The final publication is available in: Accident Analysis and Prevention, 106, 2017, 166-172.

10.1016/j.aap.2017.06.008

Can evolutionary theory explain the slow development of knowledge about the level of safety built into roads?

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ABSTRACT

In several papers, Hauer (1988, 1989, 2000A, 2000B, 2016) has argued that the level of safety built into roads is unpremeditated, i.e. not the result of decisions based on knowledge of the safety impacts of design standards. Hauer has pointed out that the development of knowledge about the level of safety built into roads has been slow and remains incomplete even today. Based on these observations, this paper asks whether evolutionary theory can contribute to explaining the slow development of knowledge. A key proposition of evolutionary theory is that knowledge is discovered through a process of learning-by-doing; it is not necessarily produced intentionally by means of research or development. An unintentional discovery of knowledge is treacherous as far as road safety is concerned, since an apparently effective safety treatment may simply be the result of regression-to-the-mean. The importance of regression-to-the-mean was not fully understood until about 1980, and a substantial part of what was regarded as known at that time may have been based on studies not controlling for regression-to-the-mean. An attempt to provide an axiomatic foundation for designing a safe road system was made by Gunnarsson and Lindström (1970). This had the ambition of providing universal guidelines that would facilitate a preventive approach, rather than the reactive approach based on accident history (i.e. designing a system known to be safe, rather than reacting to events in a system of unknown safety). Three facts are notable about these principles. First, they are stated in very general terms and do not address many of the details of road design or traffic control. Second, they are not based on experience showing their effectiveness. Third, they are partial and do not address the interaction between elements of the road traffic system, in particular road user adaptation to system design. Another notable fact consistent with evolutionary theory, is that the safety margins built into various design elements have been continuously eroded by the development of bigger and faster motor vehicles, that can only be operated safely if roads are wider and straighter than they needed to be when motor vehicles were smaller and moved slower.

Key words: road design; traffic control; evolutionary theory; history; learning-by-doing; routines

1 INTRODUCTION

In the past twenty years or so, the safety of cars has improved greatly, see Kahane (2015) for a comprehensive review. This development is to a large extent the result of systematic research and testing performed by car manufacturers, partly spurred by vehicle safety standards set by government and partly by market incentives generated by new car assessment programmes, such as EuroNCAP. This shows that a science-based approach can lead to large improvements in road safety. The contrast to the development of road design and traffic control is stark. Although it is probably correct to attribute part of the improvement in road safety in many OECD-countries after about 1970 to improvements of roads and traffic control devices (Evans 2004, Elvik et al. 2009), these developments have not been instigated by research to the same extent as recent development in vehicle safety.

In a series of papers, Ezra Hauer (1988, 1989, 2000A, 2000B, 2016) has pointed out that the level of safety built into roads, as specified in terms of design standards, is unpremeditated, i.e. not the result of decisions in which the safety impacts of the choice of design standard were considered explicitly. His examples include the minimum radius of crest curves, lane width and the minimum radius of horizontal curves. For each of these cases, Hauer shows that design standards were originally determined many years ago, and were not updated as new knowledge about the safety effects of the design standards became available. To this observation can be added that many roads were built, often to low standards to minimise costs, even before the first generation of design standards were developed. It is therefore not surprising that roads differ greatly in safety.

It is fair to ask if it remains the case even today that knowledge about how to design roads with a known level of safety is incomplete. Surely, one may argue, there have been many studies of how various road design elements are related to safety and the knowledge produced by these studies ought to have some value in predicting the safety of a new road. Unfortunately, it is not likely that even recent studies provide an adequate basis for reliably predicting safety. Consider, as an example, horizontal curve radius, one of the design parameters discussed by Hauer. Figure 1 shows the results of a number of recent studies made in the United States about the relationship between horizontal curve radius and the number of accidents in horizontal curves.

Figure 1 about here

The studies include those of Fitzpatrick et al. (2010), Bauer and Harwood (2013), Khan et al. (2013), Banihashemi (2015, 2016) and Gooch et al. (2016). Although all the studies included in Figure 1 show that the number of accidents (traffic volume is controlled for in all studies) increases as curve radius declines, there are many important differences between the studies. First, the type of traffic environment differs, although most studies refer to rural roads. Second, some studies refer to two-lane roads, others to multi-lane roads. Third, interaction with other design elements, like vertical curves, is not considered in all studies. Fourth, results vary, in particular when curve radius is less than about 200 metres.

