Causal Analysis of Incidents with Why-Because Analysis using the SERAS® Software Toolkit

CAUSALIS Ingenieurgesellschaft mbH
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1 Background to the Causal Explanation of Incidents

Humans construct artifacts to serve various purposes. Some of these artifacts are simple, to match their purpose, for example, to cut something one needs only a sharp, hard edge and some sort of a grip to hold it with. Some artifacts are more complicated, for example an aircraft to let us fly intercontinentally in comfort. Such more complicated artifacts have many individual parts serving many subsidiary purposes and are called systems. Systems are collections of interacting components, each component exhibiting behaviour. Systems can be natural (a common example is predator-prey systems) or can be engineered. We can call engineered systems which are intended to serve a particular purpose *teleological* systems. I shall be concerned here with teleological systems. Some system components can be people, for example, a piloted aircraft has a cockpit crew when it is flying. If a system essentially includes people in its operation, we call it a sociotechnical system. Rather than speaking of components of a sociotechnical system, we can call them agents (including the non-human components).

If we do not use artifacts in the intended manner, harm may result. For example, if you grasp a knife firmly by the blade. Or do not follow the proper procedures for landing the aircraft. Such situations are not intended by the designers. We can call such situations from which harm may result *hazards*. We call situations in which harm does indeed result *accidents*. Sometimes harm results even when the artifact is used in the intended manner. You press the knife too hard, and the blade shatters, hurting a hand. You land the aircraft somewhat too fast, the braking systems deploy unexpectedly late, abd the aircraft overruns the runway, say as happened at Warsaw airport in 1993.

We can learn how to avoid the situations that gave rise to accidents by causally analysing them. We might imagine a “user manual” for the knife. It said

- Don’t grasp the knife by the blade

and after a shattering incident it might say

- Don’t grasp the knife by the blade;
- Hold the blade straight to cut through hard items;
- Do not press down hard while holding it obliquely or the blade may shatter and cause injury.

I understand the braking-systems deployment logic of later models is different from that of the 1993 Warsaw accident aircraft, and the Flight Crew Operating Manual at the airline now reads differently concerning how much extra speed can be maintained on approach if the crew expects sudden changes of wind.

Questions about the properties of even a relatively simple artifact such as a knife can be difficult to answer if not enough is known of the properties of the materials from which it is made. Some artifacts, such as commercial aircraft, are inherently very complicated, partly because they are constructed out of simpler artifacts with specific functions, all of which functions go together to provide the overall function of the aircraft. When there are lots of such components, then the combinatorics of the components, how they are put together and how they might affect each other, becomes complex. Furthermore, the components may be of all sorts of different types:

- There are physical components. For example, components whose main function is mechanical, such as hydraulic lines, fluids, connectors, weight-carrying elements such as landing gear, wheels, gears, things to push and pull, parts to resist torsion, compression and extension.
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- Then there is the logic itself: the software, a very concrete form of logic. But there is also logic inherent in the design: the choice made by a designer of what the exact conditions should be under which braking systems should function and when these systems should be inhibited.
- There are human procedures with which the artifact is used.
- There are laws and regulations which determine or constrain the worldly situations in which we humans may use the artifacts.
- There is the culture or cultures of the people who use it – for example, the pilots - and who may oversee that use – for example, air traffic controllers - and other stakeholders - for example, passengers and cabin crew. The behaviors of any or all of these might come together to create a hazard, or an accident.

This is not an exhaustive list. Neither is it the only way of classifying components. But this is not my topic here.

If an accident happens, or a significant hazard occurs, and we wish to avoid such situations in the future, then we must ask why the situation arose, why the incident happened. We ran our car into the neighbor's BMW. Was it Friday 13th? Then maybe we shouldn't drive cars on Friday 13th. But then, think of all those *other* cars driving around on Friday 13th to which nothing untoward happened. So even if the date had something to do with it, there must be other influences as well, which arose in our case but which did not arise in the cases of all those others driving around happily. So we might think. What justifies this apparently obvious reasoning?

We like to think that some phenomena make other phenomena happen, force those other phenomena to occur, necessitate their occurrence. We speak of *cause*. Aristotle wrote about causes and the phenomena of physical causation 2,300 years ago and it has been of first importance ever since. David Hume famously remarked some 270 years ago that we don't have a sense organ than can sense this forcing, this causation phenomenon, as we have eyes that see red or noses that smell roses. We have to infer causation indirectly from other phenomena that we do sense.

Hume famously inferred causality, that phenomenon A causes phenomenon B, through observing *constant conjunction*, that whenever A happens, B happens also or shortly thereafter. Most of those who have tried to determine the nature of causality have focused on this repeatable regularity, leading to a form of reasoning known as *inductive inference*. However, harmful incidents occur seldom. Any harmful repeated regularity or constant conjunction would induce us to stop using the artifact forthwith, and in some jurisdictions there are laws to enforce this. It would seem to be a difficult path to try to explain rare events through considering constant conjunctions.

David Lewis noted in 1973 that Hume defined causation twice over[1]: "*we may define a cause to be an object followed by another, and where all the objects, similar to the first, are followed by objects similar to the second. Or, in other words, where, if the first object had not been, the second never had existed.*[2]" By "*objects*" Hume means phenomena. The first sentence is the constant-conjunction formulation of causality. The second sentence is the counterfactual formulation of what it means for a phenomena to cause another. There has been a renaissance of interest in the counterfactual formulation, due largely to David Lewis[3], as well as to John Mackie[4]. The formulation is called "counterfactual" because it involves a *contrary-to-fact* or *counterfactual* conditional:

- *Phenomenon A did in fact occur, and*
- *Phenomenon B did in fact occur, but*
- *Had A not occurred, B would not have occurred either.*

Considering what would have happened had A not occurred is contrary to the facts, which are that A did occur. The three bullet points constitute what we call the *Counterfactual Test* (CT).

The advantage of the counterfactual formulation for inquiring after rare events is twofold.

- First, we do not have to consider repetitions of rare events, which would stretch our powers of imagination. We must only consider how the world would have been had specific things

[1]The first sentence of David Lewis, Causation, J. Philosophy 70:556-67, 1973, reprinted in David Lewis, Philosophical Papers, Volume II, Oxford University Press, 1986.
[2]David Hume, in Section VII of An Enquiry Concerning Human Understanding, 1748.
[3]Op. cit.
[4]The Cement of the Universe: A Study of Causation, Oxford University Press, 1974.

occurred differently, which is something we do every day: "*if I go to the store in this heavy rain, I will get soaked, despite my umbrella. So I won't go*".

- Second, problems around inductive reasoning are notorious in philosophy and philosophical logic, whereas for counterfactual reasoning there exists a formal logic with a formal semantics that exactly captures the valid forms of reasoning with counterfactual statements, due again to David Lewis[5]. So we have a firmer grasp on the kinds of valid reasoning in which we may engage.
- There is also a third advantage for engineering, namely, it turns out that the semantics of the CT is quite intuitive and can often be accurately applied by all sorts of people without much training. It is, in both senses of the word, *practical* reasoning. As the U.S. Air Force says in its accident investigation manual[6], "*A cause is a deficiency the correction, elimination, or avoidance or which would likely have prevented or mitigated the mishap damage or significant injuries.*" This is exactly the counterfactual notion of cause, occurring in a practical how-to manual.

Why-Because Analysis (WBA) is a methodical way of applying the CT to the collection of facts about events and situations associated with an incident. Using the CT, we can handle causality issues concerning mechanics, electrics, software, people, procedures and laws in a uniform way. Why-Because Analysis can be used in conjunction with specialist theories of mechanics, electrics, software, people, procedures and laws, because of its minimalist character.

