver-vehicle-road) replaces (driver)

I think a much better picture would be that shown in Figure 9.
There are two main changes:

- **Firstly:** ‘system’ replaces ‘driver’ for most failures: the driver-vehicle-road system.

- **Secondly:** the more serious ‘pure’ or predominantly driver failures are a much smaller part of the whole; they are confined to ‘excesses’ and to inexperience. This is not to say that we can ignore the role of the driver within the main circle—it is still crucial to the system aspect. But we need to treat the driver failure part of the system failure far more as being routine than previously—it will be present routinely, and we should set out to cope with it better.

The argument runs something like this. Drivers routinely make errors or mistakes. These are relatively infrequent, but even a well trained, sober, alert driver will make such errors from time to time. When the circumstances of road and vehicle allow, these errors translate into collisions, sometimes with injury or death. Whilst driver training seeks to minimise such errors it cannot eliminate them.

Some drivers also make mistakes from sheer inexperience. These mistakes are markedly more frequent and often more serious than the routine mistakes of experienced drivers. These we call ‘inexperience failures’.

Some drivers also make mistakes in association with aberrant behaviour—driving when drunk, tired, or under the influence of drugs, or from a conscious choice to violate specific rules or to behave unreasonably in other respects (running a red traffic light, speeding, etc.). The frequency and seriousness of such mistakes is markedly higher than for routine error. These we call ‘failures of excess’.

Across the population, the risk of involvement in an accident involving death or injury rises with inexperience or excess. Where they have been determined, the risk relationships chart this rise. I will show them for drink-driving and driving too fast in a moment. Generally speaking, there is a continuous relationship in which risk increases progressively as the behaviour worsens. For the inexperienced driver, risk declines progressively as experience is gained; looked at conversely the worse the inexperience the higher the risk.

I believe these three types of failure should for practical purposes be considered separately. Excess and inexperience failures need to be reduced by behavioural measures, but it is generally more practical to consider the residual routine failure as part of the driver-vehicle-road system, and to apply measures to the vehicle and the road that while seeking to minimise the occurrence of errors also reduce or remove the consequences of those errors that will still occur.

An analogy may help explain why routine failure should be treated differently. In the industrial revolution, factory workers frequently suffered injury when operating machines. Mostly such accidents could be ascribed to human mistakes of one sort or another. Many injuries to machine operators, for example, would have been avoided if they had not placed their hands too closely to the exposed working parts of the machine. In those terms, the cause was behavioural. But experience showed that the only effective solution was to fit safety guards to the machines. These protected against inadvertent error by preventing the damaging consequences. In retrospect this seems an obvious step. But it goes in quite a different direction to the categorisation that has dominated road safety for a long time and still emerges far too often—in which the cause has been seen as behavioural and the potential solution as behavioural change.

To construct a new picture, I am going to start by first identifying the inexperience and excess failures. Then I will go on to see how the road and vehicle performance can be built in, so as to lead to solutions which reduce the effects of routine driver failures, or circumscribe them altogether.

**How to recognise ‘excess’ and inexperience failure**

**The nature of failure in relation to accidents**

To start, we need to take a closer look at driver error.

Figure 10 illustrates the frequency of failures and the severity of the consequences. Errors are present at all levels. The triangular shape depicts the frequency by the width (frequency increases towards the base) and the severity of the consequences by the height from the base (severity increases towards the apex).
At the bottom of the triangle, well below sea level, there is a wide range of normal driving activity. At the next level up come driver errors—they are relatively infrequent in the normal driving environment, and mostly do not lead to accidents or to police interest, in any case. At the next two levels up are the more dangerous errors and violations and then the offences: some of these will apply to aspects of more-or-less routine behaviour, but some will be for severely aberrant behaviour. At the next level again these are followed by near-misses where there is some heavy braking or swerving, but no collision. Above ‘water level’ we get real accidents; at the lowest level they simply damage vehicles or property, but at higher levels they result also in injury, in three broad classes:

- ‘slight’ – a sprained wrist, minor abrasions, etc;
- ‘serious’ – anything from a broken bone to near-fatal injuries;
- finally, fatalities.

The relative frequencies for crashes are given down the side: i.e. there are 11 times as many accidents involving serious injuries as there are involving fatalities, about 70 times as many involving slight injuries, and so on.

Over the last few years, and particularly recently, there have been some big advances in understanding which are beginning to allow us to map risk more quantitatively. In outlining some of them, I will concentrate on the broadly quantified risk areas rather than the psychological theory.

**Inexperience failures**

Several major factors underlie the risks at a personal level, and we have to pin these down before we can be more specific about behaviours.

These factors shown in Figure 11 cover the range from the most basic—age, gender etc.—through to personality traits and lifestyle issues. I am going to concentrate on aspects of the first three: age, experience, and exposure, and then go on to temporary states. Unless these first three are properly pinned down, they can easily drown everything else. They have a very basic importance. The last three open up a wide range of issues that I am not going to go into—

I should say that this list of factors is just one way of looking at the accident liability. It starts with the simpler ‘demographic’ types of variable and moves towards behaviours, psychological proclivities or traits, and the more socio-economic lifestyle aspects. Better categorisations can certainly be arrived at. For example, factors such as age and gender are in principle proxies for more fundamental behavioural factors. The arguments I am making do not, however, turn on the distinction; it is sufficient to focus on the broad descriptors.

