

## A Technique for Showing Causal Arguments in Accident Reports

C. W. Johnson; University of Glasgow; Glasgow, Scotland, UK

C. M. Holloway; NASA Langley Research Center; Hampton, Virginia, USA

Keywords: causes, argument, visualization, highway accidents, disagreements

### Abstract

In the prototypical accident report, specific findings, particularly those related to causes and contributing factors, are usually written out explicitly and clearly. Also, the evidence upon which these findings are based is typically explained in detail. Often lacking, however, is any explicit discussion, description, or depiction of the arguments that connect the findings and the evidence. That is, the reports do not make clear why the investigators believe that the specific evidence they found necessarily leads to the particular findings they enumerated. This paper shows how graphical techniques can be used to depict relevant arguments supporting alternate positions on the causes of a complex road-traffic accident.

### Introduction

A typical format for an accident report consists of four main sections: a factual narrative that lays out the sequence of events relevant to the accident and its investigation; a section that describes the analysis that was conducted during the investigation; a list of conclusions about the accident, including attribution of causes and contributing factors; and a set of recommendations for how to prevent similar accidents in the future (ref. 1). Not included as part of the typical report is any explicit description or depiction of the (usually) complex arguments that tie the various parts of the report together. Readers who are interested in understanding the underlying arguments must try to reconstruct the arguments on their own. This paper shows how a relatively simple graphical notation can be used in this reconstruction to map out the causal arguments that are left implicit in most reports.

### Case Study: A School Bus Accident

As a case study to illustrate the technique, we use the report by the U.S. National Transportation Safety Board (NTSB) about a school bus accident in Omaha, Nebraska, on October 13, 2001 (ref. 2). The accident involved a 78-passenger school bus carrying 27 children and 4 adults. The bus entered a work zone lane shift on US Route 6 in Nebraska. It was faced with another bus travelling in the opposite direction; there was no median separation and the accident vehicle departed the roadway to the right, striking a barrier on the approach to a bridge. The accident bus then steered to the left momentarily before veering back to the right, and striking the barrier once more before impacting with a three-rail barrier between a guardrail and the concrete bridge railing. The bus passed through these obstacles and rode over the bridge sidewall. It rotated in mid-air and fell about 49 feet to land in a shallow creek. Three children and one adult were killed.

The NTSB report about the accident is relatively short, consisting of less than 100 total pages. It follows the typical format described above. The Conclusions section of the report lists 22 separate findings, and gives the following probable cause statement:

The National Transportation Safety Board determines that the probable cause of this accident was the failure of the Nebraska Department of Roads to recognize and correct the hazardous condition in the work zone created by the irregular geometry of the roadway, the narrow lane widths, and the speed limit. Contributing to the accident was the accident bus driver's inability to maintain the bus within the lane due to the perceived or actual threat of a frontal collision with the approaching eastbound motorcoach and the accident bus driver's unfamiliarity with the accident vehicle. Contributing to the severity of the accident was the failure of the traffic barrier system to redirect the accident vehicle.

One member of the five-member Board, Vice Chairman Rosenker, was not satisfied with this probable cause statement; he issued the following dissenting opinion:

I agree with my colleagues and the entire report with the exception of a portion of the probable cause. Our staff's proposed probable cause, correctly in my view, identified the primary cause as the accident bus driver's inability to maintain the bus within the lane due to the perceived or actual threat of a frontal collision with the approaching eastbound motorcoach. The majority of the Board instead attributes the cause to the Nebraska Department of Roads. While I fully support that there were significant design and other deficiencies with the work zone, they did not preclude the safe operation of vehicles through the work area, and the work zone accident history undermines ascribing primary cause to the Department of Roads.

We chose this report for the case study for three reasons. Firstly, the report is unusual in that one of the NTSB members dissented from the determination of the Board about probable and contributory causes, although he accepted all of the other findings of the report. This means that the dissenter and the other members must have used different arguments to reach their final causal conclusions. This difference provides an interesting test of the efficacy of our graphical technique for illustrating arguments.

Secondly, this accident represents one of a large number of similar road traffic accidents that claim lives both in the United States and Europe (ref. 3). Thirdly, the use of this case study is motivated by the observation that similar vehicles transport children across relatively large distances and on frequent trips so that the risk exposure to future incidents may continue to be correspondingly high and with similar potential consequences.

#### Constructing a High-Level Map for Causal Arguments

The first stage of our work was to describe a high-level structure for the arguments in the report. We began by separating the probable cause statement (p. 83 of the report) and dissenting opinion (p. 85) into five individual propositions, as shown in Table 1.

Table 1— Summary of Causal Propositions

<b>Probable cause</b> was the failure of Nebraska Department of Roads to recognise and correct the hazardous condition in the work zone created by the irregular geometry of the roadway, the narrow lane widths, and the speed limits.
<b>Contributing to the accident</b> was the accident bus driver's inability to maintain the bus within the lane due to the perceived or actual threat of a frontal collision with the approaching eastbound motorcoach and the accident bus driver's unfamiliarity with the accident vehicle.
<b>Contributing to the severity of the accident</b> was the failure of the traffic barrier system to redirect the accident vehicle.
<b>Dissenting probable cause:</b> The primary cause (was) the accident bus driver's inability to maintain the bus within the lane due to perceived or actual threat of a frontal collision with the approaching eastbound motorcoach.
<b>Dissenting comment:</b> The majority of the Board instead attributes the cause to the Nebraska Department of Roads. While I fully support that there were significant design and other deficiencies with the work zone, they did not preclude the safe operation of vehicles through the work area and the work zone accident history undermines ascribing primary cause to the Department of Roads.