[5]David Lewis, Counterfactuals, Basil Blackwell Ltd, 1973, reissued Blackwell Publishers, 2001.
[6]Air Force Instruction 91-204.

2 A Narrative Incident Report

To show how a Why-Because Analysis proceeds, let us use a short narrative example. The following is excerpted from a news article by Vernon Loeb published on-line by the Washington Post on March 24th, 2002. It concerns an incident during Operation Enduring Freedom, the U.S.-led war against the Taliban in Afghanistan.

The deadliest "friendly fire" incident of the war in Afghanistan was triggered in December by the simple act of a U.S. Special Forces air controller changing the battery on a Global Positioning System device he was using to target a Taliban outpost north of Kandahar, a senior defence official said yesterday.

Three special forces soldiers were killed and 20 were injured when a 2,000-pound, satellite-guided bomb landed, not on the Taliban outpost, but on a battalion command post occupied by American forces and a group of Afghan allies, including Hamid Karzai, now the interim prime minister.

The U.S. Central Command, which runs the Afghan war, has never explained how the coordinates got mixed up or who was responsible for relaying the U.S. position to a B-52 bomber, which fired a Joint Direct Attack Munition (JDAM...) at the Americans.

But the senior defence official explained yesterday that the Air Force combat controller was using a Precision Lightweight GPS Receiver, known to soldiers as a "plugger" ... to calculate the Taliban's coordinate for the attack. The controller did not realise that after he changed the device's battery, the machine was programmed to automatically come back on displaying coordinates for its own location, the official said.

Minutes before the fatal B-52 strike, which also killed 5 Afghan opposition soldiers and injured 18 others, the controller had used the GPS receiver to calculate the latitude and longitude of the Taliban position in minutes and seconds for an airstrike by a Navy F/A-18, the official said.

Then, with the B-52 approaching the target, the air controller did a second calculation in "degree decimals" required by the bomber crew. The controller had performed the calculation and recorded the position, the official said, when the receiver battery died.

Without realizing the machine was programmed to come back on showing the coordinates of its own location, the controller mistakenly called in the American position to the B-52. The JDAM landed with devastating precision.....

..... the official said the incident shows that the Air Force and Army have a serious training problem that needs to be corrected. "We need to know how our equipment works; when the battery is changed, it defaults to his own location," the official said. "We've got to make sure our people understand this."

3 Structuring the Narrative

To analyse the incident causally, we start from the text of the friendly-fire incident given in Chapter 2, and consider its assertions about the incident individually. We can start by taking the assertions about the incident to be the individual sentences of the narrative. Then we modify these sentences according to the following principles.

Unique Identifiers

Principle 1. Terms which clearly identify a participant in the incident, an actor or component, should be chosen and then used uniformly throughout. In particular, pronouns and possessives which refer to other factors should be eliminated in favor of explicit terms.

To illustrate, consider the following from a fictional narrative of an aircraft accident:

The accident aircraft, G-ZZZZ, was damaged. Its main gear was detached and its nose was crumpled on impact with a low wall

There are two sentences, so, following our starting suggestion, two factors. In the first factor, there is a unique identifier for the aircraft, so we can use it further. In the second factor, the word "*its*" can be eliminated in favor of this identifier, as follows:

The aircraft G-ZZZZ was damaged. The main gear of G-ZZZZ was detached and the nose of G-ZZZZ was crumpled on impact with a low wall

Applying Principle 1 to the narrative in Chapter 2, we see that the controller using the GPS device is referred to variously as

A U.S. Special Forces air controller

[T]he Air Force combat controller

The controller

The air controller

We can choose one of these names to use throughout the factors, say *the Air Controller.* We can annotate this identifier, in an "Identifier Dictionary" which we can create, to say that the Air Controller was a U.S. Special Forces air controller who was a member of the U.S. Air Force.

Similarly, the GPS device is referred to as

Global Positioning System device

Precision Lightweigh GPS Receiver

"plugger"

PLGR

device

machine

GPS receiver

receiver

We can use the short term *PLGR*. We can annotate this term in the Identifier Dictionary to show that it means "Precision Lightweight GPS Device".

Separating Factors

> *Principle 2*: The factors should be decomposed into simpler factors as far as possible and reasonable.

For example, say we have a factor which contains a grammatical conjunction (for example, "*and*", "*but*", "*however*"), then one can decompose the factor into two. Continuing the aircraft example from above, the assertion/factor

The main gear of G-ZZZZ was detached and the nose of G-ZZZZ was crumpled on impact with a low wall

contains the conjunction "*and*". Applying Principle 2, it can be separated into two factors:

- *The main gear of G-ZZZZ was detached.*
- *The nose of G-ZZZZ was crumpled on impact with a low wall.*

Experience shows that factors should be separated even when information about the sequence of events is lost (say, through use of the conjunction "*and then*"). Sequencing information will be re-inserted during analysis. (Drawing timelines, also called time-actor diagrams, is a good idea.) In many or even most cases, such sequencing information is contained elsewhere in the narrative.

Consider, in our narrative, the statement

Without realising the machine was programmed to come back on showing the coordinates of its own location, the controller mistakenly called in the American position to the B-52.

First we apply Principle 1:

Without realizing the PLGR was programmed to come back on showing the coordinates of the PLGR location, the Air Controller mistakenly called in the PLGR location to the B-52.

Then we observe that there are two factors in this statement, which can be separated as

The Air Controller did not realise that the PLGR was programmed to come back on showing the coordinates of the PLGR location

The Air Controller mistakenly called in the PLGR location to the B-52

(There is a possible issue here about intention, which some people may feel to be lost through the replacement of "American position" with "PLGR location". It is known in philosophical logic as the question of referentially-transparent and referentially-opaque contexts. The position the Air Controller uploaded turned out to be the PLGR location, but he thought it was something else. I don't want to get into discussion of it here, because it turns out to be practically resolvable in most cases.)

Using Active Verbs and not Passive Verbs in Events

In an event, something happened, an action of some kind. A statement "*John kicked the football*" has the verb in (what is called by grammarians) active voice. In contrast, the semantically equivalent statement "*The football was kicked by John*" has a verb in passive voice. In active voice, *John did something to the football*. In passive voice, *the football had something done to it by John*.

Principle 3: Factors should be written as far as possible in active voice, not passive voice.

There are two reasons for applying Principle 3.

- First, active-voice shows clearly who was the actor in the event and who was acted upon. The grammatical subject of an active-voice statement is the actor, and the grammatical object the acted-upon. (It is the other way around in passive-voice statements.) Since further analysis will require the actor to be identified, this makes it easy to identify the actor formally or even automatically.

- Second, statements written in passive voice sometimes hide the actor. For example, one could write *the football was kicked*. This hides the actor, the person, *John,* who did the kicking. Hiding the actor makes it even harder to identify the actor in an event.

We can use the term *activisation* for the process of changing passive-voice statements into active-voice. To show activisation at work, we can consider further the factor

The nose of G-ZZZZ was crumpled on impact with a low wall.

There is a passive-voice assertion: the nose *was crumpled.* However, there is here no obvious actor, as with John and the football. But we can separate first, and then activise:

- *The nose of G-ZZZZ hit a low wall.*
- *The collision with the low wall crumpled the nose of G-ZZZZ.*

Here, the actions "*hit*" and "*crumpled*" are both in active voice. Note also that the wall is identified by the same term "*low wall*" in both factors. (If there had been many low walls, we could have called them "*low wall number 1*", "*low wall number 2*", and so on.)