A key result to emerge over the past ten years is the first fully successful separation of the effects of age and experience—Figure 12.

On the first horizontal axis we have the driver’s age in years; on the horizontal axis into the diagram we have the length of driving experience in years; and on the vertical axis we have the numbers of accidents per year per driver. The empty cells in the left foreground simply denote that drivers cannot for example have thirty years of driving experience if they are only thirty-five years old.
The obvious effects are that accident liability declines both with age and experience. The two are strongly correlated and there are few studies I know of that so clearly manage to separate their effects on liability.

The numbers of accidents per driver year, as plotted, is generally the quantity of interest to insurance companies (and parents!). These data show them directly, and are not normalised for differences in the annual mileage driven, which in fact varies strongly between individuals, and is itself correlated with age and experience. Young and inexperienced drivers on average drive fewer miles per year than older and more experienced drivers. The effect on the accident frequency is something like a fourth root law in the mileage driven per year. The rolled-up effect in the figure is to have flattened the peaks somewhat. If one were to plot accidents per kilometre driven on the vertical axis then the differences would be even starker.

If we remove the differential effects of the mileage driven per year and replot so as to enable us to follow an individual gaining experience and/or aging, the age-experience effect then looks like that shown in Figure 13.

For novice drivers, the pure age effect is the upper line. An average individual who started driving at 18 would follow the first steeply descending curve; and so on. Experience has a substantially faster effect than age. For example, it takes an 18 year old about two to two-and-a-half years to gain sufficient experience to be as safe as a thirty year old novice. The main point, however, is that we can now quantify these effects; and they are large.

**‘Excess’ failures**

Let us now move on to ‘excess’ failures. The main sources of such failures are listed in Figure 14.

### Drinking and driving

The risk factors associated with drinking and driving are well established. As Figure 16 shows, at 80mg/100ml blood alcohol on average one is much more than ten times more at risk of being in a fatal accident than at zero blood alcohol. Even below the limit there is substantially elevated risk, down to 20mg/100ml.
Drugs

Drugs of abuse are coming up the agenda. The frequency with which we find drugs in fatally injured drivers is now six times what it was ten years ago. In about two-thirds of cases it is cannabis that we find. We now know quite a lot about the impairing effects of cannabis on the driving task, when it is active. The problem at present is knowing whether it was active at the time of the accident, since whilst the effects are short-lived, the products remain in body tissue for weeks after ingestion. Other drugs have a range of known psychological effects, but their role in road accidents is far less well-known. The risk relationships have not been quantified. It is a complicated subject, and more work is needed.

Mobile phones

Our tests on the driving simulator indicate that using a hand-held mobile phone when driving produces about the same degree of impairment as a blood alcohol level at the legal limit. It is a big effect. Hands-free operation is only slightly less risky.

Fatigue

Much work has been done on the effects of sleep deficit on the performance of aircraft pilots, and a good deal has now been done for drivers as well. Whilst in the context of road accidents it is often difficult to assemble evidence of fatigue after an accident, recent high profile cases have drawn attention to the obvious risk factors. It is believed to be endemic in the driving population, with estimates that in some circumstances as many as ten percent of drivers are involved in sleep-related accidents.

Speed and risk

Speed has come into the news a lot lately. In research terms, it emerges as a powerful influence on accidents. It can also be used as a control variable: that is, we can use speed control as an intervention to reduce accidents. This causes public reaction in some quarters:
whilst most people accept the risks of speed, some of the more extreme lobbies argue—for rather eccentric reasons—that it hardly causes accidents at all. Whilst these arguments have not appeared in the serious scientific literature they do find their way into the popular press. To some extent they arise out of difficulties with the statistical notions of influence and cause. I am not going to pursue that now, but instead simply proceed to the risk factors.

Speed affects accidents in two ways. Firstly, at impact, vehicles have only a limited capacity to absorb kinetic energy without the occupants being injured, and since the kinetic energy varies as the square of the speed, the risk of death or debilitating injury is a very sensitive function of speed. I will come onto vehicles later on. Secondly, greater speeds increase the likelihood of misjudgement and reduce the time available for a driver to correct an error on his behalf or someone else’s. Thus, in a given set of circumstances, we would expect the frequency and severity of accidents to increase with speed. The whole point here isn’t so much whether it happens, as what kind of relationship it is. That is essentially a quantitative question. As it turns out it is quite complicated to answer, and over the past few years there have been some large research programmes devoted to it.

The results take three general forms.

Firstly, the relative speed, $S_i = V_i/V$, adopted by an individual driver $i$ (where $V_i$ is their actual speed and $V$ is the mean speed of the traffic in the stream in which the vehicle is driving) is strongly associated with the risk of being involved in an accident. Figure 19 shows on the horizontal axis the observed speed of drivers relative to the average and on the vertical axis the accident frequency for those same drivers over the previous three years, again normalised with respect to the average. The relationship follows something like an exponential form in the speed. For drivers at 25% above the average speed, the risk has gone up by seven times.

The second form of result is that shown in Figure 20.

