CHAPTER 4

An Example of Why-Because Analysis

I introduce Why-Because Analysis here before proceeding with hazard analysis (HazAn), because, although we have just seen the ontological part of Ontological Hazard Analysis, the causal-analysis part uses the technique central to WBA but enhances it. It seems like a good idea to exercise the fundamentals first, before proceeding to the enhancement.

4.1 Synopsis of the Accident

On 14th September 1993, an A320 aircraft of the airline Lufthansa landed at Warsaw airport in a thunderstorm. The landing appeared to be normal, smooth, even though somewhat fast. The pilots were unable to activate any of the braking mechanisms (spoilers, reverse thrust, wheelbrakes) for 9 seconds after 'touchdown', at which point the spoilers and reverse thrust deployed. The wheelbrakes finally became effective 13 seconds after touchdown. The aircraft was by this time way too far along the runway to stop before the runway end. It ran off the end, and over an earth bank near the end of the runway, before stopping. Both pilots were very experienced A320 operators. The captain was returning to duty after illness and the first officer was a senior Airbus captain and training officer, who was monitoring the captain's flying skills on his return to service. The first officer died in the accident, as did a passenger who was overcome by smoke and didn't evacuate the aircraft, which burned.

4.2 What We Look For in a WBA

A WBA proceeds as follows. The steps are summarised in Figure 4.1.

- First, we devise a collection of facts about the accident which we think might be causally related to it, the Potential Causal Factor List (PFL). The PFL will include the circumstances and events we think constitute the accident itself. We shall analyse and factorise the PFL as needed using OPRA techniques (so-called "controlled language" methods) as needed.
- Second, we explicitly identify what event constitutes the accident, that is, what event directly caused deaths of people and/or caused damage to the aircraft. We call this the *Accident Event* (AE).
- Third, having established what the AE is, we shall look for what events and situations directly caused the Accident Event, the *immediate causal factors* (ICF).
- Fourth, we then look for causal factors of the immediate causal factors, and then causal factors of those, and so on. We check causal-factor relations using the Counterfactual Test (CT). The CT stems from [6].
- We put all these in a visual representation, the Why-Because Graph (WBG), a boxes-and-arrows diagram
- We refine the PFL and WBG

A key part of WBA is how we determine that a particular phenomenon is a necessary causal factor in another phenomenon. This is accomplished through use of the Counterfactual Test (CT), in Figure 1.7, repeated here as Figure 4.2. The CT lends a degree of objectivity to the assessment of causal connection which gives WBA its specific character.

Before looking for the accident event, its immediate causal factors and causal factors of those, we need to develop some kind of list of candidates, a *Potential Causal Factor List* (PFL), from which we can select these factors. In the example we shall consider here, we can develop the PFL from a definitive account, namely the report of the accident investigation commission (below), using a summary list of causal statements from [5], expressed in Figure 4.4. So developing the PFL list for this

1. Establish an initial list of facts which are potential causal factors in the accident and of each other, the Potential Causal Factor List PFL
2. Establish which phenomena in the initial PFL constitute the Accident Event AE
3. Establish which phenomena in the initial PFL constitute the Immediate Causal Factors ICF of the AE; check using the Counterfactual Test CT
4. Arrange the AE and ICF in a graph (boxes-and-arrows diagram), the Why-Because Graph WBG
5. Add other items in the PFL to the WBG, using the CT to establish the causal relations with PFL items already in the WBG
6. Refine the PFL and the WBG as needed (a variety of techniques)
7. During the entire process, record what you did and why you did it!

Figure 4.1: Basic Steps in a WBA

Event A occurred
Event B occurred
Suppose A had not occurred, but “everything else” had stayed“the same”.
Would B still have occurred?
If NO, then A is a necessary causal factor (NCF) in B
If YES, or COULD HAVE, then A is not an NCF of B

Figure 4.2: The Counterfactual Test

example is a task already half-accomplished, but it will need to be lightly refined as we shall see.

When the initial PFL has been developed, and the accident event identified, then the Counterfactual Test (reiterated here as Figure 4.2) is used to determine which items in the PFL are causal factors of which others in the list. There is of course some method to going about this — we shall not test each item in the PFL against each other item. Using a certain amount of engineering common sense in our experience results in checking a number of CT instances lying somewhere between 2 and 10 times the size of the PFL.

Accident.
An occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, in which:

a) a person is fatally or seriously injured as a result of:
— being in the aircraft, or
— direct contact with any part of the aircraft, including parts which have become detached from the aircraft, or
— direct exposure to jet blast,
except when the injuries are from natural causes, self-inflicted or inflicted by other persons, or when the injuries are to stowaways hiding outside the areas normally available to the passengers and crew; or

b) the aircraft sustains damage or structural failure which:
— adversely affects the structural strength, performance or flight characteristics of the aircraft, and
— would normally require major repair or replacement of the affected component,
except for engine failure or damage, when the damage is limited to the engine, its cowlings or accessories; or for damage limited to propellers, wing tips, antennas, tires, brakes, fairings, small dents or puncture holes in the aircraft skin; or

c) the aircraft is missing or is completely inaccessible.

Note 1.— For statistical uniformity only, an injury resulting in death within thirty days of the date of the accident is classified as a fatal injury by ICAO.

Note 2.— An aircraft is considered to be missing when the official search has been terminated and the wreckage has not been located.

Figure 4.3: The ICAO Annex 13 Definition of an Accident

4.3 What is an Accident?

Accidents in commercial aviation in countries which are members of the International Civil Aviation Organisation (ICAO), a UN organisation, must prepare reports on major accidents, as specified in Annex 13 to the Chicago Convention [3]. Annex 13 specifies what shall count as an accident. The definition is in Figure 4.3.

The accident report prepared by the investigation commission on behalf of the Polish government [2], which is available in English, gives us details about the progression of the landing. I quote it at length in the Appendix 10, to illustrate

very broadly one main issue in WBA, which is the extraction of the pertinent facts that are to be causally analysed from a narrative of the incident. The narratives can be quite long, but there are typically between 20 and 150 salient facts in causal relation to the accident which can be gleaned from the narrative. The narrative here is moderately short. Many are hundreds of pages long. The account in Appendix 10 can be compared with the extraction of the causal relations in the Causal Statement List in Figure 4.4 to give some idea of what is involved in developing a PFL. In this case, we can consider that the PFL is implicitly given in Appendix 10 – the task is merely to extract it!

Considering the definition of accident in Figure 4.3, the aircraft was not missing, so we shall be looking for the event which directly resulted in deaths of people and/or damage to the aircraft, to designate it as the Accident Event (AE). Then we shall be looking for the ICFs of the AE, and go on from there.

4.4 The Potential Factor List

We won't go through the steps here to derive the PFL from the report narrative in Appendix 10. According to our experience, the Narrative-to-PFL task requires some practice. We typically devoted two 1.5-hour lecture/exercise periods to it in the WBA course at the University of Bielefeld. The task was partially automated through use of a English-narrative parser specially written for the task by the computational linguist Professor Dafydd Gibbon, implemented in the SERAS Reporter tool, and with use of the SERAS Reporter we reduced the time spent on Narrative-to-PFL in the course down to about an hour. The industrial tutorial on WBA offered by Causalis Limited and Causalis Ingenieurgesellschaft mbH takes between 1/2 – 1 hour on it. The WBA Casebook [1] includes exercises used in the university course and industrial WBA tutorial.