It may seem a little strange that the grammatical subject, "*the collision*", resulting from the rephrasing, is not an actor, in the sense that John is an actor when he kicks the football. Sometimes it happens that, in order to activise, an "abstract" subject, such as here a "collision", appears as the grammatical subject. This may lead to a rephrasing helpful to an analyst, or it may not. The reporter will determine the best phrasing of hisher report. An analyst can rephrase later if need be.

There is another meaning of "*was crumpled*" that does not refer to an action of crumpling, but to the results of the action, a *crumpled nose*, which is a description of part of the aircraft (a state). "*The nose of G-ZZZZ was crumpled*" is ambiguous. In one meaning, it describes the state of the aircraft's nose. In a second meaning, it describes in passive voice an action that caused the nose to be that way. Principle 3 is applicable to the second meaning, but not to the first, because the notion of activising makes no sense for state descriptions – they are OK as they are. Before applying Principle 3, the reporter should ask himherself whether a statement describes an occurrence, an event, or a state of something.

Principle 4: Disambiguate, particularly between interpretations as an event and as a state

There is no ready example in the friendly-fire article of a passive statement connected with a factor. There is passive voice in the first sentence, that "*the deadliest ... incident ...... was triggered... by the simple act of [changing the battery on a PLGR]*", but we have already noted that this refers not to a factor, but to an assertion of cause. The article shows no passive voice when talking about the incident itself.

Processes

There are events which occur over short periods of time, which a reporter can see are composed of lots of further events for example

The crew performed the before-landing check-list

which consists of reading out (by one pilot) and verifying (by the other pilot) a series of aircraft configurations in a list. If the list has, say, ten items, then there are twenty events (a read and a verify for each of the ten list items). It is often necessary to state that this activity occurred, but if the crew performed it normally, without any obvious problems arising, then it is probably unnecessary to analyse it further in the initial report. The series of events constituting the performance of the before-landing check-list is called a *process*. Processes should be treated akin to events. For example, processes should be activised according to Principle 3.

Principle 5: Where a process is evident and apparently untoward, include it initially as one factor, and only decompose later if necessary.

Eliminate Indirection: Human Opinions and Other Propositional Attitudes

Much information about an accident comes directly from interviews with people who observed the accident, or from people involved in activities possibly causally related to the accident in some way, for example maintenance personnel who last serviced an accident aircraft. Thus statements about what was the case often come with the notation that it is what someone said. Indeed it is one of the tasks of accident analysts to sort out what is correct and what is not correct from what people have told them.

However, human opinions of this sort *about* an accident, and other propositional attitudes such as beliefs, elicited through interview, rarely play a causal role in the accident itself. It is good journalistic and investigative practice always to note the contributor of a piece of information that might be causally relevant. However, the causal analysis focuses on a phenomenon itself, and not on who alleged the phenomenon to be present. In a causal reconstruction of an accident, factors report bare phenomena, and details of the contributor should be relegated to an annotation.

For example, consider the following sentence from the news report of the "friendly fire" incident:

The deadliest "friendly fire incident of the war.. was triggered ... by the simple act of

a U.S. Special Forces air controller changing the battery on a Global Positioning System device he was using... a senior defence official said yesterday.

The sentence says, literally, that someone said something. The "*senior defence official*" was briefing reporters after the incident occurred. That he said something at the briefing cannot be causal to the incident – causes do not follow their effects (at least in engineering; there is some philosophical debate about whether indeed they can). So the statement that the official said something at the briefing cannot be a causal factor, or in any causal chain, in a causal explanation of the friendly fire incident itself. Indeed, rather the other way around – his words were partially caused by the incident (by the CT, had the incident not occurred, he would not have been talking about it on March 23rd).

Principle 6: Eliminate irrelevant propositional attitudes.

Principle 7: Events or states that occurred after the accident event cannot be causal factors of it.

By Principle 7, what the official said cannot be a causal factor of the accident, so his saying it is an "irrelevant propositional attitude". So we apply Principle 6. The official said two things, which are extracted as possible factors:

- That an action "triggered" the incident; and,
- That this action was a controller changing a battery on a device.

The first claim is a claim about causality. By "triggered", we can interpret the official to mean "was a cause of". Heshe is of course entitled to do that – heshe is briefing reporters about "what happened" and such a briefing will often contain some partial, maybe informal, causal explanation. But we are constructing our own causal explanation – we do not need to assume one from the briefing.

Principle 8: Assertions of causality are not themselves potential causal factors.

The second claim says: a U.S. Special Forces controller changed the battery on a device he was using. We are trying to determine the causal factors of the incident and that is certainly a possible candidate to be amongst them:

A U.S. Special Forces air controller changed the battery on a ... device he was using

Using Principle 1, we can rephrase as

The Air Controller changed the battery on the PLGR

We may also want to consider whether we take this information as correct, or whether we remain sceptical about it. If we are unsure as to whether it is correct, we could label it as an assumption, to indicate uncertainty:

Assumption: The Air Controller changed the battery on the PLGR

Now we consider a sentence further down in the article which says:

The U.S. Central Command, which runs the Afghan war, has never explained how the coordinates got mixed up or who was responsible for relaying the U.S. position to a B-52 bomber......

Can we consider this as a possible causal factor of the own-troops bombing incident? Again, no, we cannot, by Principle 7. Its main action is an inaction, "*never explained*", which the U.S. Central Command indulged in *after* the incident took place, and since causes do not follow effects this inaction cannot be considered a cause. Thus no factor is extracted from this sentence.

Summary of Factor-Derivation Principles

We have used the following principles in deriving an appropriate list of factors from the narrative.

***Principle 1*:** Terms which clearly identify a participant in the incident, an actor or component, should be chosen and then used uniformly throughout. In particular, pronouns and possessives which refer to other factors should be eliminated in favor of explicit terms.

***Principle 2*:** The factors should be decomposed into simpler factors as far as possible and reasonable.

***Principle 3*:** Factors should be written as far as possible in active voice, not passive voice.

***Principle 4*:** Disambiguate, particularly between interpretations as an event and as a state

***Principle 5*:** Where a process is evident and apparently untoward, include it initially as one factor, and only decompose later if necessary.

***Principle 6*:** Eliminate irrelevant propositional attitudes.

***Principle 7*:** Events or states that occurred after the accident event cannot be causal factors of it.

***Principle 8*:** Assertions of causality are not themselves potential causal factors.

There are other principles of factor derivation, including likely some we have not yet identified ourselves. Deriving a canonical list is work in progress.

4 Using SERAS® Reporter to Isolate the Factors

Much of this massaging of a textual narrative is routine and can be accomplished relatively easily with computer software. The narrative text of the "friendly fire" incident can be entered into SERAS® Reporter, either by typing it in or by using cut-and-paste from here.

The Reporter asks first for personal information about the person reporting the incident. After completing this part and proceeding, by clicking on the "*Proceed*" button, a page requesting the narrative and title appears. We have given the title "Operation Enduring Freedom Friendly Fire Incident". The text has be entered into the "*narrative*" box area using cut-and-paste. The result looks as follows.

For increased quality in the analysis of the report you enter, it may become necessary to identify details in the incident that were not noticed by the reporter. Therefor we ask you to enter some contact information in this formular. All information will be handled confidentially and with greatest care.

Personal Data on the Reporter

Mr.