![Figure 20: The average frequency per year for stretches of roads of a given type against the mean speed of traffic on the stretch](image)

Here we have the accident rate (per kilometre per year) for all of the traffic on a particular stretch of road in relation to the average speed of traffic on that road. In the cases illustrated, for rural roads, there is a family of curves depending on the road quality, with a risk dependence for a given quality varying roughly as the square of the speed.

The third form of result is from before-and-after studies on public roads where a speed limiting intervention has been applied. The results of two types of such interventions are summarised in Figure 21. Although the comparison, before and after, is complicated by other factors, and the accident sampling takes some time, the experience is that where actual speed reductions are achieved, the accident frequency falls by about an amount consistent with the cross-sectional studies (under the second form of result above). This gives really quite a convincing picture. One of the latest results to be reported, the Nottingham area-wide speed enforcement system—which uses cameras reading number plates and computer matching as the vehicle proceeds through the city—has produced a 6mph speed reduction, and a 30-40% reduction in accidents. This is of the order we would expect from the cross-sectional studies. Overall, these results relating to vehicle speeds illustrate a fairly coherent picture of the way speed and risk are related.
Deciding what is ‘excess’ and what is due to inexperience

I have drawn those groups of behaviours together so as to illustrate how we might distinguish excess and inexperience failure from routine failure in ‘normal’ driving. Wherever the risk curve turns up rapidly because of an avoidable behaviour, we should be able to see the distinction. To be clear, when I am talking about excess and inexperience error, I do not mean that the failures themselves are necessarily of a different nature from ‘routine’ failures. The actual failure that leads to an accident might be the same as one made by an unimpaired experienced driver who is not speeding. By excess and inexperience failures I mean the phenomenon of an increased frequency of failures arising out of ‘excess’ behaviour or inexperienced behaviour.

Moving away from the old stereotypes of Figures 7 and 8 means drawing a line between the errors resulting from excess and inexperienced behaviour and those made routinely across the bulk of the driving population. If we can do that effectively we can then see accidents as arising from two paths (Figure 22).

In the first case, routine failure only results in an accident if there is an inadequacy in the level of provision or design of the vehicle or the road, in that they allow driver failures of a routine kind to be translated into accidents. This includes not only detailed matters of legal compliance, but also broader principles of design or construction as well. It seems reasonable to argue that vehicles and roads should be proof against routine driver failures as a matter of principle.

Now, although both paths represent systems failure, in the second case it would be unreasonable to expect the road and the vehicle to be proof against extreme behaviour. It is clearly a matter of judgement where the line between these two paths is drawn. A good guide is provided by the risk relationships, when we have them. Although this involves a little circularity of argument, in practical terms it is relatively straightforward. For example, we know that for a BAC level of more than around 80mg/100ml there are big increases in risk because driving judgement and skill is impaired so much. Therefore, failures made when driving in these circumstances could not reasonably be guarded against by vehicle and road design. Similarly, on the risk versus speed curve the risk is clearly too high when speed reaches a certain level, and that arises because of the error of judgement in adopting that speed. The same argument applies to the use of mobile phones, driving whilst fatigued and so on. Such behaviour tends to be violational, rather than just routine error-based failure. The first priority in such cases is to tackle the driver by law enforcement and training.

Similarly it seems unreasonable to rely solely on the vehicle and the road in an attempt to null out the additional error for inexperienced drivers. Elevated risk from inexperience (usually correlated with youth) is addressed traditionally by the training and testing regimes, and also by differential legislation applying more exacting requirements to the young and inexperienced. The latter is used more abroad than in Britain at the moment. Again, there is a line to be drawn between where the road and the vehicle should guard against routine error and when we need
instead to concentrate on enforcement and other behavioural measures including more training, education, and testing.

**What to do: the model**

From this picture, we conclude that the actions we need to take are of three types:

- **firstly:** those to counteract inadequate roads or vehicles; this applies across the whole driving population;

- **secondly:** those against failure amongst inexperienced drivers; the aim should be to reduce risk factors towards the levels applicable to the over-40s, where they are generally low; and

- **thirdly:** those against outright excessive behaviour like drinking above the limit and driving, speeding and so on.

The distinction between these types of action will, of course, tend to move with time. For example, we could if we wanted at some future time take more extreme measures on vehicle control and require alcohol interlocks to be mandatory. Then the car would refuse to drive away when it sensed from the driver’s breath that his or her blood alcohol was too high. The vehicle would then be guarding against what is currently regarded as excessive behaviour. Similarly, cars could be self-governing against speeding. The technology is perfectly capable of doing these things.

**Roads and vehicles**

Now let us come to roads and vehicles. They are clearly a key part in the model. Recently, what has been happening, *de facto*, is that we have begun to bring the definition of inadequacy for vehicles and roads out into the open. The effect of this is to bring about design changes that compensate for routine failures by the driver. Let me outline some of the emerging features of that new approach.

**Roads**

For roads it has been a progressive but rather slow process. Safety engineering has soldiered on over the last twenty years or so with great benefits; but there are still big differences in accident risk for different types of road and there are still big classes of accidents that should be avoidable. It is a substantial subject, and I am not going into it this evening except to show you some risk maps that have been produced as part of the European Roads Assessment Programme (EuroRAP), which is expanding through Europe and which I believe will have a strong influence on the roads part of the equation. It concentrates on interurban roads at present. The first step in the programme was to construct maps showing the risk for each stretch of road. There are three main types of map.

