Australasian Transport Research Forum 2022 Proceedings
28-30 September, Adelaide, Australia
Publication website: http://www.atrf.info

What happens, and why, in road accidents

T. P. Hutchinson[1]

[1]Centre for Automotive Safety Research, University of Adelaide, South Australia 5005, Australia

Email for correspondence: timothy.hutchinson@adelaide.edu.au

Abstract

This paper suggests how to describe what happens in a road accident, and why. But road accidents as a whole are too varied, and some smaller concept is needed. The strategy here is to select some class of accidents that are similar, split the events of that class of accident into stages, and attempt to understand the stages. (a) The example selected is the class of accident in which a car being driven forwards normally is suddenly faced with an obstacle in front of it. (b) Such accidents are split into three stages. 1, Preceding appearance of the obstacle. 2, From appearance of the obstacle to when the car strikes it (or stops). 3, After first contact is made (but this is not discussed in this paper, as it is reasonably well-understood in principle). (c) For stage 2, a model is proposed that implies an elementary equation for impact speed. The equation involves five quantities, namely, travelling speed, range of sensor, distance of object, reaction time, and braking strength. (d) For stage 1, cause of accident is approached using two questions. Why was the obstacle present? And, if it was present deliberately and because of human error, what was the error? Suggestions are made for classifying the answers. (e) In many of the road accidents with two active participants, one has generated the danger and the other has reacted. If data analysis proceeds without their being disaggregated, it may become difficult to perceive factors and patterns of factors that are relevant to crash causation and outcome. This disaggregation may be particularly useful when one participant is a pedal cyclist.

1. Introduction

This paper will suggest a way of thinking about what happens in road accidents, and why.

Recent decades have seen a great reduction of road fatalities in the developed world. Three methods of study have been prominent.

- Analysis of data on millions of road accidents, routinely collected by the police.
- Detailed investigation of relatively few accidents.
- Observation of the effects of many practical measures aimed at improving roads, vehicles, and human behaviour.

The present author's opinion, however, is that these methods have not given us a widely-relevant summary of events - and that vagueness about this may mean that safety measures are less than optimal.

The major sections of the paper are as below.

Overview of what will be proposed,

Selection of a class of accidents,

Frontal impact with an obstacle: Stages of the accident,

Reaction to obstacle,

The few seconds before the obstacle appears,

Discussion.

2. Overview of what will be proposed

Part of the reason for this paper is to improve understanding of accident causation. Causes of road accidents have been rather neglected for many years - it has been a habit to think about multiple contributory factors instead. In this paper, the chief meaning of "cause" refers to why an obstacle was present, and if there was some error, what that error was and why it occurred. The causes of the causes - very often, some condition of the driver, road, or vehicle that leads to errors - are not discussed. Knowledge of these has indeed improved greatly.

This paper is not critical of existing approaches to describing road accidents and improving road safety. The suggestions here are complementary.

Table 1 gives a summary of what is proposed.

Table 1: Summary of how to describe what happens in a road accident, and why.

Select.	Select a class of accidents that have something in common. Discussed in this paper are those in which a car being driven forwards normally is suddenly faced with an obstacle in front of it.
Stages of this type of accident.	1. Preceding the appearance of the obstacle. 2. From the appearance of the obstacle to the moment when the car strikes it (or stops). 3. After first contact is made.
Stage 2.	It is demonstrated that stage 2 can be modelled. The equation for impact speed is obtained.
Stage 2 (again).	The model implies that impact speed depends on five quantities - travelling speed, range of sensor, distance of obstacle, reaction time, braking strength.
Stage 1.	To help clarify the concept of cause of accident, two specific questions are worth consideration. Why was the obstacle present? And, if it was present deliberately and because of human error, what was the error? Suggestions are made for classifying the answers to those questions. However, psychological dimensions of reasons for error are only partly understood.
Initiating and reacting road users.	There may be an initiating (initiating of danger) road user and a reacting (reacting to emergency) road user. They may respectively be the focus of interest in stage 1 and stage 2. If practicable, it will often be desirable to distinguish between them in accident data.
Other matters.	Stage 1. Several factors are likely to be relevant to good performance of gap acceptance or similar task (Section 6.3). Knowledge has been sufficient to improve road safety in many ways, sometimes without full understanding of the chain of causes and effects. Stage 3 and after. Stage 3 (i.e., after first contact) is not discussed in this paper, as it is reasonably well-understood in principle. After stage 3, the medical consequences of the human impact are outside the scope of this paper, and some aspects of this are not well understood.