Our analysis then took a more detailed look at the arguments that supported or weakened each of these different propositions. The following figures use an informal graphical notation to map out the relationships between the 22 findings of the report (listed on pages 81-82 of the report) and the propositions from Table 1. These graphs are based on the argumentation structures that were originally developed in the area of design rationale (ref. 3) to provide a graphical representation of the arguments for and against particular design options. In this paper, we have extended the constructive use of these techniques to map out arguments that focus on the causes of failure in the design and operation of safety critical systems.

Figure 1 maps the various arguments that support the proposition that the Department of Roads contributed to the probable cause of the accident. We have deliberately chosen to adopt the simplest representation that we could devise. Later sections will demonstrate that many causal arguments rely on a broad and diverse array of evidence.

It was, therefore, important that any graphical overviews did not add unnecessary complexity to these already complex constructs.

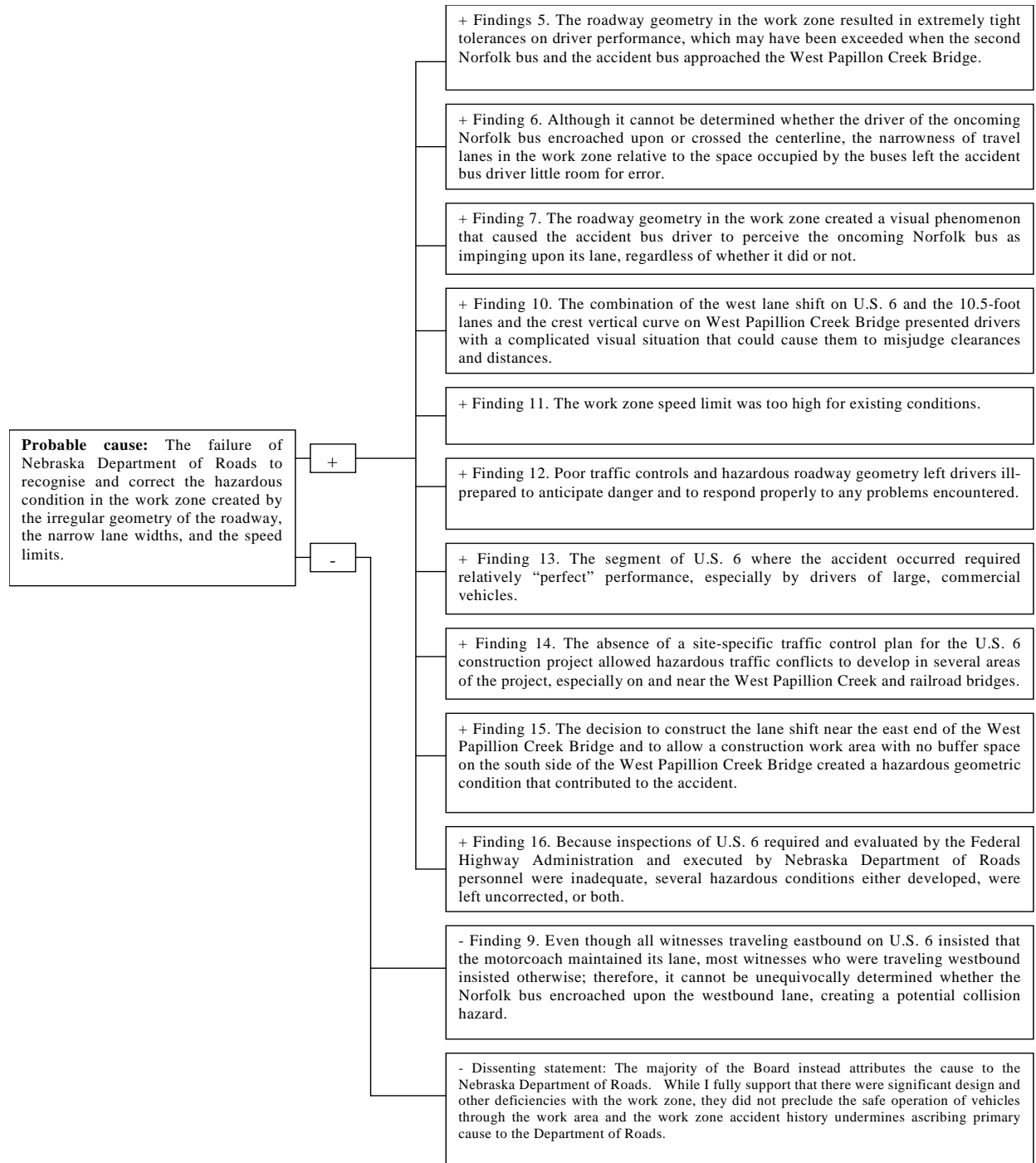


Figure 1 — Findings Related to the NTSB’s Probable Cause of the Accident

As can be seen from figure 1, most of these findings are linked to the probable cause by arcs that are annotated with the ‘+’ symbol. That is, the findings support the case for the Department of Roads’ involvement in the probable cause of the accident. These include observations such as “+ Finding 12. Poor traffic controls and hazardous roadway geometry left drivers ill-prepared to anticipate danger and to respond properly to any problems