The first type of map shows the numbers of accidents involving fatality or serious injury per unit length of the road stretch in question. Figure 23 gives an example. Risk displayed in this way is particularly relevant to the deployment of emergency services for attending to accidents.

![Figure 23: The first type of EuroRAP map](source: EuroRAP/The AA Motoring Trust)

The second type of map shows the risk for the same types of accident, but now expressed per million vehicle kilometres driven on the relevant stretch of road. This is the risk experienced on average by individual drivers along that stretch of road. From such a map—Figure 24 gives an example—drivers can see the risks experienced on average by driving along particular roads.

![Figure 24: The second type of EuroRAP map](source: EuroRAP/The AA Motoring Trust)

The third type of map, illustrated in Figure 25, shows the same risk as in the second type, but now calculated with respect to the average risk experienced by drivers on all roads of the same general type. This is particularly relevant to road engineers, and enables them to judge whether a particular stretch is more or less risky than the average for roads of that type.
These maps expose risk in a way that has not happened before, and as they are rolled out across Europe over the next few years, they are likely to have a strong formative effect. The next step that is planned is to complement them with a measure of the ‘degree of protection’ offered by the roads against the consequence of driver failure. This will focus on the four main accident types for interurban roads—run-off accidents (collisions with trees etc.); cross-over accidents (when someone crosses the central median and collides with oncoming traffic); brutal side impact at junctions; and pedestrian accidents. Together these encompass 80% of interurban accidents in most of Europe.

A particular type of run-off accident involves collisions with trees. These are a big problem in Germany and France, where they cause respectively 1600 and 800 deaths a year. Mature trees are unyielding. Consider Figures 26 and 27.

Vehicles

For cars, the process of exposing and tackling risk has been much more concentrated in time. Vehicular secondary safety has improved greatly over recent years, driven mainly by the consumer programme, NCAP, introduced about six years ago. In effect, this is complementary to the much slower regulatory process. It works on the principle that publicly exposing the risk of injury in a car of a given make and model brings consumer pressure and this motivates manufacturers to incorporate safety improvements. The test protocols on which it is based mimic impacts with a similar car. They include a 60% frontal impact at 60kph with a 200 tonne concrete block faced with ‘soft’ aluminium honeycomb (Figure 28). This is equivalent to a 50% head-on impact with an identical car.

There are two types of side impact, one with the equivalent of another car, and one with the equivalent of a pole or tree (Figures 29 and 30).

The effects of impact with pedestrians depend on the size of the pedestrian—particularly the differences between an adult and a child—and the engagement of specific body parts with the car frontal structure. Separate
tests are therefore conducted with simulated parts of bodies: the head, the leg, and so on (Figures 31), and an overall composite representation of impact built up from the results.

With the exception of one class of accidents, the consumer pressure process certainly works. Since 1997 cars have on average improved by getting on for two stars for occupant safety, on a five-point scale. This corresponds to a 15-20% reduction in death/serious injuries experienced in crashes of a given type on the road. So crashes of a given intensity are becoming more survivable for car occupants. The exception, where the process has not worked well, is for pedestrian protection. In fact it would not be costly for manufacturers to build in better protection. But consumer pressure from the car buyer is weaker here, and an EU process beginning with a voluntary agreement from manufacturers is being introduced, with the sanction of an EU Directive in the longer run if needed.

Vehicle compatibility

Apart from the exception of pedestrian protection, this all sounds very good. But it is only a part of the story, since there are important limitations.
Here we have a car being propelled into the concrete block with 100% frontal impact. The block is faced with two layers. The first layer is a matrix of load-cells, each of which records the force of impact at a particular region of the front of the car as a function of time during the impact. The second layer in front of the load cell matrix is, as before, of soft aluminium honeycomb. The effect is to enable the distribution of forces spatially across the front of the vehicle to be measured and recorded as a function of time. The results look typically something like the histogram form in Figure 33 which is 25 milliseconds after impact.

If we consider the matrix of different types of crashes, as in Figure 35, these effects arise mainly from the off-diagonal elements.

In contrast, what NCAP tests currently represent is the diagonal elements: small car to small car, medium car to medium car, and so on, with the rider that we look at the same manufacturer’s vehicle and model. In fact, of course, for each such element there are other possibilities corresponding to different models of the same general type and mass.

The present testing arrangements therefore look very much at a sub-set of all crash types. The next big step is to test for what is called ‘vehicle crash-compatibility’—to see how to represent the relative safety performance of cars recognising that vehicle-to-vehicle collisions are usually between different makes, models and types of vehicle, and at different load height conditions.

The second limitation of existing testing is that it is purely about mitigating the effects of a collision when it happens. Whilst it sets out to make crashes more survivable, it would, of course, be better not to have crashes in the first place.

### Primary NCAP

Most manufacturers are now boasting collision avoidance technology at what we might call ‘first level’—that is, by antilock brakes, electronic stability control that will prevent the driver from losing control on difficult road surfaces, and so on. They make strong claims—several manufacturers have said their systems
have shown 15% reduction in accidents involving their vehicles over the past five years, since these systems were introduced. Before we can know what to make of these claims, we need some way of testing them—of reckoning them against a common benchmark.