Instead, we shall start from the partially-analysed list of statements concerning causal factors in Figure 4.4, which we shall call the Causal-Statement List, which is taken from [5]. We shall derive PFL elements from this list concerning the Accident Event (see below), and we shall also derive their causal relations, namely, the NCF-claim list, where an NCF pair is a statement that one PFL item is "*a Necessary Causal Factor (NCF) of*" another PFL item.

a One pilot was killed because he collided with the cockpit interior elements (Section 1.13).
b The collision occurred because of the impact of the aircraft with the embankment (Conclusion from 1.12.1 and 1.13).
c One passenger was killed because he was intoxicated with carbon oxide (1.13). He was presumed unable to leave his seat because of trauma unconsciousness and could not draw attention to himself (1.15).
d The carbon oxide was produced by the burning aircraft (1.13).
e The passenger could not leave his seat because of severe fractures (1.15).
f He could not draw attention to himself because he lost consciousness (1.15).
g He lost consciousness because of the impact (1.15) and the increasing, and toxic, smoke (1.15).
h The aircraft sustained damage caused by fire (1.14) and by the collision with the embankment (1.12.1).
i The fire was caused by the collision with the embankment (1.12.1, 1.14).
j The aircraft collided with the embankment because it did not stop on the runway (1.12.1).
k The aircraft did not stop because the runway was too short for the increased speed (2.2.7) and the aircraft computer delayed the deployment of spoilers and thrust reversers by 9 (nine) seconds (1.1) and the braking commenced with the delay of additional 4 (four) seconds (1.1) and the deceleration decreased by 30% on the last 180 m of the runway (1.1).
l The increased speed of 20 kts was the crew's action (2.2.3).
m The reasons for the crew's action were the towers' warning of windshear (2.2.3) and its conformity with the flight manual instructions (2.2.3).
n The reason for the warning was the report of windshear by the preceding aircraft (1.1).
o The windshear was caused by a front passing through the aerodrome area (1.1).
p The deployment delayed because the aircraft touched the runway with the landing gear very lightly and did not compress the left landing gear leg sufficiently (1.1) (DESIGN).
q The braking delayed because the wheel brakes depend on wheel rotation being equivalent of a circumferential speed of 72 kts (1.1) (DESIGN) and because the crew used full flaps which disabled the braking system until the recorded touchdown (2.2.4) (DESIGN).
r The deceleration decreased because a layer of water on the runway resulted in aquaplaning (1.17).
s The runway was covered with water because of heavy rainfall by a front passing through the aerodrome area (1.1).

Figure 4.4: The Causal-Statement List from [5]

4.5 Analysing the Accident Event

We are looking for events which directly caused deaths or damage. There were two people killed (Statements **a** and **c**) and the aircraft was damaged (Statement **h**). We shall take these one by one. But, first, let us decompose the Causal-Statement List using OPRA. It turns out we will not do it all; we shall stop at a suitable point, and leave the rest as an exercise.

4.5.1 OPRA Decomposition

We regiment the statements in the Causal-Statement List as follows:

- Choose unique names for "important" single objects and use just these names
- (This entails substituting these names for pronouns)
- Choose unique verbs for similar/identical actions and use just these verbs
- Remove the tenses of verbs. For example, render all in the present tense
- Turn complex statements as far as possible into simpler statements and conjunctive elements
- (This entails replacing referential phrases by the complete statements which they represent)

We can either do this before the analysis or we can do it as we proceed with the analysis. I choose to do it mostly as we proceed. There is one task, though, which we can accomplish right away, namely to characterise the Accident Event, which I shall do below.

If we wish, we may be completely rigorous about this regimentation and express everything in *Controlled Natural Language* [12], in this case Controlled English, as explored in the CE4WBA tool in [10]. This befits an OPRA approach – we have seen the formulation of safety requirements in the language of simple formal logic already in Chapter 3. However, we often don't need to be quite as rigorous as in CE4WBA. Using unique identifiers for objects and unique verbs for specific actions often brings us a long way by itself.

The Accident Event is composed out of the death of a pilot, the death of a passenger, and damage to the aircraft. There is more than one pilot, so let us denote the deceased pilot by X. Similarly, there is more than one passenger, so let us denote the deceased

(1) (*Pilot X dies*) ∧ (*Passenger Y dies*) ∧ (*Aircraft is damaged*)
(2) *Pilot X dies*
(3) *Passenger Y dies*
(4) *Aircraft is damaged*

Figure 4.5: The First Four Factors in the Potential Factor List (PFL)

NCF-claim	Antecedent	Consequent
AEi	(*Pilot X dies*)	AE
AEii	(*Passenger Y dies*)	AE
AEiii	(*Aircraft is damaged*)	AE

Figure 4.6: The Formal NCF-claims Concerning the AE

passenger by Y. The aircraft is unique, so we can just continue to use the term "Aircraft", capitalised to indicate we are using it as a name. We thereby have the following statement of the Accident Event, using the usual symbol ∧ for logical-AND:

AE is: (*Pilot X dies*) ∧ (*Passenger Y dies*) ∧ (*Aircraft is damaged*)

We shall call (*Pilot X dies*) the First Conjunct, (*Passenger Y dies*) the Second Conjunct, and (*Aircraft is damaged*) the Third Conjunct, for obvious reasons. We shall also give them numerical labels. See Figure 4.5. The decomposition of the AE leads to some formal claims which I am about to call NCF-claims (see below). These are given for completeness in Figure 4.6.

4.5.2 Focus of the Analysis

We always start with the AE and its ICFs. This will lead us here to a detailed analysis of how two people died. This may seem somewhat macabre. Indeed, it is not necessarily pleasant and a certain amount of professional detachment is needed. An engineer may think, "*well, yes, people were hurt but people were hurt because something happened to the aircraft and it is the part about what happened to the aircraft and why which interests me*". I would suggest that is misplaced, for a number of reasons. First, people who deal with safety, in particular rescue personnel and investigatory

officers, do have to deal with people getting hurt and dying and they do so, in the overwhelming majority of cases, in the hope of making life better for survivors and others who may not have to endure similar events if the job is done correctly. It is surely part of the task of engineering analysis to support that enterprise where possible. Safety engineers do have to accommodate the fact that accidents happen and people get hurt, and hope that lessons may be learned through their intervention. Second, survivability engineering is just as much a part of safety engineering as any other aspect, as automobile manufacturers have shown us with seat belts, airbags, and selectively crushable structures going on for fifty years now. Indeed, at the end of our analysis, one of the exercises will ask about what could be learned from this accident about enhancing survivability in others.

We shall find that one event in the sequence, the aircraft hitting the embankment, caused most of the damage and injury that defines this history as an aviation accident. A traditional engineering analysis, concerning systems and system operators and how they behaved, may be performed according to the precepts of WBA on the precursors of the aircraft's collision with the embankment. The causal analysis of the precursors of this event is one of the exercises.

4.5.3 First Conjunct: A Pilot Died

In the Causal-Statement List in Figure 4.4, it says concerning First Conjunct that

a: One pilot was killed because he collided with the cockpit interior elements (Section 1.13).

b: The collision occurred because of the impact of the aircraft with the embankment (Conclusion from 1.12.1 and 1.13).

First, let us reformulate these in more regimented language.

a ref: (*Pilot X dies*) because (*Pilot X collides with cockpit interior elements*)

b ref: *Pilot X collides with cockpit interior elements* because (*Aircraft collides with embankment*)

Here, following the above general regimentation rules, I have replaced the phrase "the collision occurred" with its full sentential expression "Pilot X collides with cockpit interior elements" and the phrase "the impact of the aircraft...." with "Aircraft collides with....", because "impacts" and "collides" are the same action. These are evidently

statements about causal factors. Let us reformulate them using the vocabulary of "*Necessary Causal Factor*" (NCF), which is a category of statement in WBA defined by the CT [6]. When we encounter a statement "*A because B*", this will turn into the statement "*B is a NCF of A*", and we test whether this is true using the CT. Let me call a statement of the form "*B is a NCF of A*" an NCF-claim. Statement **a ref** now becomes the NCF-claim

NCF-claim (i): (*Pilot X collides with cockpit interior elements*) is a NCF of (*Pilot X dies*)

Is NCF-claim (i) correct as a causal statement? The criterion is the CT in Figure 4.2 (where it is applicable — we shall see below that there are occasional exceptions). The CT requires us to determine

> Key Question (i) (KQ1): Had NOT-(*Pilot X collides with cockpit interior elements*), would NOT-(*Pilot X dies*)?

This might seem an odd way of expressing the question (and indeed it is!). Put into other words, we are asking

> KQi: Had Pilot X not collided with cockpit interior elements, would Pilot X have died, or not, all other things being equal?