encountered” and “+ Finding 16. Because inspections of U.S. 6 required and evaluated by the Federal Highway Administration and executed by Nebraska Department of Roads personnel were inadequate, several hazardous conditions either developed, were left uncorrected, or both”.

Figure 1 also shows that some of the findings undermine the majority’s conclusion about the probable cause. In particular, finding 9 in the report states that “Even though all witnesses traveling eastbound on U.S. 6 insisted that the motorcoach maintained its lane, most witnesses who were traveling westbound insisted otherwise; therefore, it cannot be unequivocally determined whether the Norfolk bus encroached upon the westbound lane, creating a potential collision hazard”. In other words, it cannot be proven that the road characteristics caused the Norfolk bus to create a potential collision hazard.

Figure 2 continues the analysis by summarizing the NTSB findings that relate to the contributory causes of this accident. As can be seen, many of the insights from the investigation relate to the factors that may have influenced the drivers’ behaviour. It is important to stress that the construction of these diagrams relies on the subjective expertise of the analyst. Their development is not straightforward. For example, many of the factors that influenced the driver stemmed from the operations of the Department of Roads. Hence it can be difficult to determine whether a particular finding should go in either figure 1 or figure 2 or both. The key issue here is, however, to provide an explicit representation of the argument structures that were developed in the aftermath of this accident. These representations then provide a focus for further analysis. Figure 2 does not include any contradictory or negative links because the dissenting opinions sought to raise the importance of the drivers’ involvement in the accident.

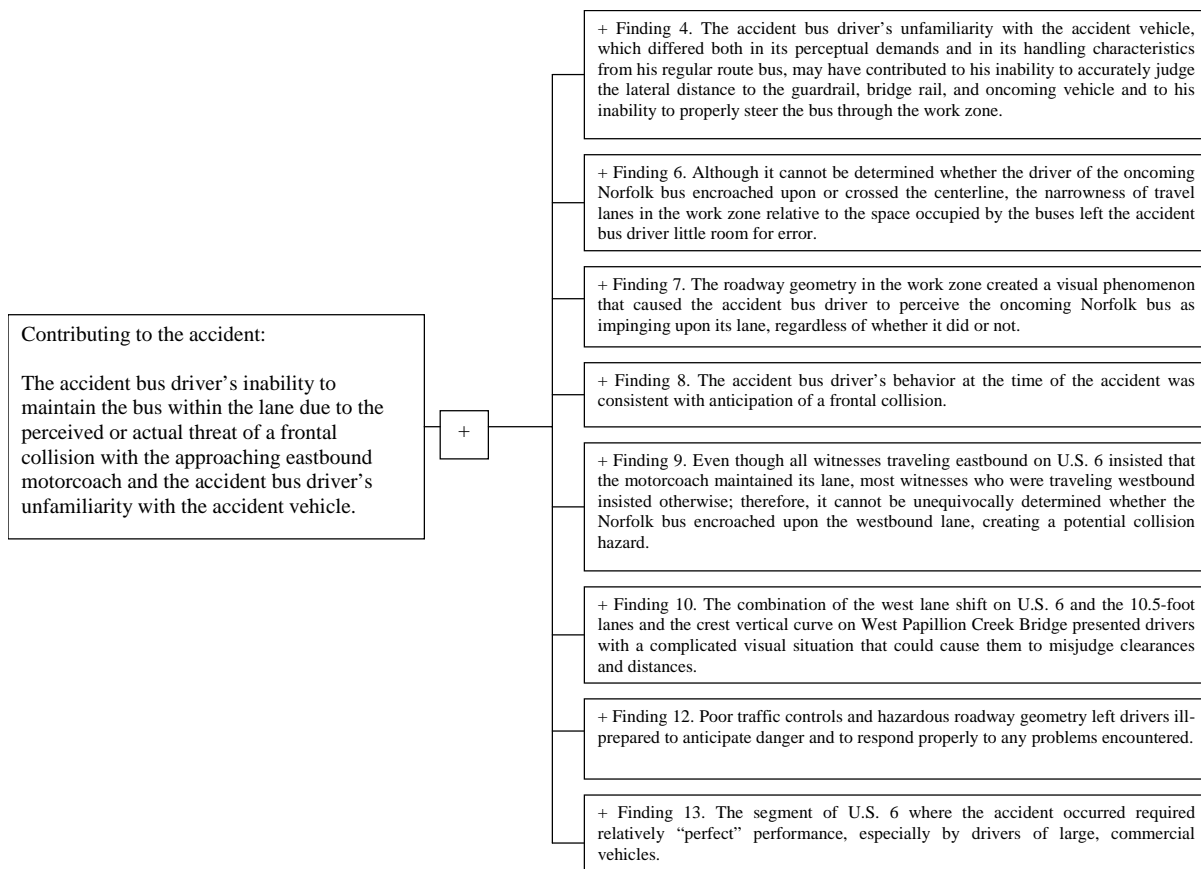


Figure 2 — Findings Related to the NTSB’s Contributory Cause of the Accident

The next diagram, Figure 3 provides an overview of the findings that support the argument that the failure of the barrier system contributed to the severity of this accident. At this level of analysis, the findings all support this argument. Again this is explained by the observation that the dissenting opinion does not take issue with the main