The systems may well be very valuable. A significant research programme is underway to investigate ways of testing the dynamic claims made for them. Figure 36 shows experimentation into vehicle handling near the limits of stability in wet conditions on adverse road surfaces. There is much yet to be done.

Figure 36: Experimentation into vehicle stability as part of the development of protocols for test of primary safety

Road and Vehicle Safety: conclusion

Together these new developments for roads and vehicles are moving us generally in a direction in which the engineering of the road and vehicle should take account of the driver, failures and all, and help to make the overall system less ‘open’. What they do, in effect, is to move the roads and vehicles into the system circle.

Summary

Let me now summarise the principles briefly.

By identifying and correcting the higher risks associated with particular aspects of roads and vehicles design, we make the system more tolerant of routine driver failure. By distinguishing excess and inexperience failure for drivers from routine failure, we define the driver-vehicle-road system domain. This domain is conceptually superior to the simple descriptor driver behaviour since it recognises that the most effective way to reduce risks for the majority of cases is to engineer the vehicle and road systems in conjunction with the known characteristics of driver behaviour, including ‘routine’ error.

This domain should expand in time. The effect of this will be to focus action to reduce casualties better, by recognising the role of vehicles and roads in reducing risk, and by exposing their performance.

Implications

At root, the argument turns on where the responsibilities are placed. In air and rail travel, we take it as given that the pilot or train driver is fully part of the whole engineering system. We expect their compliance with procedures. We would not, for example, be happy for an airline pilot to do aerobatics on a passenger-carrying aircraft.

But on the road there is still a popular belief that the driver should be more of a free agent. This arises from a confusion. It confuses the driver’s freedom to determine the detailed vehicle movement with the necessity of following procedures that limit the risk generated by that movement. That this latter is a necessity is beyond reasonable dispute. The only question is to what level the risk needs to be limited, and in what terms this should be stated.

The confusion arises in several ways. Firstly, our knowledge of the actual risk levels is incomplete. Although big steps have been made in some areas to quantify the risk, there are still many areas where it is unquantified, as yet. Secondly, people generally have a poor appreciation of the meaning of risk and its relative impact, even when it has been well quantified. And thirdly, there is the simple double-think that unless freedom of choice is unlimited (even where it impacts adversely on others) it is not true freedom. For road travel this is still too common a view.

In the model I am advocating, the engineering system would be used to absorb and limit the risks from (statistically) unavoidable routine driver failure. This would be complemented by measures acting directly on the driver to remove the big risks of avoidable driver failure.

Figure 37: The new picture

Driver failures: ‘excess’

‘System’ failures
driver / vehicle / road

Driver failures: inexperience
Who should decide exactly where the boundaries of responsibility are to be placed is a difficult question. If we move further in the direction I am advocating, it will mean road authorities and vehicle manufacturers will, *de facto*, absorb greater responsibility for removing the consequences of routine driver error. In contrast, the responsibility for counter-measures to the risk from excess and inexperience failure is ultimately with government, the police, and the courts.

Moving towards a more closed system is potentially a bigger step than it might seem. As I’ve said, there are technologies that could allow this to happen on a large scale. Intelligent speed limiters, alcohol interlocks, and active collision-avoidance systems would have a big effect; but they are difficult politically. In the next several years there are some big decisions to be made.

Which brings me back to the ratio of a hundred to one in the investment to save a life on rail and road. I wonder if we will be prepared to take the steps needed on roads to get a better balance?
DISCUSSION

Mike Bell

Thank you, Rod, for laying out for us a range of issues of how we should view risk from road traffic and what we should do about it. I am sure there will be questions!

Question

Excess is reprehensible and in that respect is very different from inexperience, but you appear to have made little distinction between the two. Whilst every driver goes through a phase of inexperience, not all go into ‘excess’: how do you make allowance for this?

Rod Kimber

I avoided ascribing moral blame. What I was trying to do was simply to separate out the big risk factors and consider how we could deal with them. Inexperience is a major issue, and as you say, everyone has to go through that phase at some time. One can speculate on what sort of measures might be taken to reduce its effects. The Government consulted on it recently. What we need to do is to find ways of accelerating the process of moving down the rather sharp risk curves [Figure 13].

The most sensitive approach would probably be to increase the amount of supervised exposure for young drivers. What happens at present is that before the test they drive something like 0.1% of their total lifetime mileage—a tiny amount. During that time they have very few accidents (in relation to that limited exposure); but the rate surges up after they pass the test, get a full licence, and can drive unaccompanied by an experienced driver. It would be very beneficial if we could extend the period of supervised exposure. In principle there are various ways of doing it. In Australia there has been a vigorous campaign to encourage parents and young drivers to increase the total number of hours of supervised driving by a factor of three or four, by continuing supervision after the test itself. In Sweden the age at which young drivers can get a full licence has been separated by an extra year and a half from the earliest age at which they can begin to learn under supervision: this is a way of encouraging them to spend longer in the supervised learning phase. And of course, there are other approaches to the young driver problem as well.

Question

Crashes in Formula 1 racing are often spectacular, yet the driver normally walks away unharmed. Is there a whole realm of engineering in Formula 1 that has yet to arrive for the private car?