There is a sense in which this paper is unbalanced.

- In principle, there are lots of different types of road accident, and each of these happens over a period of time, and is likely to have several stages.
- This paper, in contrast, concentrates on one of the types of accident, and only gives concrete results for stage 2.

There are good reasons for limiting the paper in this way.

- The type of accident discussed is a large class of frontal impacts, see Section 3 below.

- Stage 2 refers to the second or two before impact - from appearance of the obstacle to impact. What happens immediately after contact is not discussed on the grounds that it is well-understood in principle. What happens to lead to stage 2, that is, what generates the emergency, is too difficult at present, though Section 6 prepares the way.

Table 1 also makes clear that the paper tries to be helpful in different ways.

- Structuring the problem of how to think about road accidents, by selection and splitting into stages.
- Concrete results in the form of a formula for impact speed.
- Choosing preliminary questions that are intended to disaggregate accidents in such a way that may permit psychological questions relevant to causation to be asked.
- A recommendation that initiating (initiating of danger) and reacting (reacting to emergency) road users ought, if practicable, to be distinguished when tabulating accident data.

3. Selection of a class of accidents

The first step is that we need to select a smaller concept than all road accidents considered together. It is not clear how to do that, except by following long-established habit - such as a specific type of vehicle, or of site, or of driver, or of impairment. Indeed, this difficulty is part of the problem that this paper is addressing. For this paper, the choice falls upon accidents in which a car is being driven forwards in a normal manner and is suddenly faced with an obstacle in front of it. This very big class of accidents is what will be discussed further.

Other types of accident include those in which the first abnormal event refers to the way the vehicle is being driven (e.g., loss of control when cornering), or to the vehicle (e.g., tyre failure), or to the driver (e.g., sleep).

- Some, but not all, of what is said in this paper about frontal impacts is likely to be relevant also in these different circumstances.
- Some of these other types of accident are likely to be relatively more common in the case of vehicles other than cars. Riders of two-wheeled vehicles may be injured or killed by falling to the roadway, and so frontal collision with an obstacle may constitute a smaller proportion of the total injury accidents than in the case of cars. And in some circumstances, trucks are less stable than cars.

Some examples of frontal impact with an obstacle are as follows.

- Consider a pedestrian coming from the side into the car's forward path, at such a short distance that there is plainly an emergency. This is the type of accident in mind, an *intruding obstacle* coming into the path of a *reacting car*.
- A rear-end impact in traffic is in many ways similar: the vehicle ahead suddenly becomes an obstacle, and a driver needs to react. However, this is a very large class of accidents, and it could be split into several sub-classes, each requiring a slightly different model. The sub-classes might differ in respect of how heavy is the flow of traffic, how fast, whether the location is one where drivers might expect to stop (e.g., an intersection), whether the driver can see the brake lights of vehicles beyond the vehicle being followed, whether there is fog, and whether a heavy vehicle is present. Then specific models might be created for some of the sub-classes, rather than use a more general one.
- The intruding obstacle may itself be a vehicle. The front of the reacting car may strike the side of the intruding vehicle - in other language, the front of the striking car hits the

side of the struck vehicle. The alternative, probably less common, is that the side of the reacting car is struck by the front of the intruding vehicle, in which case the reacting car is the struck car and the intruding vehicle is the striking vehicle.
- Street furniture and trees do not often move into the roadway. Collisions off the road imply the car left the road for some reason.

4. Frontal impact with an obstacle: Stages of the accident

Thus we are considering a car being driven forwards normally that is suddenly faced with an obstacle in front of it. The car may be controlled by a human, or may act autonomously.

The second step is that the events of this type of accident fall into several stages.

The beginning of accident events is a nebulous idea. In contrast, first contact of the car with the obstacle is a clearly-defined moment. It is easier to consider an impact and look back a few seconds, than to start from driving or riding or walking and examine whether an accident occurs or not. The next Section of the paper is about the second or two before impact - from appearance of the obstacle to impact. The car driver (or an autonomous car) may notice the obstacle, react to it, and brake strongly. This will be referred to as stage 2.