It is increasingly understood that safety in horizontal curves depends on many characteristics of the curves (Hauer 1999): radius, the presence of transition curves, superelevation, interaction with vertical curves, distance to adjacent curves, number of lanes and whether the road is rural or urban. None of the studies included in

Figure 1 took all these factors into account. It is therefore not clear how any of the studies included in Figure 1, or a synthesis of them, can be applied in a specific context (defined in terms of the characteristics mentioned above) to predict the safety effect of a specific choice of curve radius.

Since reliable prediction of the level of safety of a given road has been impossible, and still is inaccurate, the control of the safety of roads has historically relied mostly on a reactive approach. This means that one reacts to accidents as they occur. This approach has typically been applied at the local level. Perhaps the best example of this approach is the identification and treatment of so called black spots, or concentrations of accidents at a specific location, such as a junction or a curve. While this is widely regarded as an effective approach, a critical examination of it casts some doubt on this. This paper takes the following two observations to be true:

1. It has historically been, and to some extent still is, impossible to reliably predict the level of safety built into a road.
2. A dominant approach to the prevention of road accidents has therefore been reactive, i.e. action has been taken in response to accidents as they occur.

The paper asks whether, given these two observations, evolutionary theory can explain the slow development of knowledge about the level of safety built into roads.

2 KEY ELEMENTS OF EVOLUTIONARY THEORY

There are two key elements of evolutionary theory that are relevant when trying to apply it to social phenomena: (1) Learning-by-doing, and (2) The encoding of practices thought to function well in terms of standardised routines. The first of these elements was succinctly described by the Norwegian social scientist Eilert Sundt, quoted by Hernes (1980), in his description of boat building along the coast of Norway in the middle of the nineteenth century:

"The boat builder may be very skilled, yet, no two boats are perfectly identical to the smallest detail. The differences arising this way must be regarded as random. But if a small difference between two boats is associated with a noticeable difference in performance at sea, it is not random if such a difference is detected. Sailors will urge the boat builder to copy the boat that performed best at sea. The boat builder will now try to copy the boat performing best at sea, and may embark on a set of trials, each involving a small change to the boat, in order to develop a boat that surpasses the performance at sea of any previously built boat."

The first part of evolution is often referred to as learning-by-doing. A task is performed repeatedly, the result may not be the same every time, but if the result is better than last time, the difference is noticed. The discovery of an improvement (a mutation that improves fitness and thus increases the chance it will be passed on to successive generations) will lead to attempts to copy the improvement. Learning-by-doing may then transition into a process of trial-and-error. The difference between learning-by-doing and trial-and-error is that in learning-by-doing, you are not purposely trying to improve something; if you happen to do so, it is a random event. Trial-and-error, on the other hand, is the purposeful search for improvements, which, however, may not always be attained if the process is error-prone.

In the early days of automobilism, there was clearly very limited, if any, knowledge about the safety effects of various elements of road design and traffic control. As time went by it was gradually understood that not all roads had the same level of safety and not all traffic control devices performed equally well. However, the emergence of this understanding was mostly not the result of research, but is perhaps better described as a process of discovery. The process of reacting to accident concentrations gradually became more and more formalised and took the form of what Nelson and Winter (1982:14) refer to as routines:

> *"Our general term for all regular and predictable behaviour patterns is "routine". … They are a persistent feature of the organism and determine its possible behaviour (though actual behaviour is determined also by the environment), … and they are selectable in the sense that organisms with certain routines may do better than others …"*

One may think of a routine as a standardised approach to the treatment of a problem. The detection, analysis and treatment of accident black spots, or of hired drivers sustaining more accidents than usual, has become quite standardised (has become a routine). The existence and use of routines as part of accident prevention is therefore evidence of a process of evolution, i.e. the routines have emerged gradually, first as a result of learning-by-dong, then as a result of trial-and-error.

3 HOW TO ASSESS EVOLUTIONARY THEORY

How can one assess the relevance of evolutionary in explaining the slow development of knowledge about the level of safety built into roads? The following observations are consistent with an unplanned evolution of knowledge:

1. The use of an "accident warrant" to justify the introduction of a safety treatment.
2. Evaluation of the effects of safety treatments by means of simple before-and-after studies, not controlling for any confounding factors.
3. Interpreting any improvement in safety from one period to the next as resulting solely from safety treatments introduced.

The evolution of knowledge is methodologically naïve. Since it is an essentially unplanned development, it takes all observations at face value and interprets them in ways that support the routines that have been developed for managing safety. This process of developing knowledge can be slow and highly unreliable, since it neglects the contribution of random variation to the recorded number of accidents. Regression-to-the-mean may be misinterpreted as an effect of a measure. The importance of regression-to-the-mean was not fully understood until about 1980. A collection of highly instructive examples of regression-to-the-mean is given by Hauer and Persaud (1983).