Rod Kimber

If you look through the records you will see that the safety performance of Formula 1 racing over the past ten years or so has improved enormously. The principles underlying the model I have described have to an extent been borrowed from that. Around 10 years ago, the organisers of Formula 1 became very interested in how they could engineer accidents out of the system. In the F1 case, of course, accidents have the potential to be very serious indeed. The organisers had control over most parts of the system: the track, the operations, the marshalling and so on. They could also control the safety standards of the vehicles and the safety procedures generally, and they could put limits on driver behaviour in risky situations. That is in fact what they did—and it has worked.

Our challenge is that public roads constitute a much more ‘open’ system and the degree of control that can be exercised directly in that case is obviously much more limited at present.

Question

You talked about Intelligent Speed Adaptation (ISA). Presumably there are options: it could be available voluntarily or it could be mandatory. If it were voluntary then surely there is a price issue—the technology could be expensive since the consumer who wanted it would have to hunt out suitably equipped models, or ask for a modification to be made to the car. But if it were compulsory the price would come down quite substantially since all models would then have to have it.
Rod Kimber

One could go through a process of making the technology available voluntarily and then, through a series of intermediate steps over time, one could get to the point where it was mandatory: either (a) for vehicles to be equipped to display the vehicle speed with respect to the prevailing speed limit and record it as evidence for subsequent legal action; or (b) for vehicles to be equipped to allow the speed of the vehicle to be limited directly so as to make it impossible to break the prevailing limit. But the first stage could be voluntary, as you say—and there is something more user-friendly about that approach.

As to price, there is a balance. Certainly volume production would reduce the unit price to the consumer. But whilst a mandatory requirement would force volume production, the critical path from a political viewpoint is also important, and there are some obvious barriers at present.

Question

There has been a deliberate avoidance tonight of apportioning blame. However, surely it makes a difference whether it is the driver, the pedestrian or the cyclist who is at fault? A car driver might choose to speed on a trunk road and might crash into a tree. That would be very different from speeding in a street where children might be present. In the first case the risk is to the driver him or herself; in the second it is imposed on someone else.

Rod Kimber

What this comes to, I think, is whether we should use stronger deterrents against behaviours that impose more risk on other people than the ‘self-risk’ that they impose.

Let’s first step back for a moment and consider simply how the risk divides between different users. There are big differences. For example, child cyclists have a very much higher frequency of death or injury per mile ridden than car occupants do. For motorcyclists it is even higher—about 30 to 40 times that of the average car driver, again per mile travelled. This reflects the strong asymmetries in the likely consequences to the potential ‘participants’ in a collision. An extreme case is vehicle-to-pedestrian impact. Being involved in a car-pedestrian collision is far more dangerous for the pedestrian than for the car driver because of the different level of physical protection.

As a consequence, typical behaviours generate asymmetric patterns of risk, and this is at the root of the observed differences in the frequency of casualties. A car driver’s aberrant behaviour in a suburban street where there are child pedestrians imposes a far greater risk of death or injury on the pedestrians than on the driver. Similarly, a pedestrian’s aberrant behaviour imposes a far greater risk on him or herself than on the car driver. Either way the pedestrian comes off worse by a large margin.

To return to the question: are bigger deterrents needed against those behaviours which impose risk mainly on other people? My answer is yes—if they are to have much effect. For the case of cars and pedestrians again, drivers are not easily deterred from driving too fast for pedestrians’ safety, despite a widespread awareness of the effects of vehicle speeds on pedestrians’ chances of survival. We have to install road humps or speed cameras to slow drivers down—which seems draconian in relation to the objective of modest speed reduction (usually of around 10-12mph). Drivers could voluntarily reduce speeds that much, without our applying restraint measures, but in practice they don’t.

Part of the reason that they don’t lies in who is perceived to be to blame for accidents. It has always seemed extraordinary to me that we still accept, de facto, that the driver should be excused of responsibility if, in a suburban street, a child runs out unexpectedly into the vehicle’s path and is killed because the driver was unable to stop, whilst travelling within the speed limit. Vehicle speeds at mid-link in urban and suburban areas in most cases have little effect on journey times, since junction delays, including queuing, dominate. Why then should we allow that 30mph is OK in circumstances where a child may emerge from behind a parked car—or even 20mph? What purpose can the judgement possibly serve, in terms of risk reduction, that it’s somehow not the responsibility of the driver to allow for that?
A far more rational approach would be to accept that children, no matter how well trained, do make mistakes form time to time, and that it is not acceptable to drive at a speed that does not allow for that. In Germany, for example, motorists are not allowed to plead that they were blameless if they collide with a child pedestrian who dies as a result: they have a legal responsibility not to drive in such a way that a child’s mistake results in their death. British law does not take that line, and we have to look to other means to influence behaviours. In practice, this means engineering a different type of road environment to reduce speeds, and enforcing compliance with lower speed limits.

In general, the act of assigning legal responsibility for an accident and applying a corresponding penalty is an instrument of deterrence and therefore risk reduction. Engineering the driver-vehicle-road system to filter out the effects of driver failure is another way of reducing risk. They are complementary. What matters is the proportionality of the measures and their net effects in practice.