conclusions about the role of the barrier system. Equally, however, a more sustained analysis might examine finding 18 on page 82 of the report that criticizes the Department of Roads failure to maintain the barrier system. It could be argued that such failures were symptomatic of wider problems in the management of the site.

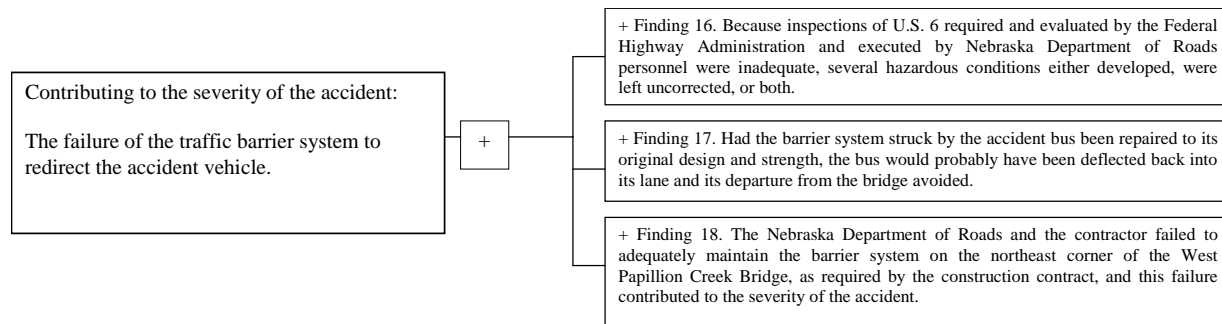


Figure 3 — Findings Related to the NTSB’s Arguments about the Severity of the Accident

Figure 4 extends our application of this graphical technique to map out key elements of the dissenting opinion that is a central feature of this accident report. As can be seen, there are strong similarities between this diagram and the summary in Figure 2 that reviews the contributory causes of the accident. This should not be surprising. The key objective behind the dissenting opinion was to raise the prominence of the drivers’ role from a contributory to a probable cause and, arguably, also to downplay the involvement of the Department of Roads. Figure 4 also shows an objection to the dissenting opinion which is based on the majority’s probable cause. In other words, the probable cause stands as an objection to the dissenting opinion just as the dissenting opinion stands as an objection to the probable cause in Figure 1. The diagram also illustrates some of the complexity in the arguments that are presented in this report by showing further dissenting arguments from Table 1 which contradict the probable cause and therefore support the dissenting opinion by arguing ‘The majority of the Board instead attributes the cause to the Nebraska Department of Roads. While I fully support that there were significant design and other deficiencies with the work zone, they did not preclude the safe operation of vehicles through the work area and the work zone accident history undermines ascribing primary cause to the Department of Roads’

This initial analysis associated the findings from the NTSB report with the probable cause, contributory factors and dissenting statements. For the sake of completeness, it is important to observe that a number of findings could not be linked to any of these issues. The first set of findings that cannot be connected to these higher-level observations exclude a number of issues from further consideration. These can be summarized as follows:

1. The accident bus driver was not impaired due to drugs, alcohol, or fatigue; further, neither the weather nor the mechanical condition of the accident bus contributed to the accident.
2. Although not detrimental to the emergency response efforts on behalf of the accident victims, communications were inadequate and resulted in a less than optimal emergency response.
3. The accident bus driver’s qualifications neither caused nor contributed to this accident.

A further cluster of findings does not directly address the causes of this incident. In contrast, they focus on the egress and rescue efforts in the aftermath of the accident. They also include observations about the bus design:

19. Because of the difficulties in identifying the passenger locations and orientations at impact after the roll and 49-foot drop, it cannot be determined whether improvements in the accident bus’s body would have mitigated the severity of the passengers’ injuries.
20. Had the Seward School District conducted emergency evacuation drills and demonstrations for all students, the passengers’ ability to open emergency exits and evacuate the vehicle in an emergency would have been greatly improved.

21. Some emergency exit levers and signage were obstructed and not clearly visible and may have hindered the evacuation of the bus after the accident.

22. Had the rescuers received school bus extrication training, rescue efforts would probably have proceeded more efficiently.