That may be distinguished from later and earlier stages of the accident.

- Stage 3. After the contact of the car with an obstacle (e.g., another vehicle, a pedestrian, a cyclist, or a tree), questions arise about velocity change, movement of vehicles during impact, movement of occupants within the vehicle, and deceleration of the occupants due to collision with the vehicle interior or with the seat belt and air bag. And there are analogous questions about the obstacle (focus might be on the obstacle if that is a pedestrian or vehicle). These questions are reasonably well understood in principle (Grime, 1966; Grime and Jones, 1969; Harper, 1953), even if a great many difficulties remain in practice. The medical consequences of the human impact are regarded as outside the scope of the present discussion; some aspects of this cannot be said to be reasonably well understood.
- Stage 1. Now consider the few seconds before the obstacle appeared. Questions arise about why the obstacle was present and, if it was present deliberately and because of human error, why that error was made. These questions are very poorly understood, though something will be said in Section 6 below.

For convenience here, each of these sets of events - before the obstacle appears, and after first contact - will be referred to as a single stage. In other contexts they might be split into several stages.

5. Reaction to obstacle

At this point, the type of accident being considered has been identified, and so has the stage of that type. The third step is to consider what is the result that we wish to know, how to model what happens, and how to calculate the result using the model.

5.1. What result do we want?

Impact speed is important in determining whether death occurs, and the severity of any injuries. The dependence of probability of death on speed is quite strong: it is usually thought that a 1 per cent reduction of speed leads to about a 3 per cent reduction of deaths.

Partly because of that, and partly because of the high numbers of deaths if we are referring to an intervention that is relevant to a broad class of accidents, it is widely considered that a reduction of speed - even quite a small proportionate reduction of speed - is well worthwhile.

Impact speed will be a useful result to know. A model will be proposed, from which it will be possible to calculate impact speed.

5.2. Model of reaction

The following may be the simplest possible theory of road collisions.

> A car is being driven normally at speed v. If there is an obstacle directly ahead at distance x and within a distance d, then emergency braking with deceleration a begins after time t.

What makes a model and an equation practicable is that *equations of motion under constant acceleration* are elementary (and are often mastered at school). It may be noted that this model does not mention any tracking of road users before they become obstacles. If tracking happens, it could be reflected in a reduced reaction time.

The general style of wording of the model is that it is careful, but various assumptions and simplifications are not necessarily spelt out. For example, the obstacle (such as a vehicle or a pedestrian) is assumed to be directly in the path of the car we are describing, and does not move out of its path; the obstacle is not moving towards or away from the car we are referring to; the car might stop before it strikes the obstacle (and this is considered as an impact speed of zero); the words "car" and "normally" are not defined; it is not made clear what might affect the five quantities in the equation (for example, characteristics and impairments of the driver, characteristics and faults of the car, condition of the road surface). Only braking is considered as a response, not steering to avoid the obstacle. The event is an emergency, requiring the strongest possible braking.

The concept of time-to-collision is sometimes used, especially in the context of autonomous vehicles. A model might employ a time instead of the distance d, that is, something would happen (such as braking, or steering) if the vehicle is within a specified time of colliding with something. Suzuki et al. (2014, Table 1) discuss models having two braking strengths, braking being initiated by time-to-collision being sufficiently small.

5.3. Equation for speed of impact

In words, the relevant equation of motion under constant acceleration is

> difference between the squares of speeds before and after acceleration
>
> = 2 × acceleration × distance over which acceleration acts

For the model stated above, the square of impact speed is

$$u^2 = \max\{0, v^2 - 2.a.\max\{0, \min\{x, d\} - v.t\}\}$$

This is much simpler than it may look.

- It is assumed that deceleration during braking is constant.
- The speed after a given distance can be calculated from the distance, the strength of acceleration, and the speed at the beginning.
- One of the well-known equations of motion under constant acceleration is $u^2 = v^2 - 2.a.x$. This is appropriate if, for example, a pedestrian dashes out in front of the car at a distance x.

Then some minor complications need to be incorporated in the equation.