A case of an "accident warrant" for the use of a measure can be found in the Manual on Uniform Traffic Control Devices (2009:50):

"In addition, the use of YIELD or STOP signs should be considered … where one or more of the following conditions exist: …C. Crash records indicate that five or more crashes that involve the failure to yield the right-of-way at the intersection under the normal right-of-way rule have been reported within a 3-year period, or that three or more such crashes have been reported within a 2-year period."

This warrant is a routine in the sense Nelson and Winter (1982) use the term. It is a trigger: If condition A is present, then do B. Perhaps the best example of how apparent success has been misinterpreted concerns the treatment of hazardous road locations, also known as black spots. It is evidence in support of evolutionary theory that all the early evaluations of black spot treatment were simple before-and-after studies, not controlling for any confounding factors and not recognising the great influence regression-to-the-mean is likely to have on the results of an evaluation (Elvik 1997). No study made before 1977 controlled for regression-to-the-mean, let alone mentioned the fact that it could bias results. When the results of evaluation studies controlling for different confounding factors were compared, Figure 2 emerged.

Figure 2 about here

Studies were classified with respect to control for four potentially confounding factors: (1) regression-to-the-mean, (2) long-term trends, (3) changes in traffic volume, (4) accident migration. No study was found that had controlled for all these factors. Studies that controlled for three of them found no effect of black spot treatment.

The history of the idea of accident proneness is very similar to that of the treatment of black spots. In an extensive defence of accident proneness, i.e. the idea that some drivers are more prone to have accidents than others, Shaw and Sichel (1971) went far in denying the very existence of regression-to-the-mean. Thus, trying to explain why the number of accidents appeared to be more stable over time in one data set than in another, they wrote (pages 293-294):

"There is much talk in statistical circles about this oscillation being a phenomenon of chance (the "regression toward the mean" so often mentioned). But an examination of the personal files of the PUTCO drivers show that these oscillations are, on the whole, anything but chance-directed. In fact, any sudden improvement is usually closely associated with disciplinary action."

One will be hard put to find a clearer example of a complete misinterpretation of changes in safety. First, if one estimates the regression-to-the-mean effect in the PUTCO data Shaw and Sichel refer to (the data are published on page 52 in the book), it is found that the changes from period 1 to period 2 are fully explained by regression-to-the-mean. There was no change in the long-term expected number of accidents. This is shown in Table 1.

Table 1 about here

The first two columns show how many drivers had 0, 1, 2 etc. accidents in the first period. There were 162 accidents in total, making for a mean of 1.141 per driver. The variance was 1.346. This information can be used to estimate the expected number of accidents in the second period, as follows:

Predicted number of accidents per driver in the second period =

$[(1.141/1.346) \cdot 1.141] + [(1 - (1.141/1.346)) \cdot X]$

X is the recorded number of accidents in the first period. The predicted number of accidents per driver is multiplied by the number of drivers who had X accidents in the first period and adjusted by the change in the total number of accidents (154/162). This results in the numbers in the rightmost column of Table 1, which are remarkably close to the recorded numbers, confirming that the changes in the number of accidents per driver were exclusively the result of regression-to-the-mean.

Second, the observed change in the number of accidents was automatically credited to a measure that was taken. Such misinterpretations can be very counterproductive. A thought-provoking example of this is given by Kahneman (2011), who tells how a lack of understanding of regression-to-the-mean in the Israeli air force lead officers to believe that praising pilots for a good landing was counterproductive (because the next landing was usually not as good), whereas punishing them for a bad landing was good (as the next landing was usually better). One can only imagine all the ineffective moral exhortations and abuse the hapless South African drivers had to put up with because their managers were statistically naïve.

4 A COMPREHENSIVE STATEMENT OF PRINCIPLES FOR THE DESIGN OF A SAFE ROAD SYSTEM

The reactive approach to road safety, dominant for a long time, did not prevent the number of traffic fatalities from increasing almost without interruption in most highly motorised countries from about 1945 to about 1970. A need was increasingly felt for finding more effective means of reducing the number of road accidents than those that were predominantly used before 1970.

Gunnarsson and Lindström (1970) attempted to give a comprehensive statement of principles for the design of a safe road system, in a book entitled: "The road to safe traffic". Their contribution can be viewed as an attempt to establish an axiomatic foundation for designing a safe road system, by stating a few simple principles that appeared to be obviously correct, or at least hard to dispute. These principles, also known as the SCAFT-principles, were:

1. The location of activities: Activities should be located so as to minimise traffic volume and the number of points at which traffic movements intersect (the number of conflict points).
2. Separation: Different types of traffic should be separated in space and/or time. By types of traffic, Gunnarsson and Lindström referred to pedestrians, cyclists and motor vehicles.
3. Differentiation: A hierarchy of roads serving different functions should be developed. Long distance traffic should be served by motorways with high capacity, local traffic by access roads, preferably not permitting through-traffic (i.e. traffic not starting or ending a trip on a property to which the road gave access).