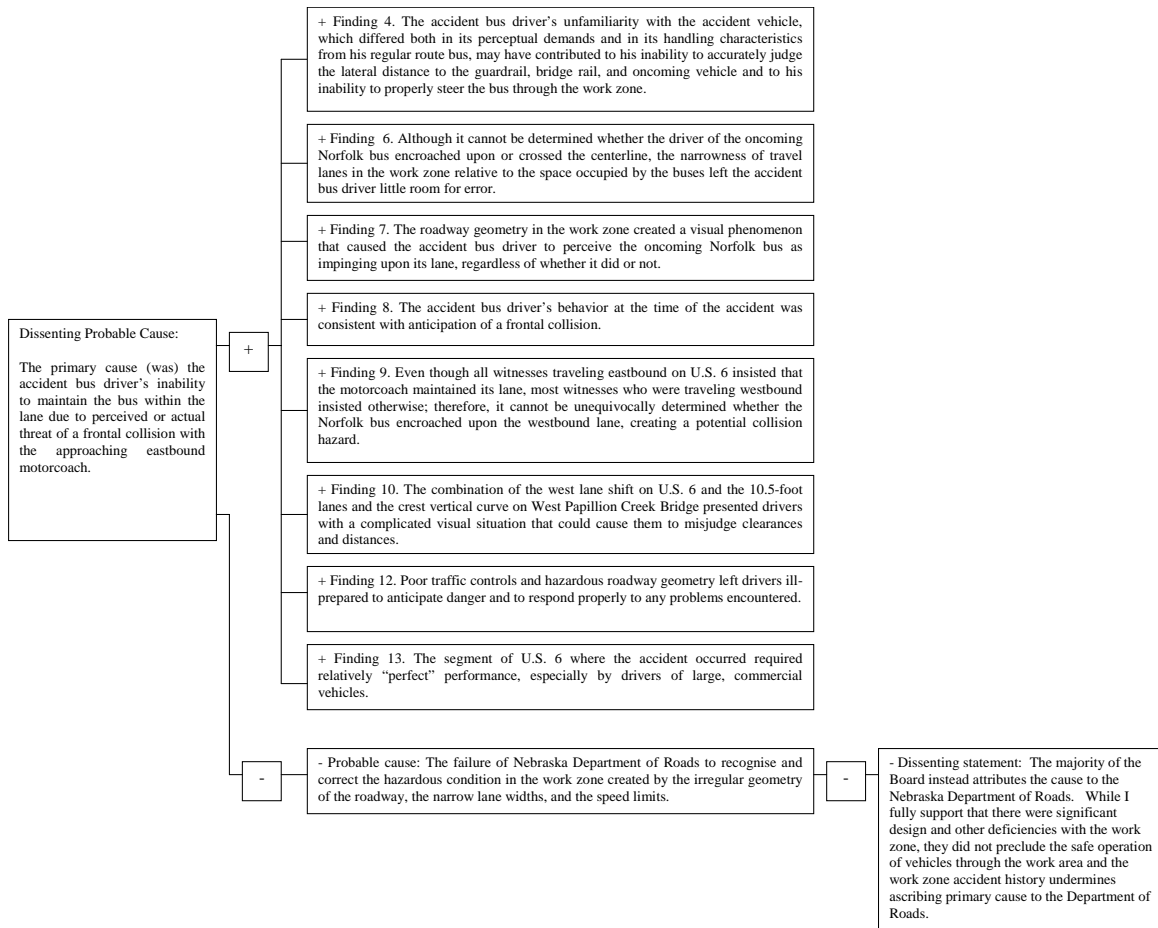


Figure 4 — Findings Related to the Dissenting Opinion as to the Cause of the Accident

Previous paragraphs have shown how high-level diagrams, based on design rationale, can be used to map out the different arguments that are left implicit in typical accident reports. In this instance, we have been able to show how various findings in the NTSB report can be used to support different arguments about the probable cause of the accident. These arguments relate to the main findings in the report but also to a dissenting opinion, which focuses on the role of the driver rather than the Department of Roads. The following paragraphs build on this analysis and look in more detail at the evidence that is presented within the body of the NTSB report.

Constructing More Detailed Maps for the Causal Arguments in Accident Reports

Figure 5 extends the analysis beyond the findings to look at the analysis that was presented to support the different causal arguments in the accident report. In this case, the focus is on the analysis that supports the probable cause that was introduced in earlier sections; 'The failure of Nebraska Department of Roads to recognize and correct the hazardous condition in the work zone created by the irregular geometry of the roadway, the narrow lane widths and the speed limits'. As can be seen, from the diagram, we have omitted this prose and have retained a placeholder in order to keep the map to a reasonable size for this paper. The numbers in parentheses denote the page number from

which the text in the diagram is taken.

The diagram expands upon the arguments that support a finding on page 81 of the report ‘The roadway geometry in the work zone resulted in extremely tight tolerances on driver performance, which may have been exceeded when the second Norfolk bus and the accident bus approached the West Papillon Creek Bridge’. As can be seen, the argument supporting this finding can be traced back to three different strands in the ‘Analysis’ section of the report between pages 60 and 69. The original finding is presented on page 81. The first line of analysis cites the results of simulations to show that the driver of the accident bus would have had to perform a number of complex and accurate maneuvers to successfully pass the on-coming bus. The second line of argument suggests that positive lane separation and medial barriers might have been used to mitigate the consequences of any driver ‘error’. The final line of analysis combines two different observations. These do not focus on whether it was possible for the two buses to have navigated the road layout but whether they could have done so at the speeds they were travelling. This argument builds on an estimated closing speed of 132 feet per second and the contention that such speeds would only have been warranted in situations where there were additional provisions to ensure adequate separation.