- To allow for the possibility that the obstacle is further than the eyes of the driver can see (or the sensor of an autonomous vehicle can detect), we need min{x, d} rather than x.
- Distance travelled during reaction time is v.t, and this needs to be subtracted. Thus distance min{x, d} − v.t is available between the car and the obstacle when braking begins.
- But that is only a relevant distance provided it is positive - a negative quantity would mean the car has already struck the obstacle (with undiminished speed v). Thus the operation max{0, min{x, d} − v.t} is needed.
- Finally, the distance available may be sufficient for the car to stop, in which case the final max operation is needed.

For the model and the equation, see Hutchinson (2018, Chapter 5), which is based on Hutchinson (2015, 2016). The equation may have been known 100 or 150 years ago. Wooller (1968, Figure 5) shows an equation in which there is "distance at which a pedestrian in the path of a vehicle becomes visible to the driver", rather than d and x separately. There is nothing here that is new to those working on systems to control vehicles autonomously or to warn drivers of impending collision.

Reaction to an obstacle is important to avoid or mitigate a crash. The obstacle may have made a mistake (e.g., misjudged a gap in traffic), and is consequently in the car's path. Whether or not there is any such mistake, the driver who is reacting may have (for example) reacted too slowly or failed to brake strongly enough. Catchpole et al. (1994) find over-representation of young drivers in accidents resulting from conflicts created by unexpected actions of other road users: young drivers may fail to detect or predict conflicts early enough.

It is likely to be easy to handle some modifications of the model.

- The action taken might be changed from "emergency braking" to "braking". Then deceleration might be quite small, rather than being limited by tyre-road friction.
- If the task is easy but reaction is late or does not occur, it can be said that reaction time is very long. If that is unappealing, the model might be made probabilistic. That is, it would state: "If there is an obstacle directly ahead .... then with probability p emergency braking .... begins, and with probability 1-p there is no braking."
- The vehicle that encounters an obstacle might be something other than a car: see Section 5.4.

5.4. Asymmetry of car-obstacle impacts

It may be that the obstacle is another vehicle. Impact speed is likely to be just as relevant to the occupants or riders of that vehicle as it is to the occupants of the car we are thinking of.

But suppose the vehicles are interchanged? The model of reaction (Section 5.2) refers to a "car" encountering an obstacle, but it is likely that it will also be relevant in the case of a pedal cycle, motorcycle, truck, or other vehicle. Relevant, yes, but it may be that the quantities v, t, x, d, a are different from those of a car and its driver.

If a car collides with a pedal cycle or a motorcycle, it will usually be the cyclist who is injured or killed. For the cyclist, a car striking a cycle may be quite a different event - as regards impact speed, for example - from a cycle striking a car. If an initiating car is struck by a reacting cycle, both vehicles' speeds are likely to be low; if an initiating cycle is struck by a reacting car, the car's speed may be high (in the case of high travelling speed and failure to brake much).

And a car striking a truck may be quite a different event from a truck striking a car. However, other features of car-truck crashes - including high velocity change of the car arising from greater mass of the truck, and under-run arising from geometric incompatibility of car and truck - tend to receive more attention.

It would be of interest to know whether the distinction between an initiating and a reacting vehicle can be made in accident datasets; and if so, whether the characteristics of the vehicles and their drivers differ.

5.5. The five important quantities

There are five quantities - v, t, x, d, a - that (in the given model) determine impact speed. It will usually be the case that

> travelling speed v is fixed (by driver choice or traffic conditions) some time before the emergency,
>
> range d is greater than x, and so is not relevant,
>
> deceleration a is determined by the coefficient of friction between tyre and road surface that is available (since it has been described as emergency deceleration),
>
> and distance x is decided by the action of the obstacle.

If we are considering the viewpoint of the driver, the above propositions are likely to be accepted. Thus four quantities are fixed, and reaction time t is the main source of variation in what happens.

Is any one of the five quantities easier to change than others? Travelling speed v is under the control of an individual driver in a way that the others are not. Thus it seems more reasonable to centre a safety campaign on choice of travelling speed than on any of the other variables.

6. The few seconds before the obstacle appears

The fourth step in this paper is to attempt to push understanding (of what happened and why) to a little earlier than the moment when the obstacle was first in the path of the car.