The Medical and Anatomopathological Report, Section 1.13, in Appendix 10 clearly says that this causality holds: he died of trauma. So let's take it at that – we don't need to apply the CT if we take the pathological determination as given, but we do anyway, as follows.

Apply the CT: We need to consider a situation with "all other things being equal" in which Pilot X did not collide with the cockpit interior in such a fashion. This situation is called in Lewisian terminology a "nearest possible" world and I shall call it henceforth a *ceteris paribus world*. We can presume Pilot X would have been able to exit the aircraft as his colleague did, and thus that he wouldn't have died. So the answer to Key Question 1 is "No". According to Figure 4.2 the CT is thereby fulfilled.

Determine Further Causal Factors: The PFL item *Pilot X collides with cockpit interior elements* is an ICF of the Accident Event, according to our definitions. What about its NCFs in turn? Statement **b** becomes the following NCF-claim:

(2) *Pilot X dies*
(5) *Pilot X collides with cockpit interior elements*
(6) *Aircraft collides with the embankment*

Figure 4.7: The Potential Factor List (PFL) from First Conjunct of AE

NCF-claim	Antecedent	Consequent
(i)	(*Pilot X collides with cockpit interior elements*)	(*Pilot X dies*)
(ii)	(*Aircraft collides with the embankment*)	(*Pilot X collides with cockpit interior elements*)

Figure 4.8: Substantiated NCF-claims Concerning the First Conjunct of AE

NCF-claim (ii): (*Aircraft collides with the embankment*) is a NCF of (*Pilot X collides with cockpit interior elements*)

Formulate the Key Question for the CT: As above, to apply the CT we ask

> KQii: Had NOT-(*Aircraft collides with the embankment*), would NOT-(*Pilot X collides with cockpit interior elements*)

that is,

> KQii: Had Aircraft not collided with the embankment, would Pilot X have collided with cockpit interior elements or not?

Apply the CT: Consider a ceteris paribus world in which the aircraft did not collide with the embankment. Would Pilot X have collided with the cockpit interior in such a way as to kill him? It seems vanishingly unlikely. His colleague didn't, despite the collision with the embankment, and other cockpit crew in runway-overrun accidents don't generally die through impact trauma in such a fashion. The answer to KQ2 is "No". According to Figure 4.2 the CT is thereby fulfilled.

We have now worked one component of the AE and its causal factors. The potential factors are summarised in Figure 4.7 and the NCF-claims in Figure 4.8. The (partial) WBG is shown in Figure 4.9.

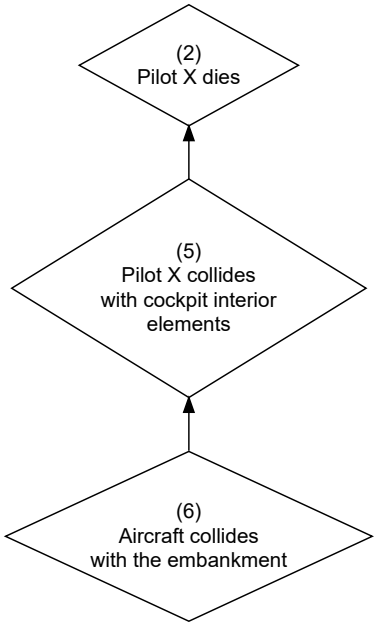

Figure 4.9: The Partial WBA of the First Conjunct

4.5.4 Second Conjunct: A Passenger Died

The Second Conjunct of the AE is the death of a passenger. What does the list say about this second casualty?

c One passenger was killed because he was intoxicated with carbon oxide (1.13). He was presumed unable to leave his seat because of trauma unconsciousness and could not draw attention to himself (1.15).

d The carbon oxide was produced by the burning aircraft (1.13).

e The passenger could not leave his seat because of severe fractures (1.15).

f He could not draw attention to himself because he lost consciousness (1.15).

g He lost consciousness because of the impact (1.15) and the increasing, and toxic, smoke (1.15).

Let us regiment the language.

c reg: (*Passenger Y dies*) because (*Passenger Y is intoxicated with carbon monoxide*).

(*Passenger Y can not leave his seat*) because (*Passenger Y is trauma-unconscious*) and (*Passenger Y can not draw attention to himself*) because (*Passenger Y is trauma-unconscious*).

d reg: (*Carbon monoxide is present*) because (*Aircraft burns*)

e reg: (*Passenger Y can not leave his seat*) because (*Passenger Y sustains severe fractures*)

f reg: (*Passenger Y can not draw attention to himself*) because (*Passenger Y is unconscious*)

g reg: (*Passenger Y is unconscious*) because (*Impact*) and because (*Carbon monoxide is present in increasing, toxic amounts*).

We are not quite where we want to be. The following questions arise.

- What is "trauma-unconscious(ness)"? Intuitively, it is unconsciousness caused by trauma. So we can change (*Passenger Y is trauma-unconscious*) into (*Passenger Y is unconscious*) and the NCF-claim (*Passenger Y is unconscious*) because (*Passenger Y suffers trauma*)
- What was this trauma? In addition, it is said that Passenger Y sustained severe fractures. That is trauma also. It is fairly obviously implied that he hit cabin interior elements: "Impact". We have earlier replaced this word with the verb "collides". What does Passenger Y collide with? Presumably parts of the cabin, in which he was seated. So let us turn this into a statement similar to that which we formulated for Pilot X earlier: (*Passenger Y collides with cabin interior elements*)
- We have two statements involving the presence of toxic gas: (*Carbon monoxide is present*) and (*Carbon monoxide is present in increasing, toxic amounts*). Let us take the stronger, and simplify it a little: (*Carbon monoxide is present in toxic amounts*)

Using these modifications we can restate the Causal-Statements:

c reg2: (*Passenger Y dies*) because (*Passenger Y is intoxicated with carbon monoxide*) AND
(*Passenger Y can not leave his seat*) because (*Passenger Y is unconscious*) AND
(*Passenger Y is unconscious*) because (*Passenger Y suffers trauma*) AND
(*Passenger Y can not draw attention to himself*) because (*Passenger Y is unconscious*).

(3) *Passenger Y dies*
(7) *Passenger Y is intoxicated with carbon monoxide*
(8) *Passenger Y can not leave his seat*
(9) *Passenger Y is unconscious*
(10) *Passenger Y suffers trauma*
(11) *Passenger Y can not draw attention to himself*
(12) *Carbon monoxide is present in toxic amounts*
(13) *Aircraft burns*
(14) *Passenger Y sustains severe fractures*
(15) *Passenger Y collides with cabin interior elements*

Figure 4.10: The Potential Factor List (PFL) for the Second Conjunct

d reg2: (*Carbon monoxide is present in toxic amounts*) because (*Aircraft burns*)

e reg2: (*Passenger Y can not leave his seat*) because (*Passenger Y sustains severe fractures*)

f reg2: (*Passenger Y can not draw attention to himself*) because (*Passenger Y is unconsciousness*)

g reg2: (*Passenger Y is unconscious*) because (*Passenger Y collides with cabin interior elements*) and because (*Carbon monoxide is present in toxic amounts*).

Similarly to Statement(s) **c reg2**, we can turn Statement **g reg2** into two "because" assertions (note that we must be careful to read "because" as "because, amongst possibly other factors" and not "because, exclusively"):

g reg3: (*Passenger Y is unconscious*) because (*Passenger Y collides with cabin interior elements*) AND
(*Passenger Y is unconscious*) because (*Carbon monoxide is present in toxic amounts*).

We appear to have derived the PFL in Figure 4.10 and the not-yet-substantiated NCF-claims in Figure 4.11.