These principles soon gained widespread acceptance, at least in the Scandinavian countries, and were encoded in the road design standards of these countries. Gunnarsson and Lindström stated the principles in very general terms and illustrated their application by means of examples. References to research were surprisingly few. There were only twenty references in total; three of them were not to research reports. Despite this, Gunnarsson and Lindström were very confident in their assertion of the principles and did not see a need for making exceptions from them. Three facts are notable about the SCAFT-principles:

1. They were stated in very general terms and did not address the details of the design of roadway elements, such as the design of junctions.

2. Their effectiveness in improving road safety was hardly documented.
3. The principles did not address the possibility that road users might adapt their behaviour to the design of the road system.

One may interpret the principles as trying to create as simple a road system as possible. The potential number of conflicts between traffic movements and types of road users should be minimised; traffic should be as homogeneous as possible and traffic volume on access roads minimised. It is correct, that complexity of the traffic environment is a risk factor (Elvik 2006). However, it does not follow that creating a simpler traffic environment will result in concomitant safety gains. Complexity leads to errors, but a good thing about errors is that one may learn from them (Amalberti 2001).

5 THE ADAPTATION TO A COMPLEX TRAFFIC SYSTEM

It is a key proposition of evolutionary theory that species adapt to the environment. Polar bears have thick fur and lots of body fat to survive in the cold Arctic environment where they live. Successful adaptation may take a long time, but is remarkably effective once it has reached a local optimum. Is it conceivable that road users adapt to a complex traffic environment in a way that may reduce the effectiveness of the SCAFT-principles? To shed light on this question, data for 16 districts of Oslo, collected many years ago by Muskaug (1980) have been analysed.

The districts were all either purely residential areas or mainly residential areas mixed with small business (shops such as groceries, clothes, small restaurants, etc.). For each area, Muskaug (1980) collected data for the years 1971-75 about the number of inhabitants, the number of people employed, area in square kilometres, length of local roads, number of three-leg junctions, number of four-leg junctions and number of junctions with the main road bordering on the area. Accident data were collected on: (1) Accidents inside each area involving cyclists or pedestrians; (2) Accidents inside each area involving motor vehicles only; (3) Accidents on the surrounding main road involving cyclists or pedestrians; (4) Accidents on the surrounding main road involving motor vehicles only. A short description of each area was provided. Based on this information, the following characteristics of each area were coded:

1. A traffic volume indicator: sum of the number of inhabitants and employed people.
2. A complexity indicator: [(Number of three leg junction · 9) + (Number of four leg junctions · 28) + (Number of junctions with main road · 9)]/Length of local roads in kilometres.
3. An indicator of differentiation: 1 if local roads do not have through traffic, 0 if at least some local roads have through traffic.
4. An indicator of separation: 1 if separate roads for walking or cycling are provided, 0 otherwise.

The sum of population and employment is a proxy for traffic volume. The number of junctions have been multiplied by the theoretical number of conflict points between the traffic movements passing each junction and added for all junctions. The sum was divided by road length. The degree of differentiation and separation is indicated by dichotomous variables. This is clearly somewhat crude, but the data do not support a finer scaling of differentiation and separation.

A negative binomial regression model was run, using the four characteristics listed above as independent variables and the four categories of accidents as dependent variables. Table 2 shows estimated regression coefficients and their standard errors.

Table 2 about here

One would expect adherence to the SCAFT-principles to improve the safety of cyclists and pedestrians more than the safety of motorists, and have a larger effect on local roads in an area than on the surrounding main road. The regression coefficients in Table 2 are broadly consistent with such a pattern. There are, however, a couple of interesting exceptions. The coefficient for complexity has a negative sign in the model for accidents involving cyclists or pedestrians inside the area. In other words, increasing complexity does not appear to increase the number of accidents. One possible interpretation of this is that cyclists and pedestrians (and possibly also motorists) adapt behaviour to the complexity of the system. It is also noteworthy that the sign for separation is the opposite of what one would expect. It must be noted, however, that the standard errors of many of the coefficients are large.

It did not take long before the SCAFT-principles were criticised. In the recent 15-20 years, a completely different approach to urban safety has been proposed: shared space.