6.1. Classification of reasons for the presence of the obstacle

It is likely that what happened was the obstacle moved into the path of the car. This is not always the case - possibly the car altered its path, e.g., because of misjudgment by the driver. (If attention is strictly on crashes in which the car is being driven normally, cases resulting from a fault of the car or the driver are likely to be rare.)

Why, then, did the obstacle move into the path of the car? The obstacle may be a human, or controlled by a human. Humans make mistakes. It is widely considered that many road accidents are due to human error. Thus it is seems appropriate to ask whether the obstacle is present deliberately, and whether it has a right to be there. Possible reasons for the presence of the obstacle are as follows.

- Deliberately, as the result of a mistake.
- Deliberately, perhaps without any mistake, but has become stuck.
- Deliberately, has a right to be there - the driver of the vehicle that is reacting to the obstacle may have made some misjudgment, or be following too closely.
- Inadvertent, or for a reason that is not a normal mistake. This includes a lot of odd things, such as an out-of-control vehicle, grossly irresponsible behaviour, and criminal behaviour. Some of these may exclude the event from the definition of a road accident.

6.2. Classification of human error

It may be that the most common reason for the presence of an obstacle is that it is there deliberately, because of mistake. A person may have accepted a gap in the stream of traffic, and tried to join or cross the traffic stream or overtake.

In principle, we might at this point consider the psychology associated with human error or human performance. However, we usually want to think, and tabulate data, about a group of accidents, not an individual accident. The opinion of the present author is that the messages in a table of data will not be seen if lots of different types of accident are not disaggregated.

Disaggregation will require several preliminary issues to be considered, as outlined below.

- The type of crash is the first of the preliminaries. In the present context, attention is on the case of an obstacle (pedestrian or vehicle) moving into the path of a vehicle.
- Then consider three cases separately. (a) The obstacle does not have right of way. (b) The obstacle has right of way. (c) Misunderstanding about who has right of way.
- Consider only short-lasting actions. (Long-lasting states, such as speeding, are a separate issue.)
- Actions should be classified in three ways: according to whether the person is taking the initiative or is reacting to something, according to whether the action is normal or is unexpected, and according to how much thought precedes the action.
- Make the contrast between errors of omission and errors of commission.

The above preliminaries are reasonably objective - it may be possible to make the classifications with crash data. Once the preliminaries are out of the way, it may be possible to consider psychological classification - attentional, sensory, judgment, decision-making, execution, and so on.

6.3. Comments

The implication of Section 6.2 is that it may be practicable to examine causes in a narrower context than the whole population of road accidents. That is, restrict attention to a road user who is about to become a potential obstacle on the road.

And before the human error? From a practical point of view, several factors are likely to be relevant to good performance of the gap acceptance task.

- These include: clear lines of sight; normal eyesight, normal decision-making ability, normal motivation, and normal ability to move; being patient and not acting on poor visual information; perception of vehicles' speeds, perception of gaps between vehicles, and appropriate expectations about vehicle speeds and the gaps between vehicles; in many cases, ability to assess gaps and speeds for two or more traffic streams simultaneously; being aware not only of what is seen but also of what may potentially be present but cannot be seen (blind spots).
- Impairment by (for example) alcohol, fatigue, or distraction is likely to increase the likelihood of generating danger.

Measures taken to make the task easier, or to prevent impairment, are likely to improve safety. The present author's opinion is that in developed countries, over a period of many decades, there has been great practical success and a broadening of knowledge - but that some links in the chain that leads to creation of an obstacle are not understood well.

7. Discussion

This paper has made suggestions about how to describe what happens in a road accident, and why. (Practicalities of what can realistically be expected of road accident data have been relegated to the background.) The suggestions were summarised in Table 1.

The descriptions in this paper have started from the moment of impact, and then looked at progressively earlier times. First, from the obstacle appearing until impact. Before then, why the obstacle was present. And before then, the mistake that was made that put the obstacle there. This may seem counter-intuitive. Certainly the intention is eventually to generate a narrative in the natural order of (1) certain causes led to (2) an error, (3) the error put the obstacle in a vehicle's path, (4) that vehicle attempted to stop, (5) a crash occurred, or was avoided. That may be possible when more progress has been made with the human errors and their causes.

From Section 5, there are specific results.

