Incident Reporting using

SERAS Reporter
and
SERAS Analyst

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Section 1: Explaining Incidents

Humans construct artefacts to serve various purposes. Some of these purposes lead to simple artefacts, for example, to cut something one needs only a sharp, hard edge and some sort of a grip to hold it with. Some of these purposes lead to complicated artefacts, for example an aircraft to let us fly intercontinentally in comfort. If one does not use the artefacts in the intended manner, harm may result. For example, if one grasps a knife firmly by the blade. Or if one does not follow the proper procedures for landing the aircraft. We can call such situations, which are not intended by the designers and from which harm may result, hazards. We can call situations, in which harm does indeed result, accidents. Sometimes harm results even when the artefact is used in the intended manner, or when one supposes the artefact is being used as intended. One presses the knife too hard, with the blade at an oblique angle, and it shatters, hurting a hand. One lands an aircraft somewhat too fast, and the braking systems deploy unexpectedly late, resulting in the aircraft overrunning the runway, as happened at Warsaw airport in 1993.

We can learn from accidents how to avoid the situations that gave rise to them. The notes on use of the knife used to say “don't grasp this knife by the blade” and now they might say “1. Don't grasp the knife by the blade; 2. 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”. The braking-systems deployment logic of the 1993 accident aircraft is different from that of later models, and the Flight Crew Operating Manual at that airline reads differently concerning how much extra speed can be maintained on approach if the crew expects sudden changes of wind.

Some accidents can be more severe than others. When the knife blade shatters, one or two people might be affected. When two large commercial jets collided on the runway at Tenerife in 1977, 583 people lost their lives. Where the artefacts and their use are complicated, and where there is potential for very severe outcomes, it seems wise to investigate untoward behaviours, including accidents, of those artefacts very carefully in order to avoid repetition of behaviour which could harm severely.

Questions about the properties of even a relatively simple artefact such as a knife can be complicated to answer if not enough is known of the properties of the materials from which it is made. Some artefacts, such as commercial aircraft, are inherently very complicated, partly because they are constructed out of simpler artefacts with specific functions, all of which functions go together to provide the overall function of the aircraft. Here we can usefully speak of components of the artefact, and combining components. When there are lots of components, then the combinatorics of the components, how they are put together and how they might affect each other, is in itself 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. Then there are physical components whose main functions are achieved through electrical means: generators to make current, motors to convert it into force, sensors to determine properties of the environment through which it moves, and computers to convert it into calculations in logic. 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 artefact is used. There are laws and regulations which determine or constrain the worldly situations in which we humans may use the artefacts. 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 behaviours of any or all of these might come together to create a hazard, or an accident.

When individual behaviours of many objects interest us, we speak of a *system* comprising those objects and their joint behaviour. We can consider any collection of objects in the world, as we like. Those objects might be people, metal, electrons, software, regulations, and so on. When different kinds of objects are in the system, say, people, mechanical devices, and digital-computer controllers, then we speak of a *heterogeneous* system. The system objects exhibit behaviour (the car drives), and some of that behaviour depends on the environment of other objects (the wall sits in front of the car; another car is also driving on the same road) and thus we may speak of joint behaviour (of the car and the wall; of the car and the other car). Do they hit? Do they miss? What happens when they hit? We have more reasons to consider some collections than others: cars in the immediate vicinity of each other we call "*traffic*" and we care what the traffic is like; a car in India together with a car in China, a car in the U.S.A., a car in France and a car in Britain makes, in contrast, quite an uninteresting collection of objects – unless, say, they are all of the same type and exhibit exactly the same peculiar, interesting and perhaps dangerous behaviour which we want to analyse. Which *systems*, collections of objects exhibiting joint behaviour, interest us, and which not, depends on the nature of the *joint behaviour* which they exhibit. If the joint behaviour is nothing more than the individual behaviour of each object, conglomerated together, then we are likely to be relatively uninterested in the system as a system. If the joint behaviour contains phenomena which we cannot so easily discern through considering simply the individual behaviours of each object in isolation, then we are likely to be more interested in considering the whole as a system. And if that intertwined joint behaviour leads to an accident with consequent harm, we might be very interested indeed, as well as very worried.

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 neighbour's BMW. Was it Friday 13^{th}? Then maybe we shouldn't drive cars on Friday 13^{th}. But then, think of all those *other* cars driving around on Friday 13^{th} to which nothing untoward happened, including those like ours as well as other BMW's. So even if the date had something to do with it, there must be other influences as well, that arose in our case that did not arise in the cases of all those others driving around happily. Or so we say, but what justifies even this - apparently obvious - reasoning?