Finally, it is sometimes argued that behaviours that mainly generate self-risk are in a sense acceptable. I feel that this too is a mistake. Motorcyclists are fond of this argument, although the statistics show that they are also involved in substantial numbers of accidents involving injury and death to others. It is worth considering the limiting case where (hypothetically) an individual’s action generates risk only to himself or herself, and not to others. Would it be OK to tolerate such an action? The simple answer is no, since in resource terms self-harm costs the same for a given set of injuries as harm to other people. It would therefore be a mistake to accept single-vehicle collisions with trees as OK, since emergency, medical, and social costs are blind to the difference. We should not therefore be content to leave self-harmers to their own devices.

**Question**

Speaking of trees, where should they be planted? The roadside can be unforgiving for those who lose control of their vehicle. Strategically placed sandbanks might prevent collisions with trees. Wasn’t there some work done on this a while ago, and on the possible use of shrubbery to slow vehicles that had run off the road?

**Rod Kimber**

Trying to devise means to prevent impact with roadside objects, or to mitigate it, is demanding. This is particularly so where there are avenues of trees very close to the edges of the road (as frequently found in France). We would need to absorb the kinetic energy and restrain the vehicle safely without letting it either fully impact with the tree or bounce back onto the opposite side of the road. There’s a challenge there: to design an aesthetically attractive device that would fit within very narrow lateral limits by the roadside and be economic to produce, install and maintain! As I said earlier, the target ‘market’ is large since the death rates from impacts with trees in Europe are high.

The TRL experiments using shrubbery as a potential restraint were done long ago, before my time. I was once told that although people had had high hopes, they found that in the event there was relatively little resistance to vehicle impact. This is a pity because they could have become a pleasant environmental feature. Wild roses, for example, were tested but apparently had almost no influence on vehicle trajectories.

**Question**

There was mention of ‘alcohol interlocks’—the devices that detect alcohol in a driver’s breath and prevent the car from working in this situation. Do these exist? Are they actually used?

**Rod Kimber**

They do exist. They are in-car devices which can analyse the driver’s breath for evidence of alcohol; if this proves positive they immobilise the car, thus preventing an offence from taking place. There are some states in the US, California in particular, where they are currently used. Their installation and use are set as a condition for drivers with a bad record, before they are allowed back onto the road. The government is researching the potential for their use over here. Since drinking and driving causes nearly 500 deaths a year, and recurrent offenders are a problem, interlocks may well have a future role.
Question

You’ve described the highway as an ‘open’ system. What about motorways, though? They are a distinct category of road. Could we have a better system for that case: for example, make a law that means you have to have been driving for two years, or pass a further test, before you are allowed to drive on the motorway?

Rod Kimber

It could be done. The way the motorway system is constructed and operated, with special regulations, means that it’s a possibility, in principle.

But there is a strong sense in which the motorway system is the place where it least needs to be done. Motorways have been designed so as to remove many of the major risks. There are no pedestrians, no cyclists, and no at-grade junctions; and there are crash barriers, good sight lines and so on. They are an example of very good engineering, which is why traffic can go fast on them but with lower risk of accidents. The casualty rate for death and serious injury is less than a quarter of that for conventional A-roads. Therefore, by their design and the operating regulations they already remove many of the potential consequences of error.

Having said that, it’s sometimes argued that learners need some prior training in motorway driving rather than being allowed alone onto motorways as soon as they pass their test. The objections to requiring such training are practical—though the present position does not seem to give rise to a large accident problem.

Question

Your EuroRAP results showed risk in terms of the number of accidents per mile travelled, i.e. with respect to ‘volume’. Instead, why not make the accident rate take into account the time that people are actually doing the journey? If you have a lot less time ‘in transit’, for example, this affects your personal exposure. Isn’t it this that should be measured?

Rod Kimber

For road travel, the quantity generally discussed is accidents or casualties per mile travelled (for each level of severity). But there are other indicators, for example the risk per hour of exposure or the risk per trip made. The argument for choosing one rather than another depends very much on the context.

For most road travel the objective is to get from A to B such as to maximise the utility on arrival at B. This is true for all journeys except those made for the pleasure of the journey itself. Achieving that objective means minimising the generalised cost of travelling by choosing the most effective route; and accidents are in effect one component of this cost.

The accident component of the cost is most straightforwardly dealt with by reckoning it as a cost in accidents per mile times the route distance in miles, since the choice is between alternative routes that usually have different lengths and different accident rates per mile. Of course, for a given route one could alternatively do the calculation in terms of the time exposed (which is inversely proportional to the average speed for a given journey) and the risk per unit time of exposure; but it comes to the same thing.

Everything turns on what type of choice is being made. A less constrained case is where one can choose between alternative trips on the basis of some higher level purpose, for example to secure the greatest utility regardless of destination. In that case one might compare the risk simply in terms of the numbers of accidents per trip. For example, one might compare two alternative business trips, the first from London to Leeds by road and the second from London to the US by air. The utility on arrival would depend on (amongst other things) the accident component of the travel cost, and this would derive from the total risks of having an accident during each trip as a whole. So then we would use the risk per trip. And so on.

People sometimes worry about the comparison of the risk per mile travelled in a journey by air, which is very low, and the risk per mile travelled by car, which is much higher. They argue that, because air journeys are on average over much greater distances but at much higher speeds, it would make more sense
to compare the risk per hour of exposure—when the figures become closer. The fact is that, except for trips made just for the pleasure of travelling, neither comparison means much on its own. What matters is the net effect in generating utility at the destination.