NCF-claim	Antecedent	Consequent
(iii)	(*Passenger Y is intoxicated with carbon monoxide*)	(*Passenger Y dies*)
(iv)	(*Passenger Y is unconscious*)	(*Passenger Y can not leave his seat*)
(v)	(*Passenger Y suffers trauma*)	(*Passenger Y is unconscious*)
(vi)	(*Passenger Y is unconscious*)	(*Passenger Y can not draw attention to himself*)
(vii)	(*Aircraft burns*)	(*Carbon monoxide is present in toxic amounts*)
(viii)	(*Passenger Y sustains severe fractures*)	(*Passenger Y can not leave his seat*)
(ix)	(*Passenger Y collides with cabin interior elements*)	(*Passenger Y is unconscious*)
(x)	(*Carbon monoxide is present in toxic amounts*)	(*Passenger Y is unconscious*)

Figure 4.11: NCF-claims About the Second Conjunct

Substantiating the NCF-claims

Subsection 1.13 is definitive. It says Passenger Y died as a result of inhaling deadly amounts of carbon monoxide:

NCF-claim (iii): (*Passenger Y inhales deadly amounts of carbon monoxide*) is a NCF of (*Passenger Y dies*)

This makes *Passenger Y inhales deadly amounts of carbon monoxide* an ICF of *Passenger Y dies*. What about checking this using the CT?

Formulate the Key Question for the CT: As above,

> KQiii: Had NOT-(*Passenger Y inhales deadly amounts of carbon monoxide*), would NOT-(*Passenger Y dies*)

that is,

> KQiii: Had Passenger Y not inhaled deadly amounts of carbon monoxide, would Passenger Y have died or not?

(Try to) Apply the CT: Consider the ceteris paribus world in which Passenger Y did not inhale deadly amounts of carbon monoxide. Would he have died? In contrast with the previous two Key Questions, this seems to be harder to answer, because the ceteris paribus world is farther away from what happened. Passenger Y was unconscious and overlooked, and apparently had some broken bones. For him not to

(16) *Passenger Y remains in his seat*
(17) *Passenger Y is not evacuated*
(18) *Smoke fills cabin*
(19) *Passenger Y remains unnoticed*

Figure 4.12: Extending the Potential Factor List (PFL) for the Second Conjunct

have inhaled carbon monoxide, the carbon monoxide would have had to have been absent from, or at least very much reduced in, the interior atmosphere of the aircraft. That entails that the aircraft would not have been burning so intensely, and that in turn seems to entail that the impact with the earth bank was reduced or avoided, and in turn that the whole progression of the accident had been otherwise, say the overrun had been modest, and in turn that the approach speeds, etc., had been lower. Maybe the accident would not have happened at all if its event sequence had been so different! But it did happen and that AE is what we are analysing. It seems that the right response to KQ3 is to say we don't know: the result of the CT is indeterminate because the ceteris paribus world is so far away from what happened. However, the pathologist was definitive about the causality, so we accept this determination.

The ICF of the Second Factor is thus *(Passenger Y inhales deadly amounts of carbon monoxide* What are its NCFs? There aren't any in Figure 4.11!! That is unsatisfactory, and is obviously due to the way of expressing it in the text. We can do some obvious interpolating using a straightforward understanding of the situation. He inhaled deadly amounts of carbon monoxide because he didn't (couldn't) leave his seat, and no one else noticed him and evacuated him from the aircraft. We already have NCF-claims as to why he couldn't leave his seat, namely that he had suffered severe fractures and he was unconscious. He wasn't noticed and evacuated because, presumably, the cabin was filled with smoke so he couldn't easily be seen (a usual occurrence in aircraft fires) and he couldn't otherwise draw attention to himself because he was unconscious. That all suggests we need four more PFs as in Figure 4.12 and a few more NCF-claims as in Figure 4.13.

We haven't yet checked any of these NCF-claims using the CT. Let us choose some to check, say:

NCF-claim (xi): (*Passenger Y remains in his seat*) is NCF of (*Passenger Y is intoxicated*

NCF-claim	Antecedent	Consequent
(xi)	(*Passenger Y remains in his seat*)	(*Passenger Y is intoxicated with carbon monoxide*)
(xii)	(*Passenger Y can not leave his seat*)	(*Passenger Y remains in his seat*)
(xiii)	(*Passenger Y is not evacuated*)	(*Passenger Y remains in his seat*)
(xiv)	(*Passenger Y remains unnoticed*)	(*Passenger Y is not evacuated*)
(xv)	(*Passenger Y can not draw attention to himself*)	(*Passenger Y remains unnoticed*)
(xvi)	(*Smoke fills cabin*)	(*Passenger Y remains unnoticed*)
(xvii)	(*Aircraft burns*)	(*Smoke fills cabin*)

Figure 4.13: Further NCF-claims About the Second Conjunct

with carbon monoxide)
NCF-claim (xiv): (*Passenger Y remains unnoticed*) is NCF of (*Passenger Y is not evacuated*)
NCF-claim (vii): (*Aircraft burns*) is NCF of (*carbon monoxide is present in toxic amounts*)

Formulate the Key Question for NCF-claim (xi): As above,

> KQxi: Had NOT-(*Passenger Y remains in his seat*), would NOT-(*Passenger Y is intoxicated with carbon monoxide*)

that is,

> KQxi: Had Passenger Y not remained in his seat, would he have been intoxicated with carbon monoxide?

Apply the CT: Consider the ceteris paribus world in which Passenger Y did not remain in his seat. He might have been noticed and helped out by crew members, as other surviving passengers were. Or he might have been conscious and able to move himself (this seems to be a further-away ceteris paribus situation than being helped out by crew, since there were other factors, namely his spinal-chord fracture, which would have mitigated against it). In neither case would he have inhaled deadly amounts of carbon monoxide, because nobody else in the aircraft did. The answer to KQ4 is thereby "No" and the CT is thereby fulfilled.

Formulate the Key Question for NCF-claim (xiv):

KQxiv: Had NOT-(*Passenger Y remains unnoticed*), would NOT-(*Passenger Y is not evacuated*)

that is,

KQxiv: Had Passenger Y been noticed, would he have been evacuated?

Apply the CT: Other passengers with need were evacuated. It is very likely he would have been also, had he been noticed. The answer to KQ5 is thereby "Yes" and the CT is thereby fulfilled.

Finally, let us consider

NCF-Claim vii: (*Aircraft burns*) is a NCF of (*carbon monoxide is present in deadly quantities*)

Formulate the Key Question:

KQvii: Had NOT-(*Aircraft catches fire*), would NOT-(*carbon monoxide is present in toxic amounts*)

that is,

KQvii: Had Aircraft not caught fire, would carbon monoxide have been present in toxic amounts?

Apply the CT: The answer to KQ6 is pretty clearly "No" and the CT is thereby fulfilled.

We have substantiated four NCF-claims. There are 11 other NCF-claims concerning the Second Conjunct which remain to be substantiated using the CT. We leave these as exercises. It may be wondered how such a short paragraph as Section 1.13 of the report can lead to such a substantial collection of NCF-claims, and also whether such a short paragraph warrants such a collection and the effort required to substantiate them using the CT. In answer to the first consideration, it is often the case that short statements indicate a more complex causality. In answer to the second, whether the complex causality is worth disentangling is a matter for judgement. Carefully disentangling all of the factors in a complex causality can lead to a variety of mitigating measures for the future. For example, better ways for the crew to know quickly and accurately where everyone is seated and to "check them out" as they

evacuate. Seat pressure sensors or safety-belt sensors, displaying by doors under the expected smoke-line, for example? Clever engineers may be induced to think about nuances. Smoke and gas extraction devices might be another thought, but such mechanisms must somehow remain integral during aircraft rump collisions in order to be effective, and they would add weight to the structure, which likely makes them not so attractive at this point. On the other hand, it does seem that, in this case, there are a lot of factors for relatively little information compared with the rest of the accident-event series, Causal-Statements **j** through *s* in Figure 4.4.

The partial WBG corresponding to the Second Conjunct is shown in Figure 4.29.

4.5.5 Third Conjunct: The Aircraft Was Damaged

We have already partially considered the damage to the aircraft. Here are two causal statements from the list in Figure 4.4 with which we have not yet dealt.

h The aircraft sustained damage caused by fire (1.14) and by the collision with the embankment (1.12.1).

i The fire was caused by the collision with the embankment (1.12.1, 1.14).