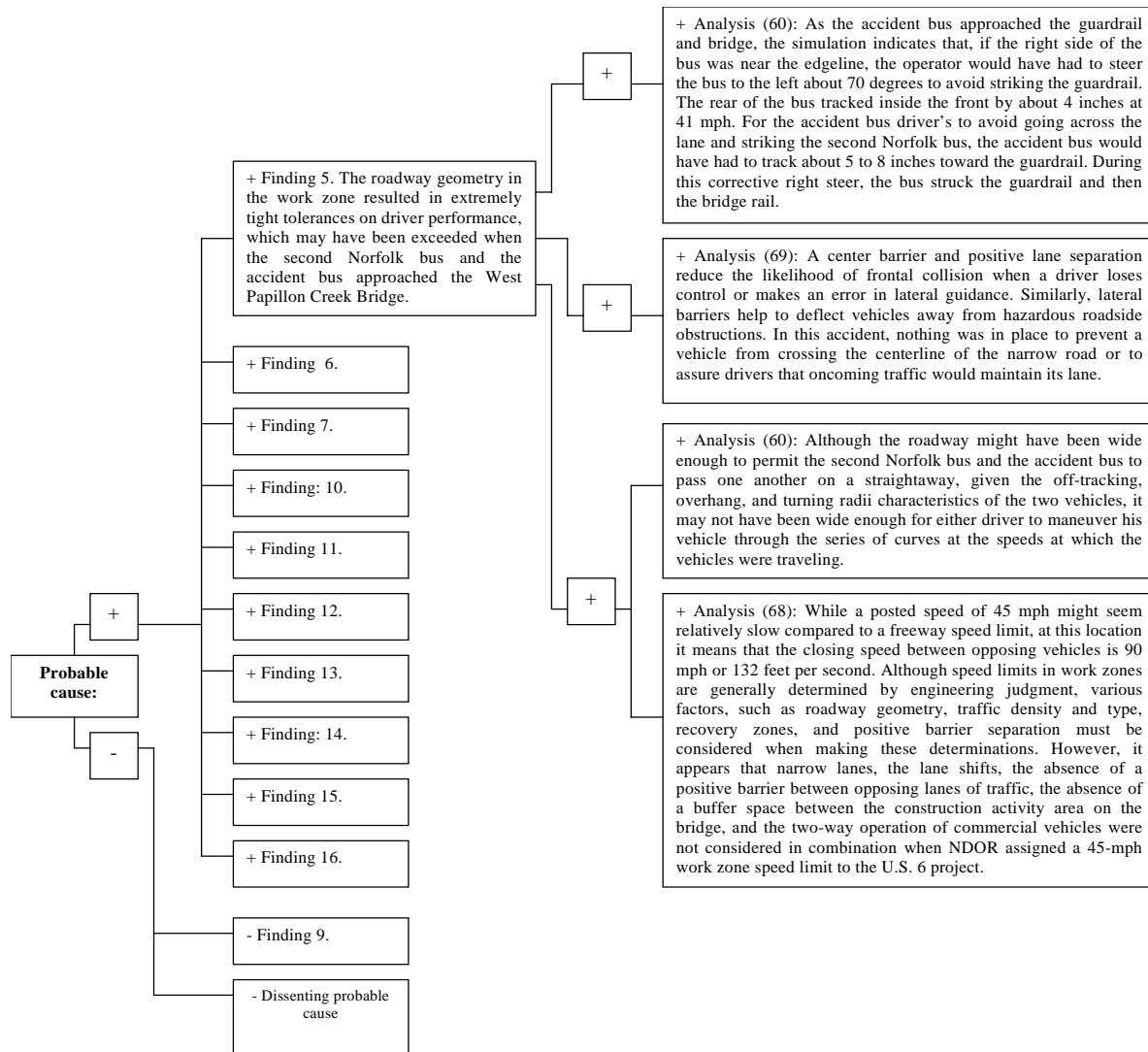


Figure 5 — Findings Related to the NTSB’s Probable Cause of the Accident

The key point here is that the graphical maps provide a high-level structure for the causal arguments that are distributed across many dozens of pages in the accident report. Algorithmic or semi-automatic means of extracting these arguments can be developed. Although the diagrams presented here reflect the subjective views of the analyst,

they provide an explicit representation of the arguments that are often implicitly embedded within the report. They, therefore, provide a focus for further discussion and debate amongst investigators who might seek to challenge the arguments in an official report. Hence, the technique might be used either within investigation teams to ensure that their findings are well justified or by other agencies, such as legal firms, seeking to challenge those findings. Additional diagrams could be developed for each of the separate findings within the report. Rather than presenting any of these diagrams in this paper, we turn our attention now to further expansion of the arguments that underlie the dissenting opinion.