Last Name:

Ladkin

First Name:

Peter

Name of your Institution:

Causalis

Contact (email, phone a/o postal address):

ladkin@causalis.com

Role:

Other

Involvement:

Just reporting

« Back to Introduction «

» Proceed »

Going on from here, the narrative is factored automatically by SERAS Reporter into separate potential factors, shown below. This preliminary factorisation is crude - it factors, for example, on punctuation symbols, so whole phrases such as "U.S. Special Command" are split into meaningless subphrases "U.S." and "Special Command". The factors must be edited at this stage to derive a passable, readable factor list, with three goals:

1. Correcting the crude parsing of the narrative
2. Eliminating causally-irrelevant statements
3. Applying the guidelines discussed above

Please give a narrative description on the incident or accident you are reporting. The information on affected people and aircraft aids in the classification of the incident's severity. The title is used for internal reference and data storage.

Narrative and Data of the Incident

Title:

Operation Enduring Freedom "Friendly Fire" incident

Please classify the occurrences severity:

People affected: Fatal injuries

A/C affected: Unknown amount of damage

Narrative:

The deadliest “friendly fire” incident of the war in Afghanistan was triggered in December by the simple act of a U.S. Special Forces air controller changing the battery on a Global Positioning System device he was using to target a Taliban outpost north of Kandahar, a senior defence official said yesterday.

Three special forces soldiers were killed and 20 were injured when a 2,000-pound, satellite-guided bomb landed, not on the Taliban outpost, but on a battalion command post occupied by American forces and a group of Afghan allies, including Hamid Karzai, now the interim prime minister.

The U.S. Central Command, which runs the Afghan war, has never explained how the coordinates got mixed up or who was responsible for relaying the U.S. position to a B-52 bomber, which fired a Joint Direct Attack Munition (JDAM...) at the Americans.

But the senior defence official explained yesterday that the Air Force combat controller was using a Precision Lightweight GPS Receiver, known to soldiers as a “plugger” ... to calculate the Taliban's coordinate for the attack. The controller did not realise that after he changed the device's battery, the machine was programmed to automatically come back on displaying coordinates for its own location, the official said.

Minutes before the fatal B-52 strike, which also killed 5 Afghan opposition soldiers and injured 18 others, the controller had used the GPS receiver to calculate the latitude and longitude of the Taliban position in minutes and seconds for an airstrike by a Navy F/A-18, the official said.

Then, with the B-52 approaching the target, the air controller did a second calculation in “degree decimals” required by the bomber crew. The controller had performed the calculation and recorded the position, the official said, when the

« Back «

» Proceed »

Applying Principle 1, we can identify some significant objects involved in the incident, choose the following identifiers for the agents in the narrative, and substitute these identifiers for them:

- The air controller
- JDAM bomb
- B-52 bomber aircraft
- PLGR
- The Allied position
- The Taliban position
- Navy F/A-18 aircraft

Revert changes
Add a factor
Join selected factors
Clone selected factors
Delete selected factors

Factorised Incident Report

Your narrative has been factorised. You can see the list of factors in the table below. If you are not satisfied with the result feel free to edit and change the list of factors below. Your narrative itself will not be changed by this refinement.

If you want to create a completely new list of factors from your narrative just delete all the factors and the narrative will be re-factorised automatically.

Please modify the factor descriptions to conform with our Guidelines for Factor Descriptions.

The deadliest “friendly fire” incident of the war in Afghanistan was triggered in December by the simple act of a U.S.
Special Forces air controller changing the batter on a Global Positioning System device he was using to target a Taliban outpost noth eof Kandahar, a senior defence official said yesterday.
Three special forces soldiers were killed and 20 were injured when a 2,000-pound, satellite-guided bomb landed, not on the Taliban outpost, but on a battalion command post occupied by American forces and a group of Afghan allies, including Hamid Karzai, now the interim prime minister.
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Central Command, which runs the Afghan war, has never explained how the coordinates got mixed up or who was responsible for relaying the U.S.
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Then, with the B-52 approaching the target, the air controller did a second calculation in “degree decimals” required by the bomber crew.
The controller had performed the calculation and recorded the position, the official said, when the receiver battery died.

We can apply Principle 6 to eliminate a couple of proffered “factors”, concerning what the U.S. Central Command “never explained”, a single statement in the narrative which was split into two components by the factoriser because of the presence of punctuation.

We can select from the first two components, as indicated in the example in the guidelines above.

In the third component, we can separate into two statements:

- People killed and injured (this constitutes the damage or harm)
- That the JDAM bomb landed on the Allied position

We can also observe further damage (5 Afghan soldiers killed and 18 others injured) in a later component, and fuse the two statements of damage into one component.

We can use Principle 5 to eliminate phrases such as "the official said". Since the narrative all comes from this one person, we could either annotate all factors as "*Assumption:*" or just take them all to be fact. We choose, for common-sense reasons, to take them all here to be fact.

We also notice some repeated information, and eliminate the repetition.

The factor list is shown below after these reductions and editions have taken place. It is now clear from this list that one crucial factor is implicit, rather than explicit. There is a factor which says that the air controller did not realise that the PLGR was programmed to come back on showing own position, but there is no explicit factor stating that the PLGR actually came back on showing its own position. This is implicit. It needs to be added explicitly. Thus we arrive at the third factor list, the final reduction in editing the factor list.

Revert changes
Add a factor
Join selected factors
Clone selected factors
Delete selected factors

Factorised Incident Report

Your narrative has been factorised. You can see the list of factors in the table below. If you are not satisfied with the result feel free to edit and change the list of factors below. Your narrative itself will not be changed by this refinement.

If you want to create a completely new list of factors from your narrative just delete all the factors and the narrative will be re-factorised automatically.

Please modify the factor descriptions to conform with our Guidelines for Factor Descriptions.

The air controller changed the battery on the PLGR
Three special forces soldiers were killed and 20 were injured. 5 Afghan opposition soldiers were killed and 18 injured.
A B-52 bomber fired a JDAM bomb at the Allied position.
The air controller was using the PLGR to calculate the coordinates of the Taliban position.
The controller did not realise that after he changed the PLGR's battery, the PLGR was programmed to automatically come back on displaying coordinates for its own location.
The air controller had used the PLGR to calculate the coordinates of the Taliban position in minutes and seconds for an airstrike by a F/A-18 aircraft.
The air controller did a second calculation in “degree decimals” required by the B-52 bomber.
The air controller had performed the second calculation and recorded the position, when the PLGR battery died.
The air controller mistakenly called in the Allied position to the B-52 bomber.
The JDAM landed on the Allied position
The U.S. Air Force and Army have a serious training problem that needs to be corrected: "we need to know how our equipment works."

« Back «

» Proceed »

Revert changes
Add a factor
Join selected factors
Clone selected factors
Delete selected factors

Factorised Incident Report

Your narrative has been factorised. You can see the list of factors in the table below. If you are not satisfied with the result feel free to edit and change the list of factors below. Your narrative itself will not be changed by this refinement.

If you want to create a completely new list of factors from your narrative just delete all the factors and the narrative will be re-factorised automatically.

Please modify the factor descriptions to conform with our Guidelines for Factor Descriptions.

The air controller changed the battery on the PLGR
Three special forces soldiers were killed and 20 were injured. 5 Afghan opposition soldiers were killed and 18 injured.
A B-52 bomber fired a JDAM bomb at the Allied position.
The air controller was using the PLGR to calculate the coordinates of the Taliban position.
The controller did not realise that after he changed the PLGR's battery, the PLGR was programmed to automatically come back on displaying coordinates for its own location.
The air controller had used the PLGR to calculate the coordinates of the Taliban position in minutes and seconds for an airstrike by a F/A-18 aircraft.
The air controller did a second calculation in “degree decimals” required by the B-52 bomber.
The air controller had performed the second calculation and recorded the position, when the PLGR battery died.
The air controller mistakenly called in the Allied position to the B-52 bomber.
The JDAM landed on the Allied position
The U.S. Air Force and Army have a serious training problem that needs to be corrected: "we need to know how our equipment works."
The PLGR resumed after battery change showing the Allied position.