We can say that Statement **h** claims that

NCF-claim (xviii): (*Aircraft burns*) is a NCF of (*Aircraft is damaged*)
NCF-claim (xix):(*Aircraft sustains non-fire-caused damage*) is a NCF of (*Aircraft is damaged*)

We have two of these Potential Factors already, but two are new.

We can say that Statement **i** claims that

NCF-claim (xx):(*Aircraft collides with the embankment*) is a NCF of (*Aircraft burns*)

in addition, we shall need to add that

NCF-claim (xxi):(*Aircraft collides with the embankment*) is a NCF of (*Aircraft sustains non-fire-caused damage*)

We do not have any of these NCF-claims yet.

(6) *Aircraft collides with the embankment*
(4) *Aircraft is damaged*
(13) *Aircraft burns*
(20) *Aircraft sustains non-fire-caused damage*

Figure 4.14: The Potential Factor List (PFL) for the Third Conjunct

NCF-claim	Antecedent	Consequent
(xviii)	(*Aircraft burns*)	(*Aircraft is damaged*)
(xix)	(*Aircraft sustains non-fire-caused damage*)	(*Aircraft is damaged*)
(xx)	(*Aircraft collides with the embankment*)	(*Aircraft burns*)
(xxi)	(*Aircraft collides with the embankment*)	(*Aircraft sustains non-fire-caused damage*)

Figure 4.15: NCF-claims About the Third Conjunct

Substantiating the NCF-claims

The Key Question for NCF-claim (xviii):

KQxviii: Had NOT-(*Aircraft burns*), would NOT-(*Aircraft is damaged*)

that is,

KQxviii: Had Aircraft not caught fire and burned, would Aircraft not have sustained damage?

Apply the CT?: This is a case we haven't seen so far. The answer to KQ7 is pretty clearly "Yes", that it would have sustained damage anyway. Does that mean the CT is *not* fulfilled? No, it does not. There are a couple of considerations. First, the aircraft sustained impact damage as well as fire damage, so the fact that *Aircraft damaged* is said to be *overdetermined*: there are two NCFs of *Aircraft is damaged*, each of which alone is sufficient. If one of them were not to have been the case, the other would still have ensured *Aircraft is damaged*. Overdetermined cases are known to be problematic for the CT (see, e.g., the Postscript [9] to [6], and the three examples in the Index of [2] under "Overdetermination, symmetric"). The trick here is to observe first that this situation is overdetermined, expect the CT not to work, and determine the causal relation between the potential factors otherwise.

(6) *Aircraft collides with the embankment*
(4) *Aircraft is damaged*
(13) *Aircraft burns*
(20) *Aircraft sustains non-fire-caused damage*
(21) *Aircraft sustains fire-caused damage*

Figure 4.16: A Possibly Revised PFL for the Third Conjunct

NCF-claim	Antecedent	Consequent
(xviii-i)	(*Aircraft burns*)	(*Aircraft sustains fire-caused damage*)
(xviii-ii)	(*Aircraft sustains fire-caused damage*)	(*Aircraft is damaged*)
(xix)	(*Aircraft sustains non-fire-caused damage*)	(*Aircraft is damaged*)
(xx)	(*Aircraft collides with the embankment*)	(*Aircraft burns*)
(xxi)	(*Aircraft collides with the embankment*)	(*Aircraft sustains non-fire-caused damage*)

Figure 4.17: Possibly Revised NCF-claims Corresponding with the Possibly Revised PCL

In this case, though, it seems the semantics of the (expression of the) phenomena lead us to affirm the NCF-claim. An aircraft which is burning is ipso facto sustaining damage. The semantics of the potential causal factors alone entails the NCF-claim.

It might be thought that this overdetermination can be avoided by introducing a specific clause for fire-caused damage, as in Figure 4.16 and a corresponding set of NCF-claims in Figure 4.17. But in fact this just shifts the overdetermination, to the NCF-claim (xviii-ii) Figure 4.17. The aircraft is damaged even without the fire, through collision, so the CT fails for NCF-claim (xviii-ii). (It doesn't fail for NCF-claim (xix) because it is the collision with the embankment which caused the fire; had their been no collision there would have been no fire, we estimate, so neither collision damage nor fire damage would have resulted.) This factorisation brings no apparent advantage to the analysis, so we stay with NCF-claim (xviii), and do not introduce potential factor (18).

The Key Question for NCF-claim (xix): The same is true of NCF-claim 19, but here it seems even more clear. The antecedent, (*Aircraft sustains non-fire-caused damage*) is just a special case of the consequent (*Aircraft is damaged*) so of course it entails it.

NCF-claim 19 is thereby substantiated.

The Key Question for NCF-claim (xx):

> KQxx: Had NOT-(*Aircraft collides with the embankment*), would NOT-(*Aircraft catches fire*)

that is,

> KQxx: Had Aircraft not collided with the embankment, would it have caught fire?

Apply the CT: In most runway-overrun accidents, the aircraft doesn't catch fire. In some cases, landing gear may collapse, engines are thereby damaged and fuel lines ruptured, and fire starts, but in most cases not. The answer to KQ8 is thereby "No" and the CT is thereby fulfilled.

The Key Question for NCF-claim (xxi):

> KQxxi: Had NOT-(*Aircraft collides with the embankment*), would NOT-(*Aircraft sustained non-fire-caused damage*)

that is,

> KQxxi: Had Aircraft not collided with the embankment, would it have have sustained non-fire-caused damage?

Apply the CT: This is a little more tricky. The question is really not whether it would have sustained *some* damage – for most runway-overruns result in minor damage, but whether it would have sustained the damage that it did sustain. The question really concerns the imprecision of the statement *Aircraft sustained non-fire-caused damage*. The answer to KQ21 is "No", it wouldn't have sustained the non-fire-caused damage that it did sustain. The CT is thereby fulfilled.

The partial WBG associated with the Third Conjunct is shown in Figure 4.18.

4.5.6 Summarising the Analysis

Putting all this together, we have derived the list of potential factors in Figure 4.19 and the partly-substantiated NCF-claims in Figure 4.20. This forms in our experience

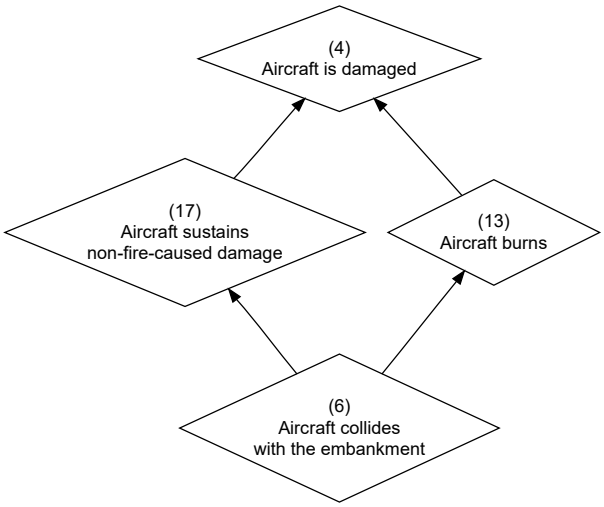

Figure 4.18: The Partial WBG Corresponding to the Third Conjunct

a fairly typical WBG, with a few more NCF-claims than causal factors.

The list of NCF relations is synonymous with input to the `dot` programming language. The `Graphviz` package compiles graphs[1].

A Why-Because Graph (WBG) is a visual representation of the relations amongst causal factors in the PFL, in which the factors in the PFL are represented as nodes or boxes, containing their text, and the NCF relation is represented as arrows between these boxes. The results of our analysis are presented as a WBG in Figure 4.31.

4.5.7 Checking We Have Done This Right

There are three questions which need to be answered in order to check whether we have performed the analysis correctly.

1. Have we got an adequate PFL?
2. Do we have all the NCF claims which should be made?

1 that is, it compiles discrete-mathematical graphs from `dot`. These kinds of graphs have *nodes* and *edges* (if you are a mathematician) or *boxes* and *arrows* (if you are a informatician). A Why-Because Graph (WBG) is a visual representation of a NCF collection as one of these graphs.