Since in practice most travel alternatives are between surface transport journeys in which the utility is realised at the destination, the most common approach is to use the risk per mile travelled. But it’s important always to bear in mind how the risk information is to be used.

**Question**

Comparisons have been made between pilots and drivers. Can you not inhibit bad driving habits by a re-testing regime that takes into account the results shown on your graph of accident rate against experience? Drivers may be more likely to stick to desirable habits if they know they will be re-tested.

**Rod Kimber**

For newly qualified drivers there is an element of that already. The New Drivers Act, for example requires that if a new driver chalks up more than six penalty points within two years of passing the test, they have to go back to square one and re-take their test. That’s a major social deterrent since they feel very silly, and it’s a good way of capping some of the excess risk for the inexperienced.

By the time most drivers have accumulated some years of experience—for example for most of the over-40s—the risk factors have come down so much that routine re-testing would be much less efficient, in terms of the benefits per pound invested, than if we concentrated on the high risk areas. So I do not think there would be much to be gained from re-testing normal drivers beyond the first 10 years of driving experience.

I said most over-40s because there are exceptions. For drivers with bad drink-driving records, for whom recidivism is commonplace (generating particularly disproportionate risk), re-testing serves a very real function. This goes alongside a requirement for a medical examination to determine how free they are from any residual dependence on alcohol.

**Question**

Doesn’t the graph [Figure 13] show that the driving test actually tests the wrong thing? If this is so, then a re-testing regime may not actually be effective anyway.

**Rod Kimber**

Well, people have argued that the driving test is just a test of vehicle-handling ability and that’s all—rather than a test of the ability to drive well and avoid accidents. I think that’s an extreme view; but it certainly needs to be addressed.

Whilst vehicle-handling ability can be evaluated in a relatively short time, assessing the propensity to risky behaviour (whether deliberate or from a lack of awareness) is much more difficult. This is in essence a ‘sampling’ issue. Even though the duration of the test has been extended [it’s now about 40 minutes], the probability of facing or creating a potentially dangerous situation in a test of limited duration is very small. A subject could drive through a traffic light 100 times without making a mistake and then on the 101st time make a dangerous mistake; and they could get through a driving test without ever once doing it, because they might only make a dozen or so transits of traffic lights in the test. Now, someone who seriously violated red lights in one percent of transits after passing the test would be a menace. So there is an issue in terms of the inevitable shortness of the test, compared with the much more extensive exposure experienced by motorists subsequently. Much work has been done on the driving test in recent years, and it has improved a great deal. I don’t know whether the consequences of that work have really worked themselves through into the risk curves—maybe there are benefits coming through that we haven’t yet seen.

What is a concern, as I said earlier, is that the amount of supervised exposure that young drivers get before passing their test and being allowed out on their own (or with friends of similar age and experience) is so incredibly small. It amounts to around a tenth of a percent of the average total lifetime mileage driven. In
general the ability to recognise and deal with risky situations depends strongly on the number of times a subject has encountered them before, in one guise or another. Aircraft pilots are required to undergo very specific minimum training/practice time ‘on type’ for each craft they are to fly subsequently. Another example is that the rate of successful diagnoses by medics increases markedly with the number of relevant cases they see per year. And so on. Monitored/supervised practice in a role is a key part of learning the skills and higher-level decision-making that are essential to safe operation.

But for practical and economic reasons, we can’t put large numbers of learner drivers though the same rigour of training as airline pilots or train drivers. That controlled exposure is important for driving is illustrated by the fact that there is a distinct correlation between inexperience in drivers and an inability to recognise hazardous road situations until a very late stage. This low hazard perception ability in recently qualified drivers has been known about for a long time, and tests based on hazard recognition are now incorporated in the driving theory test. Whilst that is a step forward, I feel we should be doing a lot more to generate a very significant increase in the amount of supervised exposure new drivers experience before joining the ‘normal’ driving population.

Mike Bell

Unfortunately time is beginning to run out, and I’m afraid we’ll have to finish shortly. But there is one thing I would like to ask. You have suggested that the freedom of the driver’s decision making should be reduced—as has happened in large-scale tests of Intelligent Speed Adaption systems. However, reducing the amount of decision making associated with risk may not necessarily make the roads a safer place, since drivers’ responses to this may not themselves be risk-free.

Rod Kimber

That’s true. Much depends on the circumstances. One may set out to remove the consequences of a particular type of risky behaviour only to find that it is replaced by another risky behaviour or an exaggeration of the first. The behaviour may adapt to take up the potential benefit of risk reduction in another way. Big improvements in vehicle handling could save more accidents if drivers did not choose to drive faster instead. In practice there is usually a mixture of response: driving faster erodes some of the potential safety benefits but not all. If vehicles were developed that were capable of avoiding collision in a range of circumstances then drivers’ responses outside of this range might become weakened through lack of attention or a belief that the system was more all-embracing than it really was.

In contrast, there are certain types of benefits where there is no offsetting behavioural change. The introduction of seat-belts is an example—where the reduced risk was not closely coupled to some alternative competing benefit.

Mike Bell

On that note, we really do need to close. In doing so, I’d like to extend our thanks once again to Rod for his enjoyable lecture and for stimulating such a lively debate.