« Back «　　　» Proceed »

Use of the SERAS Reporter then proceeds through the following stages:

- the Reporter asks the client to indicate which items state the damage caused during the incident

- The Reporter asks the client to indicate which events were directly responsible for the damage – how did the damage directly happen? This event or events constitute the accident.

- The Reporter asks which factors are the necessary causal factors of the accident event – that is, using the CT, which factors are such that, had they not occurred, the accident event would not have occurred either.

  Here, we are applying the CT informally and intuitively without explaining it at all. We shall go into it in more detail as we work the example with the SERAS Analyst tool.

- The Reporter asks the client to indicate the environmental conditions present which were necessary factors for the incident to have occurred.

The concept of "environmental conditions" is similar to that of Mackie's notion of context. The environmental conditions may be identified by asking which of the factors remain constant as the incident plays itself out. These would be

- the behavioral specification of the PLGR, that it is programmed to come back on after battery change showing own position, which in this case is identical with Allied position
- the state of knowledge of the Air Controller about the PLGR
- the "training problem" enunciated by the official
- that the PLGR was being used to identify the Taliban position for a bombing attack

The last factor, that the PLGR was being used to identify a Taliban position for a bombing attack, may not seem at first glance to be a constant factor, in the way in which the other three factors are constant. The first three factors remain constant over days, months, even years, whereas the fourth phenomenon, the specific use of the PLGR in this instance, seems to be momentary.

What qualifies the fourth phenomenon as an environmental factor is that the phenomenon persists throughout the time frame of all of the other factors mentioned. It "frames", in time, the complete incident as it plays out. As do the other environmental factors, only with wider frames. The fourth phenomenon is indeed part of the context in which the series of direct actions and misactions that led to the accident occur and thus qualifies along with the other three as an environmental factor.

Report Summary

The incident reported was:

Operation Enduring Freedom "Friendly Fire" incident

Factor	The air controller changed the battery on the PLGR
Damage	Three special forces soldiers were killed and 20 were injured. 5 Afghan opposition soldiers were killed and 18 injured.
Cause	A B-52 bomber fired a JDAM bomb at the Allied position.
Environmer	The air controller was using the PLGR to calculate the coordinates of the Taliban position.
Environmer	The controller did not realise that after he changed the PLGR's battery, the PLGR was programmed to automatically come back on displaying coordinates for its own location.
Factor	The air controller had used the PLGR to calculate the coordinates of the Taliban position in minutes and seconds for an airstrike by a F/A-18 aircraft.
Factor	The air controller did a second calculation in “degree decimals” required by the B-52 bomber.
Factor	The air controller had performed the second calculation and recorded the position, when the PLGR battery died.
Cause	The air controller mistakenly called in the Allied position to the B-52 bomber.
Incident	The JDAM landed on the Allied position
Environmer	The U.S. Air Force and Army have a serious training problem that needs to be corrected: "we need to know how our equipment works."
Factor	The PLGR resumed after battery change showing the Allied position.

The incident was reported by:

Reporter:	Mr. Peter Ladkin
Institution:	Causalis
Contact:	ladkin@causalis.com
Role:	Other
Involvement:	Just reporting

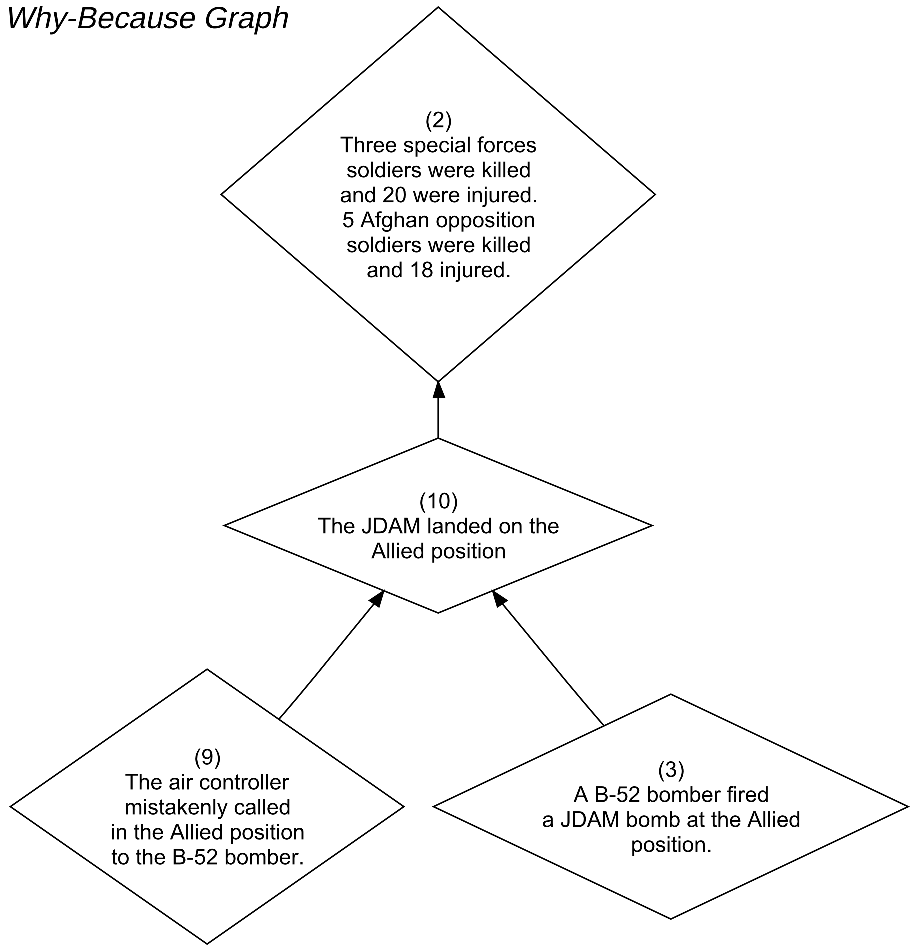
« Back « » Save »

5 Developing the Causal Analysis with the SERAS® Analyst Tool

The output from the SERAS Reporter, produced in an XML dialect called BARD-ML, may be directly imported into the SERAS Analyst tool, which converts BARD-ML into its interface language, CausalML.

The causal analysis may be represented as a *combinatorial graph,* called a *Why-Because Graph,* WB Graph or WBG. In a WBG, the factors are represented as script inside boxes of various different shapes. These boxes with their script are called *nodes*. An *edge*, that is, a line with an arrow on one end indicating a direction, is drawn between two nodes just in case the node at the tail of the edge is a necessary causal factor (NCT), of the node at the arrow end of the edge. Which nodes are NCTs of which other nodes is determined by applying the CT.

So far, we have identified the damage, the accident event which directly caused the damage, and two necessary causal factors which directly resulted in the accident event. Upon import of the analysis from the SERAS Reporter, the WBG shows these four nodes with the three arrows representing NCF-hood. The SERAS Analyst can print these, as well as the Factor List. The result follows.



Factor List

1 The air controller changed the battery on the PLGR
2 Three special forces soldiers were killed and 20 were injured. 5 Afghan opposition soldiers were killed and 18 injured.
3 A B-52 bomber fired a JDAM bomb at the Allied position.
4 The air controller was using the PLGR to calculate the coordinates of the Taliban position.
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10 The JDAM landed on the Allied position
11 The U.S. Air Force and Army have a serious training problem that needs to be corrected: "we need to know how our equipment works."
12 The PLGR resumed after battery change showing the Allied position.