We like to think that some phenomena *make* other phenomena happen, *force* those other phenomena to occur. To use a bigger word, to *necessitate* the occurrence of those other phenomena. As David Hume famously remarked some 270 years ago now, we don't have a sense organ than can sense this forcing, as we have eyes that see red or noses that smell roses. We have to infer it indirectly from the phenomena that we do sense.

It does seem like a good idea, in the case of an incident of a sort we are concerned to avoid in the future, to inquire about this *forcing*. For if there is a collection of other phenomena which somehow jointly *forced* the incident to occur, then maybe we in turn could *force* some of those other phenomena not to reoccur, and then our incident will not reoccur. The word we use for this indirectly inferred influence is *cause*. The forcing is *causal*; the phenomena that force are *causes* or *causal factors*, and the inferences we make about causes is the science of causality.

Hume famously inferred causality, that phenomenon A causes phenomenon B, through observing *constant conjunction*, that whenever A happens, B happens also or shortly thereafter. This form of repeatable regularity has focused the attention of most of those who have tried to determine the nature of causality, the indirectness noted by Hume leading to a form of reasoning known as *inductive inference*. However, harmful incidents are seldom, we hope. Any unwanted repeated regularity or constant conjunction would induce us to stop using the artefact forthwith. So it would seem to be a very indirect and even difficult path to try to explain rare events through constant conjunctions.

As David Lewis said, 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 here what we call 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. The renaissance of interest in the counterfactual formulation is 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 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 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, the problems of 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, namely, that it turns out that the semantics for the counterfactual conditional is quite intuitive and can often be accurately applied by all sorts of people concerned with trying to explain the events of everyday life. 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." Exactly the counterfactual notion, in a practical how-to manual.

Why-Because Analysis (WBA) is a methodical way of applying this notion of cause to the collection of facts about events and situations which we form in the aftermath of an incident. I, my students, and colleagues have been applying it for a dozen years, and it is currently part of the methodology of two transport divisions of a large multinational engineering firm. It has also proved its worth in civil and criminal court cases resulting from accidents, as well as in extra-legal negotiations. We have found that this minimalist approach, rigorously applied to data gathered "in the field", yields worthwhile and insightful explanations, as well as helping to correct mistakes in the analyses of others. Using such an approach, we can handle issues with mechanics, electrics, software, people, procedures and laws in a uniform way, without needing special physical theories, theories of software, of human psychology and other human factors, of procedures, or of the law, and

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

attempting to integrate them all, to try to explain what fell in between the cracks of all the specialist understandings of all the specialist parts of the system, to cause the incident to occur.

While fruitful in itself, Why-Because Analysis can be used in conjunction with specialist theories of mechanics, electrics, software, people, procedures and laws, all these heterogeneous components of systems, because of its minimalist character. To judge whether a phenomenon is a cause of another, WBA, following Hume-2, Lewis and Mackie, says to evaluate a counterfactual conditional. Specialist theories can help you to evaluate such a counterfactual conditional, rather than leaving you in the dark. Evaluating counterfactuals in itself cannot conflict with a specialist theory, cannot constitute its rival. It is rather a way of framing the information which you need to assess using your specialist theory, and all the other specialist theories for all the other information, in order ultimately to help you find out why and how the incident occurred. Thus WBA offers a solid methodical basis on which to apply specialist theories.

Section 2: A Narrative Report

To show how a Why-Because Analysis proceeds, we start with a simple 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.”

Beginning a WBA: Structuring the Narrative

To analyse the incident causally, we start from the text of the friendly-fire incident in Chapter 2, and consider its assertions about the incident one by one. As a crude start, we can take the assertions about the incident to be the individual sentences of the narrative. We proceed to modify these sentences according to the following principles.

Unique Identifiers

Terms which clearly identify a participant in the incident should be chosen and used uniformly, throughout. In particular, pronouns and possessives which refer to other factors should be eliminated in favour of explicit terms. For example, consider the two factors:

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

In the first factor, there is a unique identifier for the aircraft, which we may further use. In the second factor, the word “*its*” can be eliminated in favour of the identifier:

> *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 this to the narrative, we see for example 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*, and if necessary annotate this identifier elsewhere (say, in an “Identifier Dictionary” accompanying the analysis) 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 Lightweight GPS Receiver*
> *“plugger”*
> *PLGR*
> *device*
> *machine*
> *GPS receiver*
> *receiver*

The choice seems to be easy. We can use the term *PLGR*. We also annotate this term in the Identifier Dictionary to show that it means “Precision Lightweight GPS Device”.