AE (*Pilot X dies*) ∧ (*Passenger Y dies*) ∧ (*Aircraft is damaged*)
(2) *Pilot X dies*
(3) *Passenger Y dies*
(4) *Aircraft is damaged*
(5) *Pilot X collides with cockpit interior elements*
(6) *Aircraft collides with the embankment*
(7) *Passenger Y is intoxicated with carbon monoxide*
(8) *Passenger Y can not leave his seat*
(9) *Passenger Y is unconscious*
(10) *Passenger Y suffers trauma*
(11) *Passenger Y can not draw attention to himself*
(12) *Carbon monoxide is present in toxic amounts*
(13) *Aircraft burns*
(14) *Passenger Y sustains severe fractures*
(15) *Passenger Y collides with cabin interior elements*
(16) *Passenger Y remains in his seat*
(17) *Passenger Y is not evacuated*
(18) *Smoke fills cabin*
(19) *Passenger Y remains unnoticed*
(20) *Aircraft sustains non-fire-caused damage*

Figure 4.19: The Accumulated Potential Factor List (PFL)

3. Have we included NCF claims which shouldn't be made?

The ways in which we can check are thus:

1. Did we have difficulty (other than through overdeteminism) in establishing whether the CT was fulfilled or not fulfilled in any of the cases? If so, we might consider refining the PFL. More advanced, there is a test called the Causal Completeness Test (CCT) which can be used to determine whether we have all necessary factors. See Section 15.1.1. of [8] for a definition of the CCT.
2. To be thorough, we need to pair all the potential factors with all the other potential factors and apply the CT to each pair. But we did not do that and experience suggests that intuition is mostly a good guide to potential NCF-claims. However, there is one specific short check which is particularly useful, as we

NCF-claim	Antecedent	Consequent
AEi	(*Pilot X dies*)	AE
AEii	(*Passenger Y dies*)	AE
AEiii	(*Aircraft is damaged*)	AE
(i)	(*Pilot X collides with cockpit interior elements*)	(*Pilot X dies*)
(ii)	(*Aircraft collides with the embankment*)	(*Pilot X collides with cockpit interior elements*)
(iii)	(*Passenger Y is intoxicated with carbon monoxide*)	(*Passenger Y dies*)
(iv)	(*Passenger Y is unconscious*)	(*Passenger Y can not leave his seat*)
(v)	(*Passenger Y suffers trauma*)	(*Passenger Y is unconscious*)
(vi)	(*Passenger Y is unconscious*)	(*Passenger Y can not draw attention to himself*)
(vii)	(*Aircraft burns*)	(*Carbon monoxide is present in toxic amounts*)
(viii)	(*Passenger Y sustains severe fractures*)	(*Passenger Y can not leave his seat*)
(ix)	(*Passenger Y collides with cabin interior elements*)	(*Passenger Y is unconscious*)
(x)	(*Carbon monoxide is present in toxic amounts*)	(*Passenger Y is unconscious*)
(xi)	(*Passenger Y remains in his seat*)	(*Passenger Y is intoxicated with carbon monoxide*)
(xii)	(*Passenger Y can not leave his seat*)	(*Passenger Y remains in his seat*)
(xiii)	(*Passenger Y is not evacuated*)	(*Passenger Y remains in his seat*)
(xiv)	(*Passenger Y remains unnoticed*)	(*Passenger Y is not evacuated*)
(xv)	(*Passenger Y can not draw attention to himself*)	(*Passenger Y remains unnoticed*)
(xvi)	(*Smoke fills cabin*)	(*Passenger Y remains unnoticed*)
(xvii)	(*Aircraft burns*)	(*Smoke fills cabin*)
(xviii)	(*Aircraft burns*)	(*Aircraft sustains damage*)
(xix)	(*Aircraft sustains non-fire-caused damage*)	(*Aircraft is damaged*)
(xx)	(*Aircraft collides with the embankment*)	(*Aircraft burns*)
(xxi)	(*Aircraft collides with the embankment*)	(*Aircraft sustains non-fire-caused damage*)

Figure 4.20: The Accumulated NCF-claims So Far

shall show here. So-called "root factors" are factors which are the antecedent of some NCF-claim but which are not the consequent of any NCF-claim. They represent the "start" of the causal connections that lead to the accident. Here we can ask: are there any "hanging root factors", apparent root factors which should evidently be the consequence of other factors in the PCL? The reasons this is a particularly useful check are, first, that it is easy, and, second, there are indeed often hanging root factors, as we shall see here.

3. Is there any NCF claim which we have not substantiated through using the CT, apart from cases of over determinism? If so, let us drop them.

To determine the root factors, we go through the antecedents of the NCF-claims in Figure 4.20 and check, for each antecedent, if it appears as a consequent. If so, it is not a root factor. If not, it is a root factor. According to our analysis so far, the root factors are as in Figure 4.21. We can check this quickly by checking these factors

(6) *Aircraft collides with the embankment*
(10) *Passenger Y suffers trauma*
(14) *Passenger Y sustains severe fractures*
(15) *Passenger Y collides with cabin interior elements*

Figure 4.21: Root Factors So Far

are present in the "Antecedent" column of Figure 4.20 but not in the "Consequent" column. Alternatively, we can draw the WBG from Figure 4.20 and pick out the root factors by eye, because they are quite obvious visually.

There are some obvious things wrong with the putative root factors in Figure 4.21:

- Passenger Y suffered trauma presumably because he collided with the cabin interior elements
- Passenger Y suffered severe fractures presumably because he collided with the cabin interior elements.
- Passenger Y suffering severe fractures entails that Passenger Y suffered trauma, by the meaning of the words, but the converse does not follow, because, in addition to suffering severe fractures, Passenger Y became unconscious. The unconsciousness is presumably due to trauma to the head.
- Both types of trauma suffered by Passenger Y were presumably caused by his colliding with cabin interior elements.
- Passenger Y collided with cabin interior elements presumably because the aircraft collided with the embankment, just as Pilot X collided with cockpit interior elements for precisely this reason.

We thus add the additional NCF-claims in Figure 4.24, to arrive at the list of NCF-claims in Figure 4.26.

But we are not done yet. In principle, as suggested above, we might check every potential factor against every other potential factor using the CT, for thoroughness. In this example, which, remember, is only a partial analysis, that would have involved some almost 400 claims, calculated as follows. We are sure in advance of the relations between Factors (1) – (4), since (2) – (4) are separate items contributing to the AE, which is Factor (1). We might want therefore to check all Factors (5) – (20) against each other, which would give us $16.15 = 240$ pairs to check. That is a lot of claims to

(7) *Passenger Y is intoxicated with carbon monoxide*
(12) *Carbon monoxide is present in toxic amounts*

Figure 4.22: Potential Claims About Carbon Monoxide

NCF-claim	Antecedent	Consequent
(xxv)	(*Carbon monoxide is present in toxic amounts*)	(*Passenger Y is intoxicated with carbon monoxide*)

Figure 4.23: The Final Missing Claim

check.

If we were to do so, we would find two claims specifically involving carbon monoxide that we imagine might well be related, but which do not occur in the NCF-claims, namely those in Figure 4.22. It is clear from Section 1.13 of the report that carbon monoxide caused the death of Passenger Y, and it could surely not have done so had it not been present in toxic amounts. That is just the CT, which in turn justifies the so-far-missing NCF-claim in Figure 4.23. The missing NCF-Claim is included in the final list of claims in Figure 4.27 and in the corresponding Second-Conjunct partial WBG in Figure 4.30, and of course in the final WBG in Figure 4.31.