The Counterfactual Test

The Counterfactual Test is the crucial test to be applied to determine whether a phenomenon A is a *necessary causal factor*, or NCF, of a phenomenon B. It is as follows:

Counterfactual Test (CT): Phenomenon A is a necessary causal factor of phenomenon B if and only if

- *A occurred*
- *B occurred*
- *had A not occurred, B would not have occurred either.*

In order to apply the CT, we need to know how to interpret the counterfactual statement whose truth we have to determine, namely

had A not occurred, B would not have occurred either

We have found that an intuitive consideration of this counterfactual suffices to be able to apply the CT in most practical cases. However, in the course of many analyses an analyst will sometimes come upon such statements whose truth heshe cannot immediately determine. Some careful thought is required, and it may be that sometimes the answer cannot be determined from the data. One may then be motivated to search for more information that will determine the truth or falsity of the statement, or one might decide pragmatically whether the counterfactual holds or not, and continue the analysis. A WBA has value even in cases in which logical rigour is not uniformly applied. An analyst can single out specific cases in which heshe was unsure of the judgement and bring them to the attention of hisher clients.

Applying the Counterfactual Test

We now apply the Counterfactual Test to all factors, in pairs.

In most cases, the application is routine, an immediately obvious judgement. If there are *n* nodes, there are *n x (n-1)* different pairs to consider, which is $(n^2 - n)$ judgements, but, in our experience, only some *2n* to *4n* of those CT judgements will require serious thought. One way of reducing the number of pairs to consider is by building the WBG as we are doing, "top down", starting from the accident event, identifying the NCFs of that, and so on. "Top down" will not always work throughout, but it is a helpful rule-of-thumb.

Applying the CT is a relatively straightforward exercise in the example we are considering, since we only have 12 factors and 2 of them constitute the accident event and the damage. We have only 10 to consider, amongst them two which are already in the WB Graph.

We consider the factors, one by one. We select a factor A, and go through the list of the other 9 factors to see which ones satisfy the Counterfactual Test as NCFs. The SERAS Analyst numbers the factors, which makes it easier.

- **(3)** *A B-52 bomber fired a JDAM bomb at the Allied position*. It did so because those were the coordinates it received from the air controller (9). Had it not received those coordinates, the JDAM would not have landed on the Allied position. So the CT is satisfied between Factor 9 and Factor 3. Also, the coordinates were received because they were sent and because the transmission was correct (a fact not – yet – in our factor list. With all communications there is a more-or-less standard list of ways a communication can go wrong and it is worth going through the list to see that – and how – everything is in order with the communication itself). That the transmission was correct does not necessarily need to be stated or explained, but maybe we should inquire about the sending. They were sent because they were the result of the sequence of actions that the air controller had performed when he thought he had done a calculation. This leads us to Factor 8, but it is not quite Factor 8 as written.

  Also, there is some context here which is not yet explicit. We should note that the B-52 bomber fired the JDAM bomb at those coordinates it received because that is part of its standard attack procedure. Were this not to be standard attack procedure, the JDAM would not necessarily have been fired, or not necessarily at those coordinates. Were the bomber not to have been attacking, say during a practice exercise, the JDAM would not necessarily have been fired. So we may need to add some factors to make this context – the actual deployment – explicit. Let us see.

  We have been led to Factor 8, so let's look at that.

- **(8)** *The air controller had performed the calculation and recorded the position, when the PLGR battery died.* Looking at this more carefully, we see there are really two factors fused into one statement:

  The air controller performed the calculation and recorded the position.

  The PLGR battery died.

  We can apply Principles 4 to "the calculation". There were two calculations performed. This is referring to the second calculation. The air controller had already successfully performed the first. Performing the second calculation ran the battery down and out. We introduce two more unique identifiers for the two calculations: *Calculation-1* and *Calculation-2. Calculation-1* was in minutes-and-seconds units for the F/A-18. *Calculation-2* was in degree-decimal units for the B-52 bomber.

  That the air controller performed Calculation-2 is also stated in Factor 7. So maybe we can express the facts about the calculations in a more uniform way and get the factors more neatly separated. For example:

  The air controller performed Calculation-1 for the F/A-18 aircraft.
  Calculation-1 was in minutes-and-seconds units.
  The F/A-18 aircraft requires target positions in minutes-and-seconds units.
  The air controller performed Calculation-2 for the B-52 bomber aircraft.
  Calculation-2 was in degree-decimal units.
  The B-52 bomber aircraft requires target positions in degree-decimal units.

  Looking at the two factors we have extracted from Factor 8, we can assess their NCFs with the help of this list. To do so, we first modify Factor 8 in SERAS Analyst to refer to Calculation-2, and then we add a factor that *the PLGR battery died*.

  Once we have considered these factors, we can ask again about the NCFs of Factor 9. Why did the air controller call in the Allied position? Intuitively, because he thought he was calling in the Taliban position. If he had thought he was calling in his own position, he would not have done so (we may assume). That is a counterfactual, but it is a counterfactual with a component that is not yet in our factor list. It seems as if we might need another factor:

Assumption: The air controller thought he was calling in the Taliban position.

This is Factor 14 when we put it in the SERAS Analyst. We are now in a position to apply the CT with regard to Factor 9. Had the air controller not thought he was calling in the Taliban position, he would not have called in the position, which was the Allied position, to the B-52 bomber. So Factor 14 is by the CT a NCF of Factor 9. (I noted earlier that referentially-opaque contexts were usually routinely handled in the course of analysis. That is what we have just done.)

Similarly, had the PLGR not resumed after battery change showing the Allied position, this position would not have been called in to the B-52 mistakenly as a target. So Factor 12 is by the CT also a NCF of Factor 9.

- **(12):** *The PLGR resumed after battery change showing the Allied position.* Most obviously, had the battery not been changed, the PLGR would not have resumed showing the Allied position. So Factor 1 is by the CT a NCF of Factor 12.

- **(14):** *Assumption: The air controller thought he was calling in the Taliban position.* Most obviously, had he realised that the PLGR reverted to own position after battery change, he would not have thought he was calling in the Taliban position (he would have realised he would be calling in his own position). So Factor 5 is by the CT a NCF of Factor 14.