A shared space is an area where all groups of road users are permitted to travel and mix at low speeds. There are no formal rules. Travel lanes are not marked, there are no yield or priority signs, no traffic signals, no sidewalks separated from driving lanes by means of kerbstone. The idea is that by mixing road users at low speed, informal communication between them is encouraged, and road users will agree on who waits or goes first as a result of informal communication.

When reviewing studies that have evaluated the effects on accidents of shared space, it is almost as seeing history repeat itself (Høye et al. 2017). Nearly all studies that have evaluated the effects on accidents of shared space are simple before-and-after studies, not controlling for any confounding factors, and likely to overestimate effects. These studies have all been made by advocates of the shared space concept, who probably believe that they have discovered an ingenious new approach to urban safety. It is almost unbelievable that these simple-minded and erroneous evaluation studies are still performed, nearly forty years after Hauer (1980) drew attention to the gross errors that may be committed and started to develop the Empirical Bayes method (Hauer 1997), which controls for regression-to-the-mean and other confounding factors.

Thus, the introduction of new concepts and measures intended to improve road safety by modifying road design elements and traffic control devices still proceeds as a random walk: Someone stumbles onto something that looks like a bright idea; performs a hasty and amateurish evaluation of the idea and starts to propagate it as an effective road safety measure. Hauer (1989) called for a separation of evaluation and implementation. There is, in a similar vein, a need for separating evaluation and activism.

6 THE ADAPTATION OF THE ENVIRONMENT TO THE SPECIES

Evolutionary theory describes and explains how species adapt to their environment. As far as the historical development of road design standards is concerned, there is evidence that a reverse process has also occurred: the environment as adapted to changing characteristics of the species populating it. This is evident in successive editions of the design standards for roads in Norway.

These guidelines are revised periodically and published by the Norwegian Public Roads Administration (Statens vegvesen). There are absolutely no references to research in the design guidelines. When a design parameter is changed, there is thus no way of knowing why this is done. Indeed, new editions of the guidelines do not even refer to earlier editions and do not comment on the changes made.

One hypothesis about changes in design guidelines for road elements, consistent with evolutionary theory, is that roads must be widened or straightened in order to make room for the ever-larger vehicles using the roads. A comparison of some key design parameters in the 1981, 1992 and 2013 editions of the Norwegian road design guidelines indicates this (Statens vegvesen 1981, 1992, 2013). Table 1 shows the evolution of some key parameters.

Table 3 about here

It is seen that the total minimum width of roads with an AADT below about 4000-5000 has increased from 7 metres (1981), to 7.5 metres (1992) and finally to 8.5 metres (2013). For roads with a higher traffic volume, required width has increased from 8.5 metres (1981 and 1992) to 10 metres (2013). The minimum radius of horizontal curves has also increased markedly. In 1981, the largest design vehicle that was described in the design guidelines was 15 metres long and 2.5 metres wide. By 1992, this had increased to 22 metres and 2.5 metres, respectively. These dimensions were almost unchanged in 2013; only the width of the design vehicle had increased to 2.6 metres.

Car manufacturers, in particular manufacturers of buses and heavy goods vehicles, adapt to more generous road standards by making the vehicles larger. Each vehicle can then carry more passengers or more tons of goods, which reduces the cost per passenger or per tonne. Road authorities adapt to this by making design standards more generous. They can then argue that a large share of roads do not satisfy current design standards and require replacement or upgrading. This is a way of protecting road investment budgets from cutbacks. It is worth noting that low-volume roads built to 1981-standards would be classified as sub-standard by 1992-standard. Roads built to the 1992-standards would not meet the 2013-standards. Thus, the need for upgrading roads to higher standards is perpetuated.

Environments and the species populating them live in a happy symbiosis and adapt to each other to mutual benefit.

7 DISCUSSION

Is it really the case, as suggested by Hauer (1988, 1989, 2000A, 2000B, 2016), that knowledge about the safety effects of road design elements and traffic control devices develops slowly and comes in small doses? Is it true that this knowledge does not make its way into design standards for roads and criteria for the use of traffic control devices? There are, after all, hundreds of studies of the safety effects of various elements of road design and traffic control. The research tradition is long, going back at least 70 years. The oldest study of the effects of road lighting quoted in the Handbook of Road Safety Measures (Høye et al. 2017) was published in 1948.

This is true, but it is also true that many decisions regarding road design and traffic control, have historically been made without much, or any, knowledge about their likely effects on safety. Furthermore, it is a fact that many older studies evaluating the safety effects of design elements or traffic control devices were simple before-and-after studies that did not control for important confounding factors like regression-to-the-mean.

Recent studies of how horizontal curves radius is related to the number of accidents are only beginning to uncover the complexity of the relationship. These studies show that one cannot predict the safety performance of a curve by using a simple rule, for example, that the accident rate in a curve with a radius of 200 metres is twice that of a straight road section. It is more complex. It depends, among other things, on the length of the curve and whether are similar curves nearby.