Separating Factors

The factors should be separated from each other as far as possible and reasonable. For example, if the factor is formed from two statements using a conjunction (for example, "*and*", "*but*", "*however*"), then one can separate the factor, for example the factor

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

which contains the conjunction "*and*", 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 if information about the sequence of events is lost (as indicated, for example, by use of the conjunction "*and then*"). Sequencing information will be re-inserted during analysis. In most cases, it turns out that such sequencing information is contained elsewhere in the narrative.

Consider, in the 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 the transformation on the identifiers:

> *Without realizing the PLGR was programmed to come back on showing the coordinates of its own location, the Air Controller mistakenly called in the American position 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 its own location*
>
> *The Air Controller mistakenly called in the American position to the B-52*

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*.

Factors should be written as far as possible in active voice, not passive voice. There are two reasons.

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 call the process of changing passive-voice statements into active-voice *activisation*.

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 "*wall number 1*", "*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. It is for the reporter to determine the best phrasing of hisher report. An analyst will rephrase later if need be.

Note that 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). One may say "t*he nose of G-ZZZZ was crumpled*" in order to describe the state of the aircraft's nose, rather than the action that caused it to be in that state. This is very often so, and a reporter should ask himherself whether a statement describes an occurrence, an event, or a state of something. The notion of activising makes no sense for state descriptions – they are OK as they are.

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 likely unnecessary to analyse it further in this 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.

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 that could be 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 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, in and of themselves rarely play a causal role *in* the accident itself. (There is of course an exception to this general observation: some opinions might well have played a role if human actions taken which contributed causally to the accident were based on opinions held by the actor or expressed to himher, say by maintenance personnel.) It is good journalistic and investigative practice always to note the contributor of a piece of information that might be causally relevant, but a 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 that briefing cannot be causal to the incident, since causes rarely if ever follow their effects (according to the folk science, to which we adhere here. Others such as Immanuel Kant are also of this opinion). So the statement that the official said something at the briefing cannot be a causal factor, or a causal factor of another causal factor, or anything like this, in any causal explanation of the friendly fire incident itself. Indeed, rather the other way around - his words were partially caused by the incident, not causal of it (evaluate the counterfactual: had the incident not occurred, he would not have been talking about it on March 23rd).

What the official said was two things. First, that an action "triggered" the incident; and, second, that this action was that a controller changed 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" (maybe something stronger such as "was a proximate cause of" if one has a notion of "proximate cause"). The second claim says: a U.S. Special Forces controller changed the battery on a device he was using.

We are trying to write down the causal factors of the incident. The second claim is a possible candidate:

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

Using the "unique identifiers" guideline, and reading a sentence further down in the narrative, that this device is a

> *... Precision Lightweight GPS receiver, known to soldiers as a "plugger"...*

which is further explained in a footnote (omitted) to mean PLGR, we might write as the final version of a (potential) factor

> *A U.S. Special Forces air controller changed the battery on his 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: A U.S. Special Forces air controller changed the battery on his PLGR*

As a second example, 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 co-ordinates 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, for its main action is an inaction: "*never explained*" which is an inaction the U.S. Central Command in-dulged in *after* the incident took place, and again by the folk principle that causes do not follow their effects this inaction cannot be considered a cause. Thus no factor is extracted from this sen-tence.

Section 3: Using SERAS® Reporter to Isolate the Factors

Much of this massaging of a textual narrative is routine and can be accomplished relatively easily through using appropriate computer software. For example, the text of the "friendly fire" incident can be entered into the WWW-based SERAS® Reporter, at ***reporter.causalis.eu*** either by typing it in or by using cut-and-paste from one's local machine.

The Reporter asks first for personal information about the person reporting the incident. After completing this part and proceeding, by clicking on the green "*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, by using cut-and-paste. The result looks as follows.

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SERAS® Reporter

« Back « » Proceed »

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

By proceeding to the next stage, the narrative is factored automatically by the SERAS® Reporter into separate factual components. This factorisation is shown next. It is crude - it factors, for example, on punctuation symbols, so whole phrases such as "U.S. Special Command" are split into here-meaningless sub-phrases "U.S." and "Special Command". The factors may – indeed, must! - be edited at this stage to derive a passable, readable factor list, with two goals:

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

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SERAS® Reporter

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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

Applying the *unique identifier* guideline, we can identify at first sight 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

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- 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 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 can apply the causal-relevancy guideline 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:

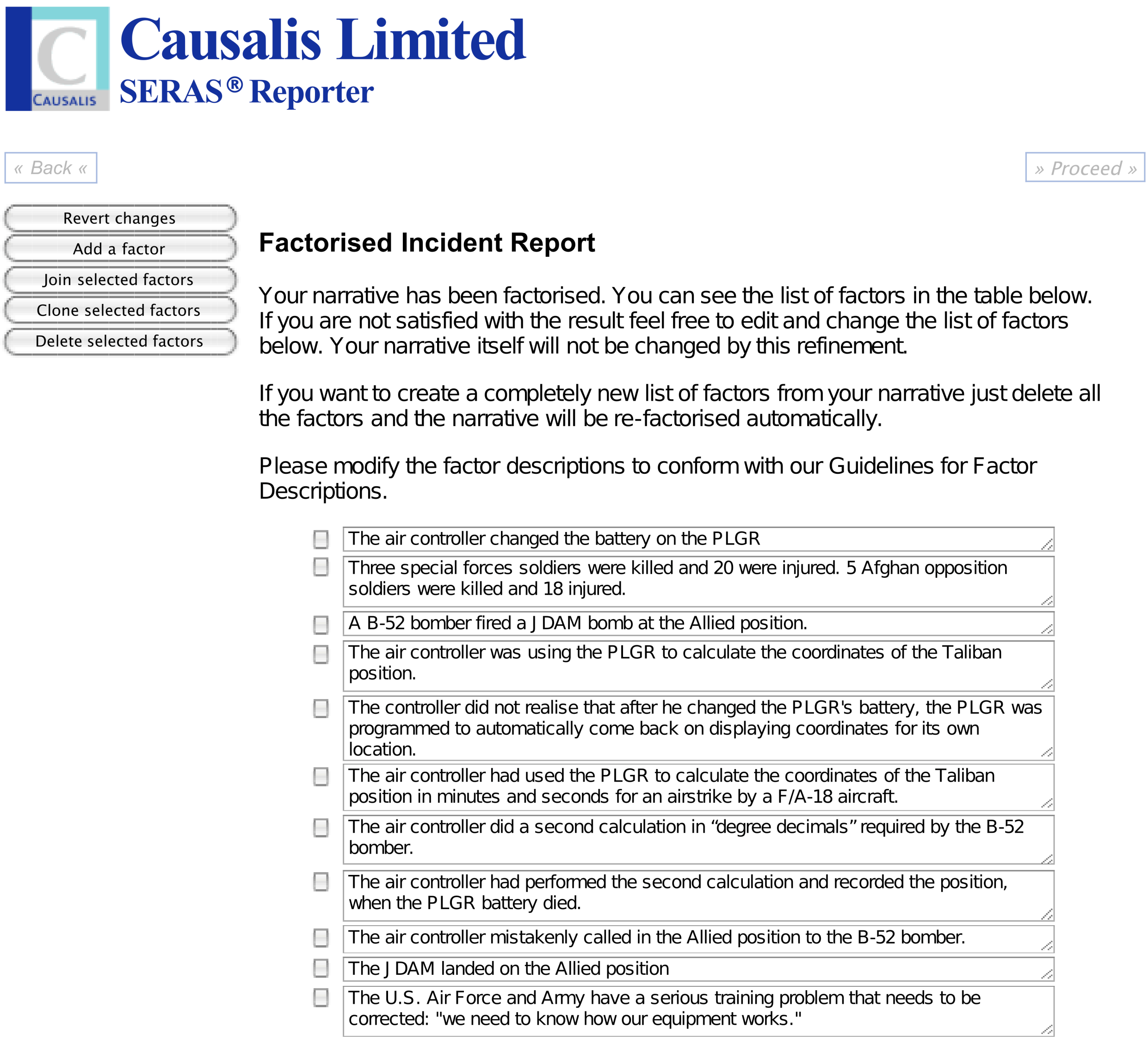
- People killed and injured (this constitutes the damage or harm)
- That the JDAM bomb landed on the Allied position

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 also eliminate throughout the statements "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, which we can reduce to a single factor per piece of information.

The factor list is shown 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.

Causalis Limited
SERAS® Reporter

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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 J DAM 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 J DAM 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.

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, which factors are such that, had they not occurred, the accident event would not have occurred either.
  This test, which factors are such that, had they not occurred, the accident event would not have occurred either, is the kernel of Why-Because Analysis and is called the Counterfactual Test. Here, we are applying it 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 behavioural 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 specific use of the PLGR in this instance is momentary.

What qualifies the phenomenon that the PLGR was being used to calculate the Taliban position as an environmental factor is the observation that, with the exception of the three other environmental factors, this phenomenon persists throughout the time frame of all of the other factors mentioned. It frames in time, if you like, the incident as it plays out. So do the other environmental factors, only with wider frames. Thus the phenomenon, that and why the PLGR was here being used, is 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.