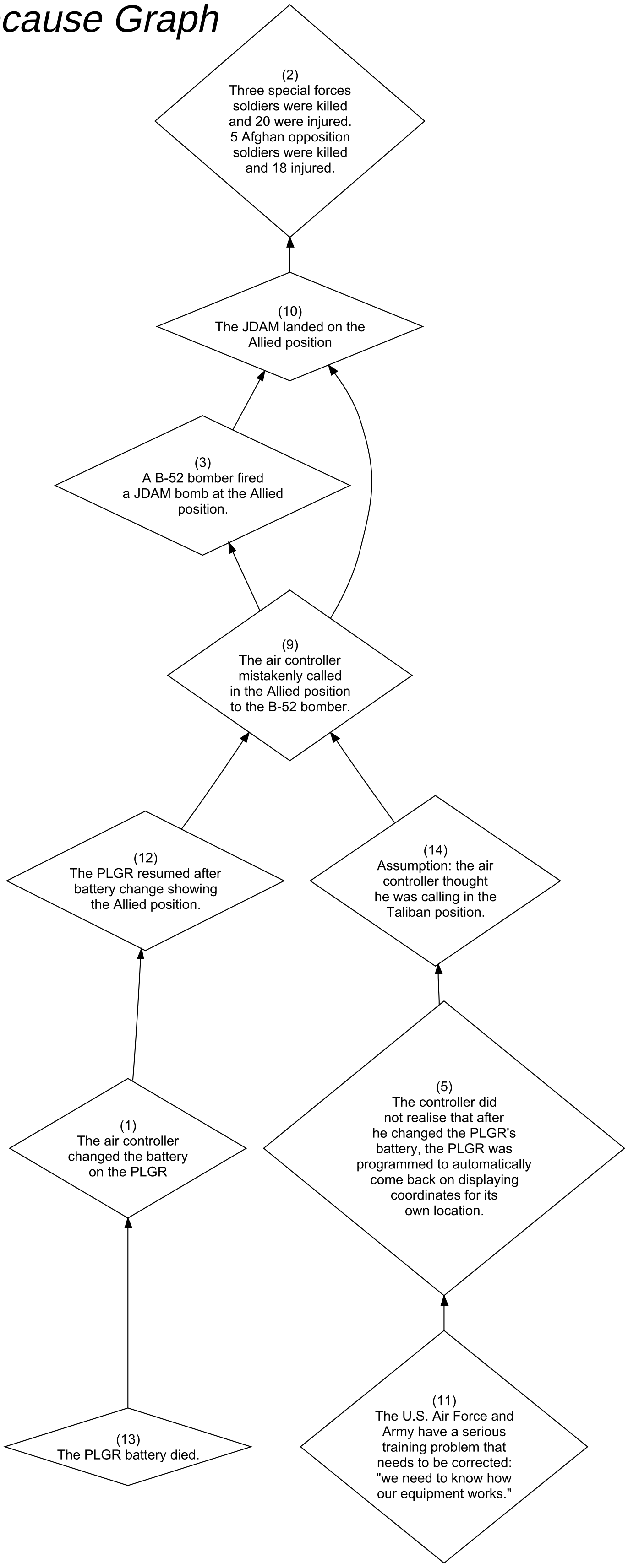
  How we are proceeding here through the factors can be made explicit. We have taken the Factors 3 and 9, which were the NCFs of the accident event according to the SERAS Reporter preliminary analysis, and asked what the NCFs of these are. We have discovered that Factor 9 is itself an NCF of Factor 3. Then we asked about the NCFs of Factor 9 and decided on Factors 12 and 14 by the Counterfactual Test. We asked in turn about the NCFs respectively of Factor 12 and Factor 14, and decided on, respectively, Factor 1 and Factor 5. We now ask in turn about the NCFs of Factors 1 and 5.

- **(1):** *The air controller changed the battery on the PLGR.* Obviously, he did so because the battery had died. Had the battery not died, the air controller would not have changed the battery on the PLGR. So Factor 13 is by the CT an NCF of Factor 1.

- **(5):** *The air controller did not realise that after he changed the PLGR's battery, the PLGR was programmed to automatically come back on displaying coordinates for its own location.* Most obviously, he did not realise this because, according to the official briefer, there is a training problem as in Factor 11. Were there not to be this specific problem, that the troops "*need to know how our equipment works*" but (being specific) do not know in this case (it was asserted) how the PLGR works in detail, then the air controller would have known that the PLGR reverts to own position after battery change. Hence Factor 11 is by the CT an NCF of Factor 5.

Collecting these decisions about NCFs together, we arrive at the WBG as follows. We are almost, but not quite, finished with this factor list.

Why-Because Graph



Factor List

1 The air controller changed the battery on the PLGR
2 Three special forces soldiers were killed and 20 were injured. 5 Afghan opposition soldiers were killed and 18 injured.
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4 The air controller was using the PLGR to calculate the coordinates of the Taliban position.
5 The controller did not realise that after he changed the PLGR's battery, the PLGR was programmed to automatically come back on displaying coordinates for its own location.
6 The air controller had used the PLGR to calculate the coordinates of the Taliban position in minutes and seconds for an airstrike by a F/A-18 aircraft.
7 The air controller did a second calculation in degree decimals required by the B-52 bomber.
8 The air controller had performed the second calculation and recorded the position, when the PLGR battery died.
9 The air controller mistakenly called in the Allied position to the B-52 bomber.
10 The JDAM landed on the Allied position
11 The U.S. Air Force and Army have a serious training problem that needs to be corrected: "we need to know how our equipment works."
12 The PLGR resumed after battery change showing the Allied position.
13 The PLGR battery died.
14 Assumption: the air controller thought he was calling in the Taliban position.

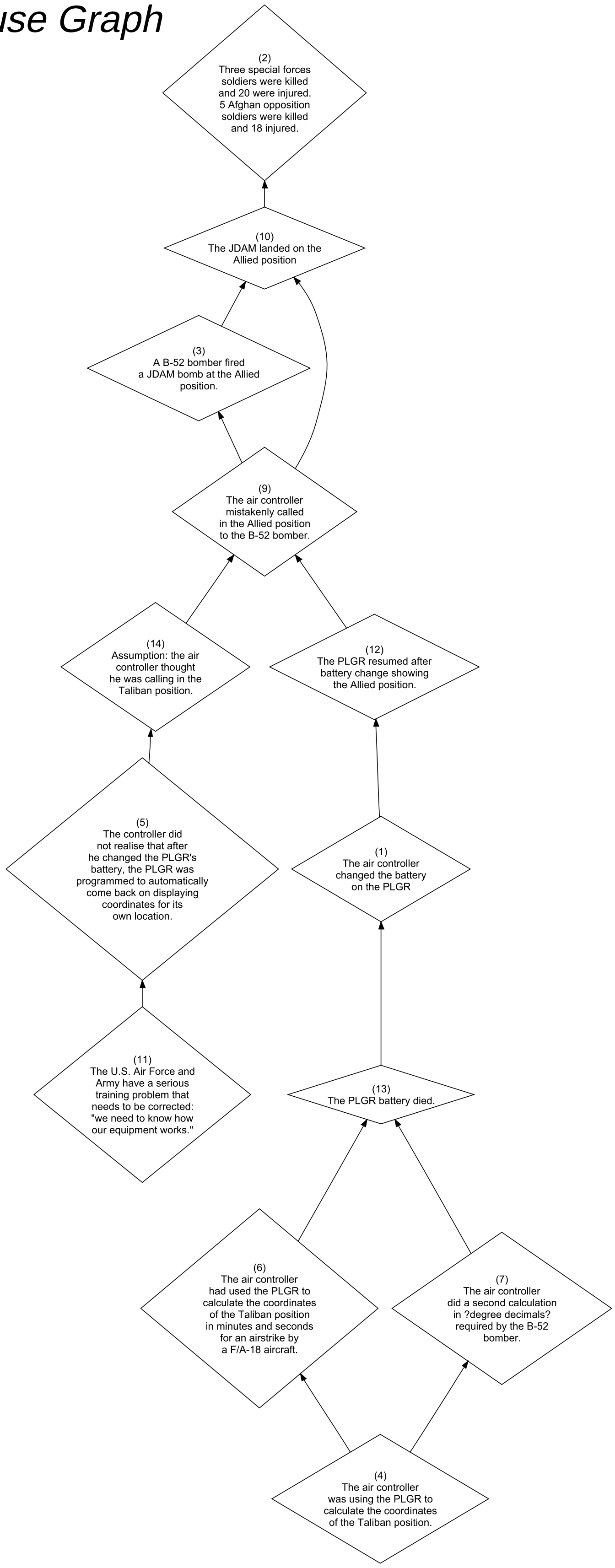
There are four factors not yet in the WB Graph, and some of them might well be NCFs of Factors 11 and 13. First, we may observe that there is no factor in the list which is a candidate to be a causal factor of Factor 11, the "training problem". But there may well be candidates for NCFs of Factor 13, that *the PLGR battery died*.