- Impact speed depends on travelling speed, range of sensor, distance of obstacle, reaction time, braking strength.
- For the model suggested, there is an elementary equation for impact speed in terms of those five variables.
- A helpful way of thinking about road accidents is to consider, for any vehicle, which category it falls into - it strikes something else (after either reacting or failing to react to its presence); or was struck by something else; or the accident was of some other type. Rather than striking versus struck, a better description is reacting (to an obstacle) versus initiating an action (intruding into the roadway and becoming a potential obstacle).
- There is asymmetry between car and two-wheeled vehicle. Also, fall-to-road impacts are important in the case of two-wheeled vehicles. Thus the classification as reacting or initiating or something else may be particularly helpful for two-wheeled vehicles.

From Section 6, there is nothing so definite as the above, but there are steps towards accident causation. First, ask why the obstacle (which may be human, or a vehicle, or an object) was present in the path of a vehicle. Second, ask what was the nature of the error, if indeed the presence of the obstacle was deliberate and due to some error. And then, some day in the future, a psychological classification of the reason for the error may be practicable.

An advantage of thinking about road accidents in the way suggested is that it identifies the aspects that are most difficult: the stage or stages before the obstacle appears, and particularly the psychological dimensions of any human error that occurred.

In the promotion of road safety, five factors commonly highlighted as dangerous are speed, failure to wear a seat belt, alcohol (and drugs), fatigue, and distraction.

- Of the factors important at stage 2 of the accident, travelling speed is most important in that it is to some extent controlled by the driver (Section 5.5).
- A seat belt operates at a very late stage, the human impact.
- Impairment of human performance - whether by alcohol, drugs, fatigue, distraction, or something else - presumably operates by increasing the probability of human error (stage 1) and by slowing reaction (stage 2).

Section 5 and Section 6 have respectively considered the reacting vehicle and the road user that created the obstacle. That is, in many of the road accidents with two active participants, one initiates action (and perhaps generates danger) and the other reacts to it. Indeed, it is common experience of road users to sometimes initiate an action (e.g., for a pedestrian to cross the road) and sometimes react (e.g., braking in response to seeing brake lights). If the two types of participant, or two types of action, are too readily aggregated together in analysis of road accident data, it may become difficult to perceive factors and patterns of factors that are relevant to crash causation and outcome. And this is perhaps one of the most attractive opportunities to come out of this paper - to determine whether this distinction can be made in accident datasets, and if so, what the results are.

Acknowledgements

The Centre for Automotive Safety Research, University of Adelaide, is supported by the South Australian Department for Infrastructure and Transport. The views expressed are those of the author, and do not necessarily represent those of the University of Adelaide or the funding organisation.

References

Catchpole, J.E., Cairney, P.T., and Macdonald, W.A. (1994). Why are young drivers over-represented in traffic accidents? Special Report 50, Australian Road Research Board, Vermont South, Victoria.

Grime, G. (1966). Safety cars. Principles governing the design of cars and safety devices. RRL Report 8, Road Research Laboratory, Harmondsworth, U.K. https://trl.co.uk/sites/default/files /LR008.pdf

Grime, G., and Jones, I.S. (1969). Car collisions - The movement of cars and their occupants in accidents. Proceedings of the Institution of Mechanical Engineers: Automobile Division, 184, Part 2A, No. 5, 87-125 (Discussion, 126-136).

Harper, W.W. (1953). Prevention and reduction of injuries in traffic collisions. Journal of Criminal Law, Criminology and Police Science, 43, 515-529.

Hutchinson, T.P. (2015). The theory of reduction of impact speeds. Traffic Engineering and Control, 56, 177-180.

Hutchinson, T.P. (2016). A method of constructing models of reaction to an imminent road crash. Traffic Engineering and Control, 57, 97-103.

Hutchinson, T.P. (2018). Road Safety Theory. Available at RoadSafetyTheory.com.

Suzuki, K., Tanaka, H., Miichi, Y., and Aga, M. (2014). Collision-mitigation level of collision-avoidance braking system. International Journal of Vehicle Safety, 7, 1-16.

Wooller, J. (1968). Road traffic accidents in Adelaide and Brisbane, Australia - Excerpts from a report in preparation. Proceedings of the 4th Conference of the Australian Road Research Board, 4(1), 976–994.