In our experience, the number of validated NCF-claims is a little more than the number of potential factors involved in at least one NCF-claim, usually somewhere between one and three times as many. That is, the number of valid NCF-claims is usually roughly linear in the number of potential factors which are involved in at least one valid NCF-claim (that is, those factors which occur in the WBG). If we perform such a thorough check of every potential factor against every other, that would be a process that is quadratic in the number of factors ("quadratic" means: as N^2 is to N). In this example, we would have been checking 240 pairs to come up with 25 validated NCF-claims (24 which pass the CT, and one which didn't as a result of overdetermination). That is only one in ten. Checking all pairs might be thorough, but it is not very efficient! Can we do better, while being thorough? As an example of how visual inspection can help, let us look at the partial WBG we constructed for the Second Conjunct, in Figure 4.29. We might have begun by constructing an OPRA ontology (but we did not). Had we done so, we would have identified *carbon monoxide* as a specific object (it is what linguists call a "mass term" rather than a

NCF-claim	Antecedent	Consequent
(xxii)	(*Passenger Y collides with cabin interior elements*)	(*Passenger Y suffers trauma*)
(xxiii)	(*Passenger Y collides with cabin interior elements*)	(*Passenger Y sustains severe fractures*)
(xxiv)	(*Aircraft collides with the embankment*)	(*Passenger Y collides with cabin interior elements*)

Figure 4.24: Additional NCF-claims from the Check

(6) *Aircraft collides with the embankment*

Figure 4.25: Final Root Factor

"count noun", something which identifies a mass of "stuff" rather than an individual). As an additional check which may be more efficient tham checking all pairs, we could consider

- for each object *ob* in our OPRA ontology, list the potential factors involving *ob* and check their NCF-claims against each other using the CT.

This check would have detected the missing NCF-claim in this case, as we checked the potential factors involving carbon monoxide against each other. It seems as if it might be a useful check to make in general. It is not going to identify all factors, though, as a simple inspection of Figure 4.27 shows. It is not going to identify the NCF-claim (x) for example: antecedent and consequent share no objects in common.

Inspecting the final WBG in Figure 4.31, we can see that there is now just one root factor, in Figure 4.25. If we were not interested in the specifics of damage to people and aircraft, we might want to summarise the entire analysis in the single NCF-claim in Figure 4.28! In fact, this is exactly what was done in Figure 1.8.

NCF-claim	Antecedent	Consequent
AEi	(*Pilot X dies*)	AE
AEii	(*Passenger Y dies*)	AE
AEiii	(*Aircraft is damaged*)	AE
(i)	(*Pilot X collides with cockpit interior elements*)	(*Pilot X dies*)
(ii)	(*Aircraft collides with the embankment*)	(*Pilot X collides with cockpit interior elements*)
(iii)	(*Passenger Y is intoxicated with carbon monoxide*)	(*Passenger Y dies*)
(iv)	(*Passenger Y is unconscious*)	(*Passenger Y can not leave his seat*)
(v)	(*Passenger Y suffers trauma*)	(*Passenger Y is unconscious*)
(vi)	(*Passenger Y is unconscious*)	(*Passenger Y can not draw attention to himself*)
(vii)	(*Aircraft burns*)	(*Carbon monoxide is present in toxic amounts*)
(viii)	(*Passenger Y sustains severe fractures*)	(*Passenger Y can not leave his seat*)
(ix)	(*Passenger Y collides with cabin interior elements*)	(*Passenger Y is unconscious*)
(x)	(*Carbon monoxide is present in toxic amounts*)	(*Passenger Y is unconscious*)
(xi)	(*Passenger Y remains in his seat*)	(*Passenger Y is intoxicated with carbon monoxide*)
(xii)	(*Passenger Y can not leave his seat*)	(*Passenger Y remains in his seat*)
(xiii)	(*Passenger Y is not evacuated*)	(*Passenger Y remains in his seat*)
(xiv)	(*Passenger Y remains unnoticed*)	(*Passenger Y is not evacuated*)
(xv)	(*Passenger Y can not draw attention to himself*)	(*Passenger Y remains unnoticed*)
(xvi)	(*Smoke fills cabin*)	(*Passenger Y remains unnoticed*)
(xvii)	(*Aircraft burns*)	(*Smoke fills cabin*)
(xviii)	(*Aircraft burns*)	(*Aircraft is damaged*)
(xix)	(*Aircraft sustains non-fire-caused damage*)	(*Aircraft is damaged*)
(xx)	(*Aircraft collides with the embankment*)	(*Aircraft burns*)
(xxi)	(*Aircraft collides with the embankment*)	(*Aircraft sustains non-fire-caused damage*)
(xxii)	(*Passenger Y collides with cabin interior elements*)	(*Passenger Y suffers trauma*)
(xxiii)	(*Passenger Y collides with cabin interior elements*)	(*Passenger Y sustains severe fractures*)
(xxiv)	(*Aircraft collides with the embankment*)	(*Passenger Y collides with cabin interior elements*)

Figure 4.26: The Extended NCF-claims (Missing One, It Turns Out)

NCF-claim	Antecedent	Consequent
AEi	(*Pilot X dies*)	AE
AEii	(*Passenger Y dies*)	AE
AEiii	(*Aircraft is damaged*)	AE
(i)	(*Pilot X collides with cockpit interior elements*)	(*Pilot X dies*)
(ii)	(*Aircraft collides with the embankment*)	(*Pilot X collides with cockpit interior elements*)
(iii)	(*Passenger Y is intoxicated with carbon monoxide*)	(*Passenger Y dies*)
(iv)	(*Passenger Y is unconscious*)	(*Passenger Y can not leave his seat*)
(v)	(*Passenger Y suffers trauma*)	(*Passenger Y is unconscious*)
(vi)	(*Passenger Y is unconscious*)	(*Passenger Y can not draw attention to himself*)
(vii)	(*Aircraft burns*)	(*Carbon monoxide is present in toxic amounts*)
(viii)	(*Passenger Y sustains severe fractures*)	(*Passenger Y can not leave his seat*)
(ix)	(*Passenger Y collides with cabin interior elements*)	(*Passenger Y is unconscious*)
(x)	(*Carbon monoxide is present in toxic amounts*)	(*Passenger Y is unconscious*)
(xi)	(*Passenger Y remains in his seat*)	(*Passenger Y is intoxicated with carbon monoxide*)
(xii)	(*Passenger Y can not leave his seat*)	(*Passenger Y remains in his seat*)
(xiii)	(*Passenger Y is not evacuated*)	(*Passenger Y remains in his seat*)
(xiv)	(*Passenger Y remains unnoticed*)	(*Passenger Y is not evacuated*)
(xv)	(*Passenger Y can not draw attention to himself*)	(*Passenger Y remains unnoticed*)
(xvi)	(*Smoke fills cabin*)	(*Passenger Y remains unnoticed*)
(xvii)	(*Aircraft burns*)	(*Smoke fills cabin*)
(xviii)	(*Aircraft burns*)	(*Aircraft is damaged*)
(xix)	(*Aircraft sustains non-fire-caused damage*)	(*Aircraft is damaged*)
(xx)	(*Aircraft collides with the embankment*)	(*Aircraft burns*)
(xxi)	(*Aircraft collides with the embankment*)	(*Aircraft sustains non-fire-caused damage*)
(xxii)	(*Passenger Y collides with cabin interior elements*)	(*Passenger Y suffers trauma*)
(xxiii)	(*Passenger Y collides with cabin interior elements*)	(*Passenger Y sustains severe fractures*)
(xxiv)	(*Aircraft collides with the embankment*)	(*Passenger Y collides with cabin interior elements*)
(xxv)	(*Carbon monoxide is present in toxic amounts*)	(*Passenger Y is intoxicated with carbon monoxide*)

Figure 4.27: The Final NCF-claims

NCF-claim	Antecedent	Consequent
(SummaryClaim)	(*Aircraft collides with the embankment*)	(*AE*)