- **(13):** *The PLGR battery died.* Looking at this intuitively, there is no suggestion here that the battery died because it was defective, or because of some other anomaly. It had performed one calculation already, but it seems as though there was not enough current left to record and transmit the results of the second calculation. So performing one calculation was OK, but performing the second calculation after the first ran it down. One might also surmise that the battery was not fully charged to begin with, but nothing about this is said. It is generally not wise to engage in suppositions without attempting to gain some more information. Would the battery have died had the air controller not performed Calculation-2? No. (It did not even die during performance of Calculation 2, but at the end of the calculation.) So Factor 7 is by the CT a NCF of Factor 13. Similarly, had the air controller not performed Calculation-1 beforehand, there would likely have been enough current left to transmit the correct coordinates after the calculation for the B-52. So Factor 6 is by the CT a NCF of Factor 13.

- **(6) and (7):** The air controller was using the device to perform multiple calculations. Why? Because he was using the PLGR to calculate the coordinates of the Taliban position for an attack. This is Factor 4. So let us try the CT with respect to Factor 4. Had he not been using the PLGR to calculate the coordinates of the Taliban position, would he have calculated that position in minutes and seconds for an air strike by the F/A-18? Obviously not. So by the CT, Factor 4 is a NCF of Factor 6. Similar it follows that Factor 4 is an NCF of Factor 7.

At this point, we have all the Factors in the WB Graph except for Factor 8, that *the air controller had performed Calculation-2 and recorded the position.* What is the status of Factor 8? At this point, it seems to record a particular place in the sequence of events, in the timeline of the incident, at which some event happened. Its role in a timeline is important, to locate events in their sequence, but not everything in a timeline must play a causal role. We have causally-linked all other factors, so nothing is missing from the WB Graph as it is except for Factor 8. So be it. The WB Graph developed from this incident narrative is finally as follows.

Why-Because Graph



Factor List

1 The air controller changed the battery on the PLGR
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10 The JDAM landed on the Allied position
11 The U.S. Air Force and Army have a serious training problem that needs to be corrected: "we need to know how our equipment works."
12 The PLGR resumed after battery change showing the Allied position.
13 The PLGR battery died.
14 Assumption: the air controller thought he was calling in the Taliban position.

6 Stopping Rules and the Causal Completeness Test

What We Have Accomplished So Far

We have a WB Graph which contains all of the factors we identified in the narrative report, with one exception. We have checked all of them, although we proceeded more systematically than by checked each factor against every other factor. The WB Graph we have obtained shows all the relations, of one factor being a necessary causal factor of another, that stand amongst the original factors gleaned from the narrative.

Stopping Rules and the Causal Completeness Test

Do we stop with the WB Graph we have developed, or is there more to do? Indeed, we may stop here if we wish, by applying the *stopping rule* that we only take into the WB Graph factors which are identified in the original narrative. We may wish to go further, however. A narrative from which we are working may not be complete, and we may wish to consider factors that are not explicitly included therein. For example,

- Did the training really omit the PLGR detail that it reverts to own-position on battery change? Or was this in the training but the Air Controller had overlooked it in this case?
- Was the PLGR battery run down normally, or was there some battery defect that did not allow it to hold its charge, and therefore run down prematurely?
- What was the role of the design of the PLGR, that it reverts to own-position in this manner? Could a different design have shown this explicitly on the display, rather than relying on an operator's understanding? Say a "confim" message: "*You are communicating own-position. Do you really want to do this?*"
- Were the coordinates sent and received correctly in each transmission? Consider the CT, if the own-position coordinates had been faultily sent or received, the bomb would have landed elsewhere.

The WBA as is is sufficient for some purposes, say those of explaining the incident to the military and considering changes in training. But it may not be sufficient for designers or military procurers, who might well want to consider the influence of design, and therefore the questions above. Their stopping rule would not be so curt. Developing this theme takes us somewhat beyond the scope of this exercise. However, there is a key component of WBA which we have not yet considered.

We know that there may be some missing factors which may be relevant to a causal explanation. Consider Factor 9, that the B-52 fired the JDAM. There is nothing in logic that requires the B-52 to fire a JDAM when it receives coordinates from a PLGR. It did so because (we may presume) that is what standard procedures require it to do. We could add “*standard attack procedures were followed*” as a necessary causal factor of Factor 9. Then Factor 9 becomes *necessitated* by the NCFs which are indicated, as follows:

- Standard procedures require that a JDAM be fired at the coordinates when these coordinates are received from the PLGR;
- Coordinates were received from the PLGR;
- Standard procedures were followed;
- Ergo the JDAM was fired at the coordinates.

This is a form of completeness: we have enough NCFs of Factor 9 to necessitate that it occurred. The **Causal Completeness Test** (CCT) asks whether a phenomenon is necessitated by the NCFs displayed. This leads to an extended stopping rule: for each factor, we may try to formulate and add NCFs until the factor is indeed necessitated by its NCFs. Applying the CCT tells us when we have enough. Doing this here would take us beyond the scope of the current exercise.

Applying the CCT takes a certain amount of analytical experience. For example, certain phenomena are consequences of the (rough) validity of Newtonian mechanics on earth. Would we wish to add an NCF “*Newtonian mechanics*” for every phenomenon that occured because of terrestrial mechanics? Newtonian mechanics is part of the context within which we operate on this earth, so there seems good reason to assume it as part of the context of analysis rather than include it explicitly.

However, we may well wish to retain “*standard operating procedures*” explicitly as an NCF of Factor 9, because we may wish readers of the analysis to ask themselves whether standard operating procedures should be retained or changed. Similarly, we may want to include explicitly a factor expressing a legal context in some civil accident analysis, to give rise to thoughts about whether and how the law might be changed.

So an analyst usually does need to set the scope of an analysis, to define a context to which certain phenomena belong and which thereby would not be adduced as NCFs when applying a completeness test. Do we accept the laws of physics as context? Normally, yes. Do we accept the laws of the land in which the accident took place as context? Often so, but then we may wish explicitly to show how a given legal environment contributed to an accident or its consequences[7]. Do we accept the standard operating procedures of the organisation within whose remit the accident occurred? Very often, we may wish to question these. If so, they would not be part of the context, and we would need to include causally relevant features of them explicitly.

[7] In particular, Hopkins’s Accimaps show such general context, in general terms. There are also socio-technical models which can apply more generally, such as that of Rasmussen and Svedung used in Leveson’s STAMP analyses.

Application of the CCT , then, usually proceeds relative to a context. It is possible to apply it without defining a context, at the cost of adding factors, maybe many factors, which do not contribute much to explanation.

A stopping rule is necessary for any causal inquiry, whether or not context is considered, and it is best if the rule is explicitly formulated. Again, this requires some analytical experience. A stopping rule is necessary, to stop an analyst being led further and further back in the past without bound. For example, consider damage. A person could not have been killed had heshe not been born. By the CT, then, that person's being born is by logic a necessary causal factor of the damage. But do we wish to include “Person A was born” in a causal analysis of how Person A might have died? Likely not. Similarly, consider an operator action causally contributory to an accident. The operator could not have performed that action had heshe not been born, but practically we do not want to put hisher birth into a causal explanation of the accident. We do need a stopping rule which stops before this.

A discussion of the choice of stopping rules will take us beyond where I wish to go. I stop here.

Acknowledgements

Many thanks to Drs. Bernd Sieker and Jan Sanders for help with the first version of this introduction a decade ago. Many thanks to Sören Bollmann, Hauke Kaufhold, Tim Schürmann and Andrea Weber for help with this version and for the updated SERAS software.