Evolution is an unplanned, non-thinking and slow process, resulting in local optima in which the species of a location are adapted to the living conditions at that location or very similar locations. A reactive approach to safety management, triggered by accident experience resembles evolution in that the knowledge gained from it is unplanned, is often accepted at face value, and thus highly error-prone.

One example is the use of accident warrants for the use of traffic signs, for example yield or stop signs. Such warrants are likely to be entirely spurious and capitalise on chance, unless they are accompanied by a fairly extensive guide about how one should estimate the long-term expected number of accidents. One does not find any such guide in the Manual on Uniform Traffic Control Devices. It merely states that the sign (yield or stop) can be used if so and so many accidents have been recorded. Not even traffic volume is mentioned, although, say, five accidents may not be abnormally high for a high-volume site, but far above the normal for a low-volume site. An accident warrant will often act as a permanent learning trap, since installing the sign will often be associated with a (random) decline in the number of accidents.

The long-term history of some approaches in traffic engineering and some road design elements lend support to an evolutionary interpretation. Black spot treatment was long hailed as the epitome of a scientific approach to accident prevention. Today, it is in ruins, as most of the evaluations that found it to be effective had to be rejected on methodological grounds. The SCAFT-principles were intended as a comprehensive statement of a preventive, rather than reactive, approach to safety management. The principles neglected the possibility of road user adaptation to design elements and thus most likely overstated the safety benefits that could be obtained. Shared space has recently emerged as one possible new solution, mixing rather than separating different categories of road users. The naivete of the initial evaluations of its safety effects virtually guarantees that someday, someone more critical of it than the current activists, will do a rigorous evaluation leading to its demise.

8 CONCLUSIONS

The question this paper asks is whether evolutionary theory can explain the slow accumulation of knowledge about the level of safety built into roads conforming to the design standards prevailing at any time. According to evolutionary theory, the initial development of knowledge is unplanned: knowledge is discovered through learning-by-doing. What is learnt this way will be copied and if copying is seen as successful, it may develop into a routine that is followed without much reflection. Reactive safety management, being based on accident history, resembles a process of evolution in this sense. The claims made about the success of the reactive approach, as routinised most strictly in the identification and treatment of black spots or high-risk drivers, are exaggerated because the reactive approach for a long time was based on a statistically naïve approach that mixed up regression-to-the-mean with real changes in safety. As a result, many flawed studies were made that did not produce valid knowledge. Evolutionary theory can only be applied as a heuristic device to help interpret and understand the development of knowledge. It is not really a testable theory, since history does not produce a control group that followed a different path of development.

ACKNOWLEDGEMENT

This research was funded by the Research Council of Norway, grant number 210486.

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LIST OF FIGURES AND TABLES

Table 1:

Number of accidents	Number of drivers	Total accidents	Accidents second period	Predicted number of accidents
0	52	0	47	47.8
1	44	44	45	46.8
2	26	52	27	31.4
3	16	48	27	21.7
4	3	12	4	4.5
5	0	0	0	0.0
6	1	6	4	1.8
Total	142	162	154	154.0
Mean per driver	1.141			
Variance	1.346			

Table 2:

	Coefficients of negative binomial regression – standard errors in parentheses			
Terms	Cyclists and pedestrians inside area	Motor vehicles inside area	Cyclists and pedestrians on main roads bordering area	Motor vehicles on main roads bordering area
Constant term	-5.767 (1.423)	-5.770 (1.577)	-4.143 (2.275)	0.893 (2.443)
Traffic indicator	0.973 (0.158)	0.983 (0.178)	0.687 (0.267)	0.281 (0.287)
Complexity	-0.003 (0.003)	0.001 (0.003)	0.015 (0.005)	0.004 (0.006)
Differentiated	-0.658 (0.219)	-0.565 (0.240)	0.426 (0.322)	-0.043 (0.327)
Separated	0.041 (0.562)	0.302 (0.515)	-0.521 (0.678)	-0.601 (0.630)
Over-dispersion	0.022 (0.042)	0.081 (0.056)	0.235 (0.103)	0.267 (0.102)
Elvik index	0.854	0.905	0.790	0.302

Table 3:

	Editions of design guidelines					
	1981	1981	1992	1992	2013	2013
Design parameter	**AADT 1500-4000**	**AADT 4000-8000**	**AADT 1500-5000**	**AADT 5000-10000**	**AADT < 4000**	**AADT 4000-6000**
Lane width (m)	3	3.25	3	3.25	3.25	3.5
Shoulder width (m)	0.5	1	0.75	1	1	1
Total width (m)	7	8.5	7.5	8.5	8.5	10
Minimum horizontal curve radius (m)	100	150	160	230	250	300
Length of largest design vehicle (m)	15	15	22	22	22	22
Width of largest design vehicle (m)	2.5	2.5	2.5	2.5	2.6	2.6

Figure 1:

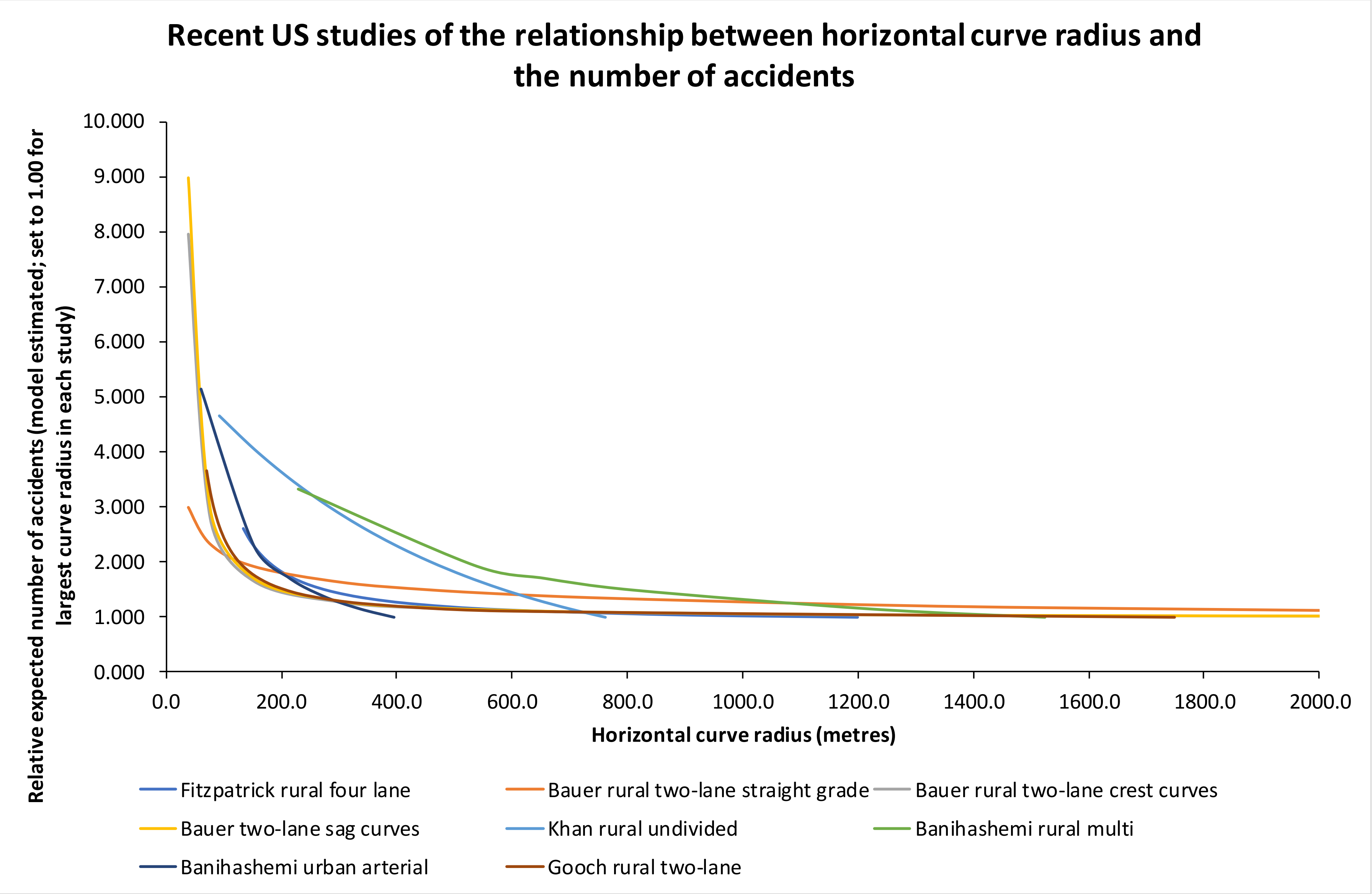
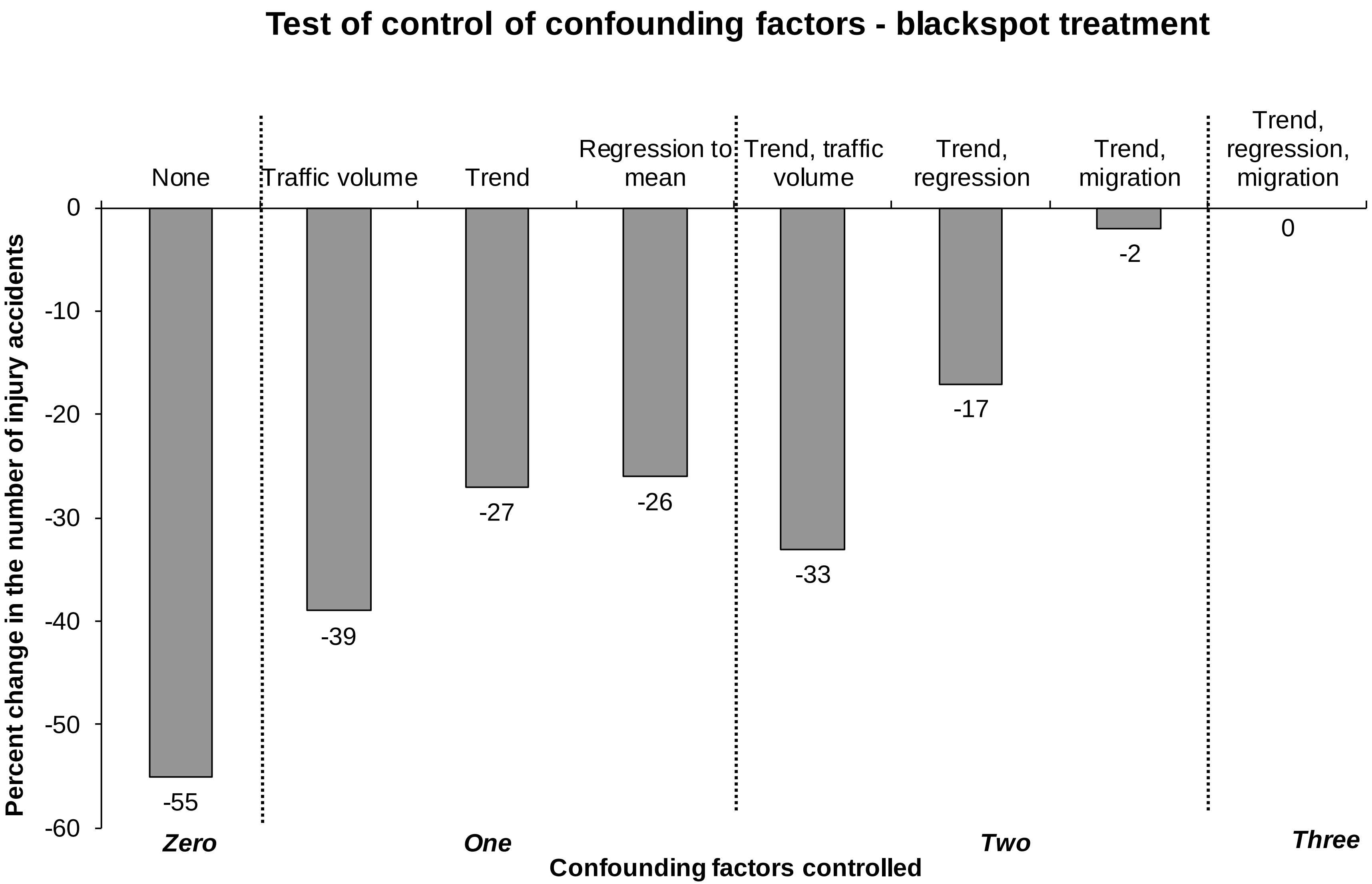

Recent US studies of the relationship between horizontal curve radius and the number of accidents
Relative expected number of accidents (model estimated; set to 1.00 for largest curve radius in each study)
10.000
9.000
8.000
7.000
6.000
5.000
4.000
3.000
2.000
1.000
0.000
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0
1600.0
1800.0
2000.0
Horizontal curve radius (metres)
Fitzpatrick rural four lane
Bauer rural two-lane straight grade
Bauer rural two-lane crest curves
Bauer two-lane sag curves
Khan rural undivided
Banihashemi rural multi
Banihashemi urban arterial
Gooch rural two-lane

Figure 2:


Test of control of confounding factors - blackspot treatment
None
Traffic volume
Trend
Regression to mean
Trend, traffic volume
Trend, regression
Trend, migration
Trend, regression, migration
0
-10
-20
-30
-40
-50
-60
-55
-39
-27
-26
-33
-17
-2
0
Percent change in the number of injury accidents
Zero
One
Two
Three
Confounding factors controlled