Figure 4.28: The Summary NCF-claim

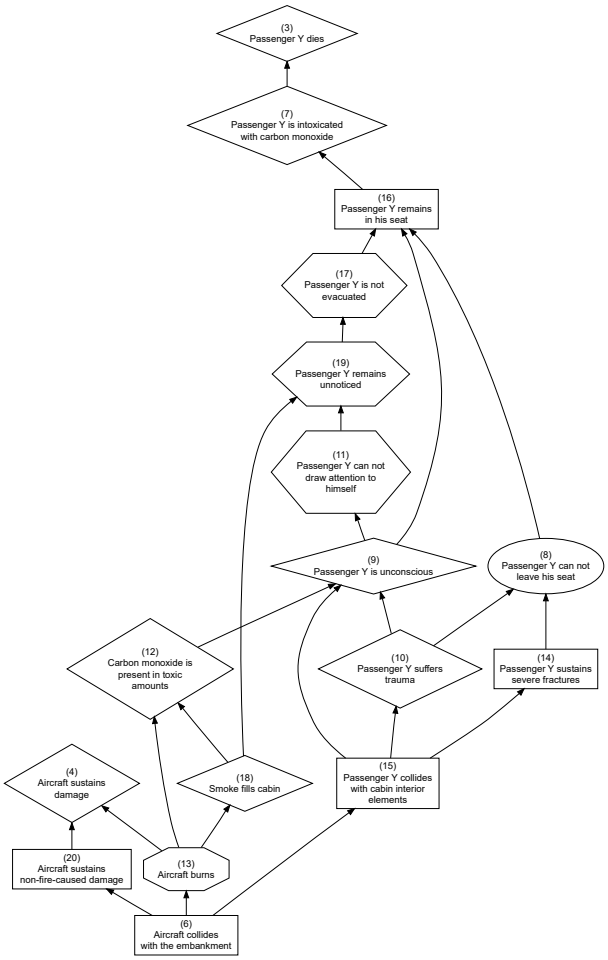

Figure 4.29: The Partial WBG So Far Corresponding to the Second Conjunct

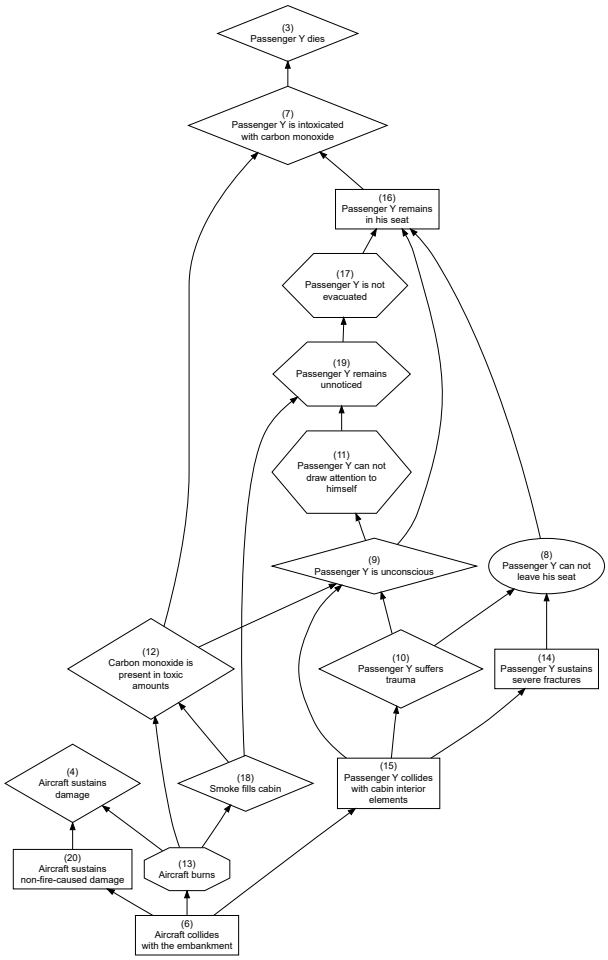

Figure 4.30: The Partial WBG Corresponding to the Second Conjunct

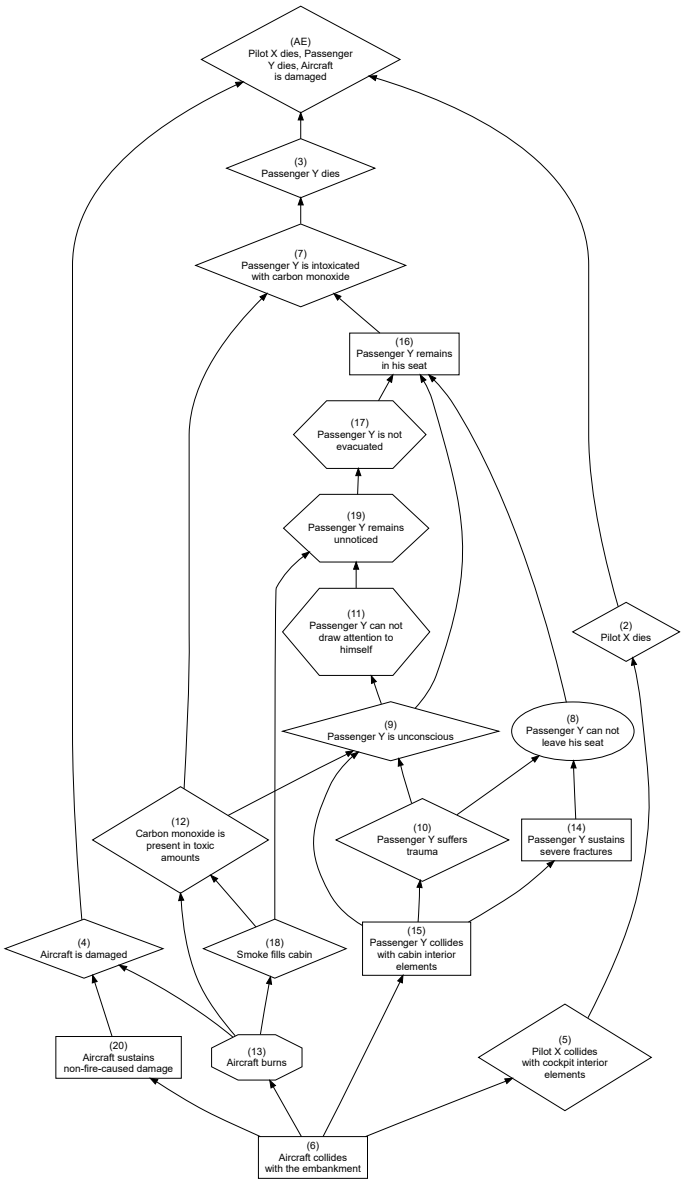

Figure 4.31: The Partial WBG Corresponding to the Entire AE

4.6 Exercises

1.
   - Check that each item in the PFL in Figure 4.19 occurs in some NCF-claim derived in the textual reasoning.
   - , as Check that each item which occurs in some NCF-claim derived in the textual reasoning is present in the PFL in Figure 4.19
   - Check that each NCF-claim in Figure 4.20 occurs in the textual reasoning from Figure 4.4.
   - Check that each item in Figure 4.4 is reflected in one or more NCF-claims.
   - Check that all the NCF-claims that should be present are in fact in Figure 4.27.
   - Check that the Counterfactual Test is satisfied between the antecedent and the consequent of every NCF-claim in Figure **??**. Remember that there is at least one case in which it is not!
   - Check that the CT is *not* satisfied for any pair of potential factors in the Potential Factor List in Figure 4.19 which are not in the NCF-claims in Figure **??**. (That is a lot of factor-pairs to check if you methodically check each and every one. What kinds of short cuts are there?)

2. Check that every edge between boxes in the WBG in Figure 4.31 corresponds to an NCF-claim in Figure 4.27

3. Check that every NCF-claim in Figure 4.20 corresponds to an edge between boxes in the WBG in Figure 4.31

4. Derive a PFL from Statements **j** – **s** as I have done above for Statements **a** – **i**.

5. Derive a NCF-claim list from this PFL for Statements **j** – **s**.

6. Perform the checks suggested in the text, and enumerated above in the first exercise, on the NCF-claim list for Statements **j** – **s**, including in particular that the Counterfactual Test has been correctly and thoroughly applied.

7. Draw the WBG from the NCF-claim list for Statements **j** – **s** using your favourite graphics tool (which can be pencil and paper!). Perform the check, as in the second and third exercises, between the WBG and the NCF-claim list.

8. Finally, connect the partial WBG for Statements **j** – **s** with the partial WBG for Statements **a** – **i** to form a complete WBG of the accident from the Causal-Statement List. Check using the Counterfactual Test that all the causal connections (NCF-claims) between the two partial analyses are correct, and that you have not missed a causal connection (an NCF-claim) between the two partial analyses.

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