### Mapping Out the Arguments Behind a Dissenting Opinion

Figure 6 shows how the analysis in the official report can provide an argument in favor of the dissenting opinion from the Vice-Chairman. In this case, the overview shows how the dissenting opinion is contradicted by the majority view of the probable cause. This, in turn, is supported by the observation that highway engineers have a responsibility to mitigate hazards, or 'limitations', that affect a representative segment of the population. In contrast, the dissenting view is supported by the analysis that the 'safe operation of many vehicles through the work area and the work zone accident history undermines ascribing primary cause to the Department of Roads'. This initial analysis shows that much of the disagreement focuses on the problems of determining whether a 'representative segment' was placed at risk by the various work zone hazards. On the one hand the majority argued that the accident occurred and that faults could be identified hence there was a significant risk. The dissenting opinion in contrast, looked at the number of previous road users who had not been involved in any incident and argued that other factors may have been better ascribed as probable causes rather than the road layout in isolation.

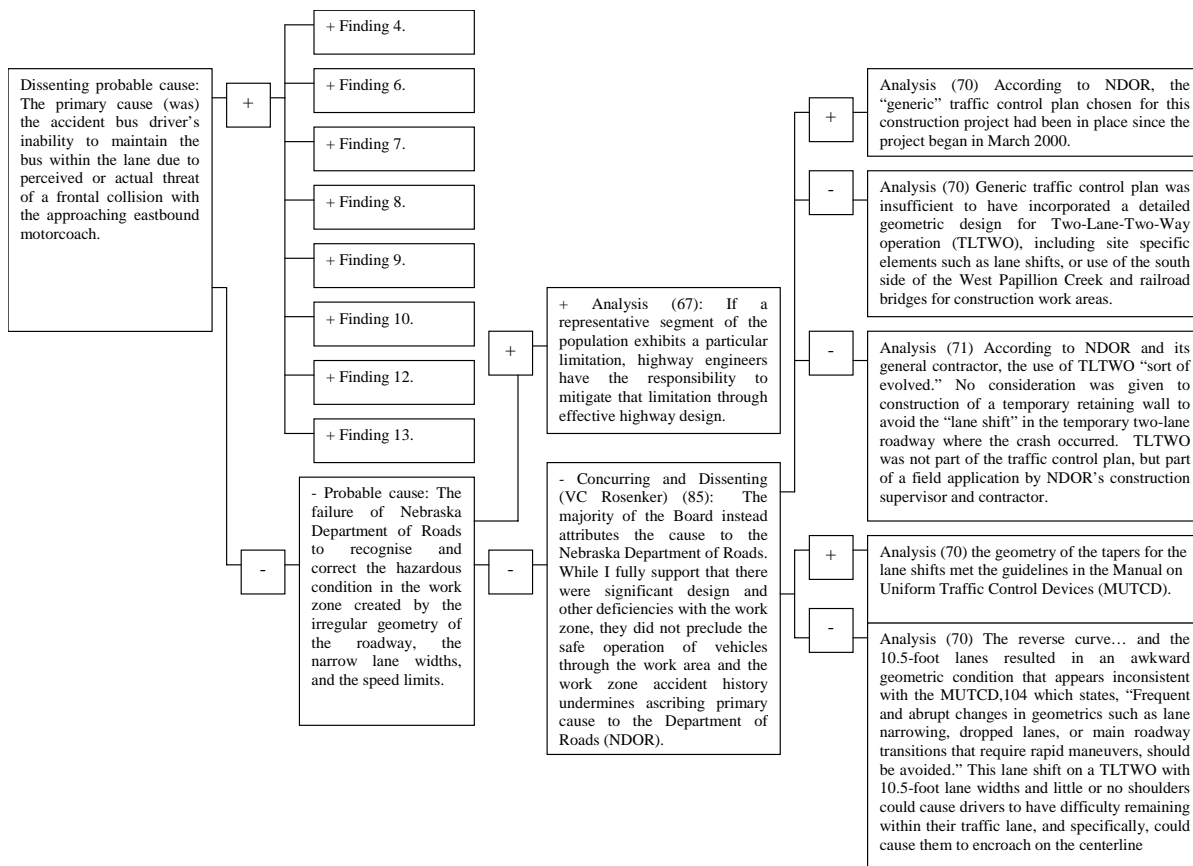


Figure 6 — Findings Related to the Dissenting Opinion



The top-right rectangle in the argument sketch in Figure 6 shows that the Nebraska Department of Roads had accepted the 'generic' traffic control plan for the site. This supports the dissenting argument that some thought had been paid to the safety of traffic through the work zone and that the design need not have precluded the safe operation of vehicles in the site. However, this dissenting argument can be weakened by reference to the analysis in other parts of the NTSB report. As can be seen in Figure 6, the generic traffic plan was deemed to be insufficient in the aftermath of the accident because it did not provide a detailed justification for the safety of Two-Lane-Two-Way Operation (TLTWO). The TLTWO procedures were not mentioned in the plan because they 'evolved' during the work. The bottom two rectangles in the previous diagram provide further analysis of the dissenting opinion. This argument is supported by the observation that the geometry of the tapers for the lane shifts met the guidelines in the US Department of Transportation's Manual on Uniform Traffic Control Devices (1993). However, this support for the geometry is again weakened by the observation that the reverse curve seemed to violate a more general requirement in the MUTCD to avoid 'frequent and abrupt changes in geometrics'.

### Concluding Remarks

In the prototypical accident report, specific findings, particularly those related to causes and contributing factors, are usually written out explicitly and clearly. Also, the evidence upon which these findings are based is usually explained in detail. However, it can often be difficult to reconstruct the arguments that connect the findings, analysis and evidence. Reports do not make clear why the investigators believe that particular lines of argument necessarily lead to the particular findings they enumerated. This paper showed how a simple graphical technique can be used to depict relevant arguments supporting alternate positions on the causes of a complex road-traffic accident.

The diagrams presented in this paper seem to show that the balance of argument is in favor of the majority view and against the dissenting opinion. Our work has, however, been limited to the official report. It would, therefore, be very remarkable if we found in favor of a minority view. Conversely, it is likely that if we extended the scope of our analysis beyond the contents of the official report that it would be possible to represent alternative arguments and evidence to support dissenting opinions. Previous pages have suggested particular ways in which this might be done for our case study accident. This extension to the basic approach hints at possible applications in the litigation that takes place in the aftermath of an incident or accident.

We are not satisfied with the graphical notation that has been used in this paper. To this extent, our work represents a first cut attempt to map out the arguments in accident reports. There are numerous alternatives. We have already mentioned that there is a host of graphical notations for representing design arguments. Many of these stem from Toulmin's work on alternate approaches to logic for reasoning about decision-making (ref. 5). Other notations are based on ideas first developed for reasoning in legal cases (refs. 6, 7). As we have seen, however, the arguments in accident reports can themselves be extremely complex and we are reluctant to introduce additional complexity by a more formal graphical notation unless the benefits can be shown to outweigh the costs in terms of readability and accessibility.

One side effect of this work on this case study has been to refocus our attention on a central issue in accident investigation; the role of human responsibility. The majority view in the accident report reflects the modern mantra of systemic failure. In this view, the individual's actions are largely shaped by their context. The dissenting view, arguably, harks back to an earlier time when personal responsibility played a greater role in determining the cause of accidents and incidents. The graphical analysis in this report provides important tools for representing the two sides of a controversy that continues to this day.

### References

1. International Civil Aviation Organization. *Aircraft Accident and Incident Investigation, Annex 13*. Ninth Edition. July 2001.
2. National Transportation Safety Board, *Highway Accident Report: School Bus Run-off-Bridge Accident, Omaha, Nebraska, October 13, 2001*, NTSB/HAR-04/01, Notation 7610. Washington, D.C. Adopted February 10, 2004.
3. C.W. Johnson. *Handbook of Accident and Incident Reporting*. University of Glasgow Press, Glasgow, Scotland, United Kingdom, 2004. Available on-line at: <http://www.dcs.gla.ac.uk/~johnson/book>

4. U.S. Department of Transportation, Federal Highway Administration, Manual on Uniform Traffic Control Devices (Washington, DC: FHWA, 1988), chapter 6 (revision 3–1993).
5. Stephen Toulmin. *The Uses of Argument*. Updated edition. Cambridge University Press, 2003.
6. David A. Schum. *Evidential Foundations of Probabilistic Reasoning*. John Wiley & Sons, Inc., New York, 1994.
7. Joseph B. Kadane and David A. Schum. *A Probabilistic Analysis of the Sacco and Vanzetti Evidence*. John Wiley & Sons, Inc., New York, 1996.

#### Biographies

Prof. Chris Johnson, Dept. of Computing Science, University of Glasgow, Glasgow, G12 9QQ, email - johnson@dcs.gla.ac.uk, telephone - +44.141.330.6053, facsimile - +44.141.330.4913.

Chris Johnson is Professor of Computing Science at the University of Glasgow in Scotland. His research focuses on the development of novel incident and accident investigation techniques. He has worked in a number of application areas, investigating accidents in aviation, healthcare, the military and the process industries. His current work focuses on the development of the European Strategic Safety Action Plan for Air Traffic Management with Eurocontrol. He is also active in the development of interactive evacuation simulation tools for large public buildings. Further information is available from <http://www.dcs.gla.ac.uk/~johnson>.

C. Michael Holloway, C/O NIA, 100 Exploration Way, Hampton VA 23666, email - c.m.holloway@nasa.gov, telephone - +1.757. 325.6912, facsimile - +1.757.325.6988.

C. Michael Holloway is a senior research engineer at the NASA Langley Research Center in Hampton, Virginia. He is currently enjoying the second year of a two year research sabbatical as one of NASA Langley's Floyd Thompson Fellows. His primary research interest is accident and incident investigation and reporting for software intensive systems. Mr. Holloway has a B.S. in computer science from the University of Virginia, and completed all-but-dissertation towards a Ph.D. from the University of Illinois. He is a member of the IEEE, the IEEE Computer Society, and the System Safety Society. Mr. Holloway is married and has two children.