The report may be downloaded from the WWW onto the local machine, where it may be further developed, in particular as a Why-Because Graph, using the SERAS® Analyst tool, YBT2.

Causalis Limited
SERAS® Reporter

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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 J DAM bomb at the Allied position.
Environment	The air controller was using the PLGR to calculate the coordinates of the Taliban position.
Environment	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 J DAM landed on the Allied position
Environment	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

Section 4: Developing the Causal Analysis with SERAS® Analyst

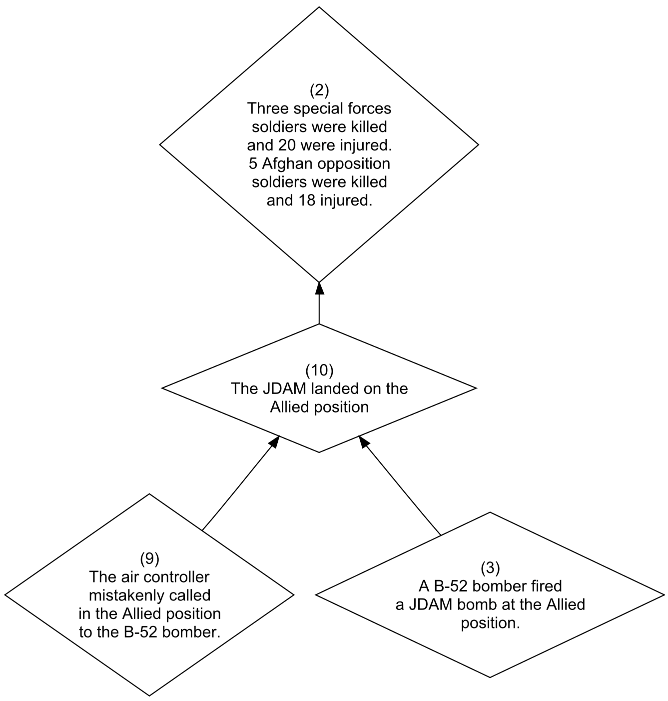
The output from the SERAS® Reporter, produced in an XML dialect called BARD-ML, may be directly imported into the SERAS® Analyst tool, which converts BARD-ML into its interface language, CausalML.

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 , or NCT, of the node at the arrow end of the edge.

The notion of combinatorial graph, also known just as *graph*, comes from combinatorial mathematics and logic. A graph consists of nodes, joined by edges, as above. In mathematics, there is no inherent meaning attached to the nodes or the edges – mostly just mathematical properties are investigated. However, *graph algorithms* form a significant research area in computer science and undergraduate computer science students learn the most important graph algorithms in an undergraduate degree course. The Why-Because Graphs discussed here are not abstract combinatorial entities, however, but have a meaning. The nodes represent phenomena that are causally involved in a particular event on which we are focussing, an accident event, from which damage has resulted. The edges represent the relation of one node being a NCF of another node, which nodes are connected by an edge with the direction showing which is the NCF and which the caused phenomenon.

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.

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.
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.
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.

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

As I indicated already, the CT is the core of most conceptions of singular causality. In order to apply it, 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*

Why-Because Analysis uses the interpretation of this counterfactual statement due to David Lewis, *op. cit.* We have found that an intuitive statement of this interpretation suffices to be able to apply it in most practical cases. However, an analyst will almost inevitably come upon such statements whose truth heshe cannot immediately determine. Some extra careful thought is required, and it may be that 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 on truth or falsity, and continue. A Why-Because Analysis shows its value even in cases in which philosophical-logical rigour is not uniformly applied. An analyst can single out specific cases in which heshe was unsure of the appropriate judgement and bring them to the attention of readers of the analysis.

Applying the Counterfactual Test

The next step is to apply the Counterfactual Test to all factors, in pairs. This 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, so we have only 10 to consider, amongst them two which are already in the WB Graph. Let us 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 in our factor list, but 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 belongs to what it was doing – it is standard attack procedure. Were this not to be standard attack procedure, the JDAM would not necessarily have been fired, or fired at those coordinates. Were the bomber not to have been attacking, say it had been on a practice exercise, the JDAM would not necessarily have been fired. So we may need to add some factors to make this context explicit. We'll 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 the guidelines further. There were two calculations performed, and it may be useful to distinguish them. This was the second. The air controller had already successfully performed the first. Performing this second ran the battery down and out. So it looks as if we need 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.*
  > *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 decimals.*

  So looking at the two factors we have extracted from Factor 8, we can assess their NCFs with the help of this list. To do this, we first modify Factor 8 in SERAS® Analyst to just talk about 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. 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.

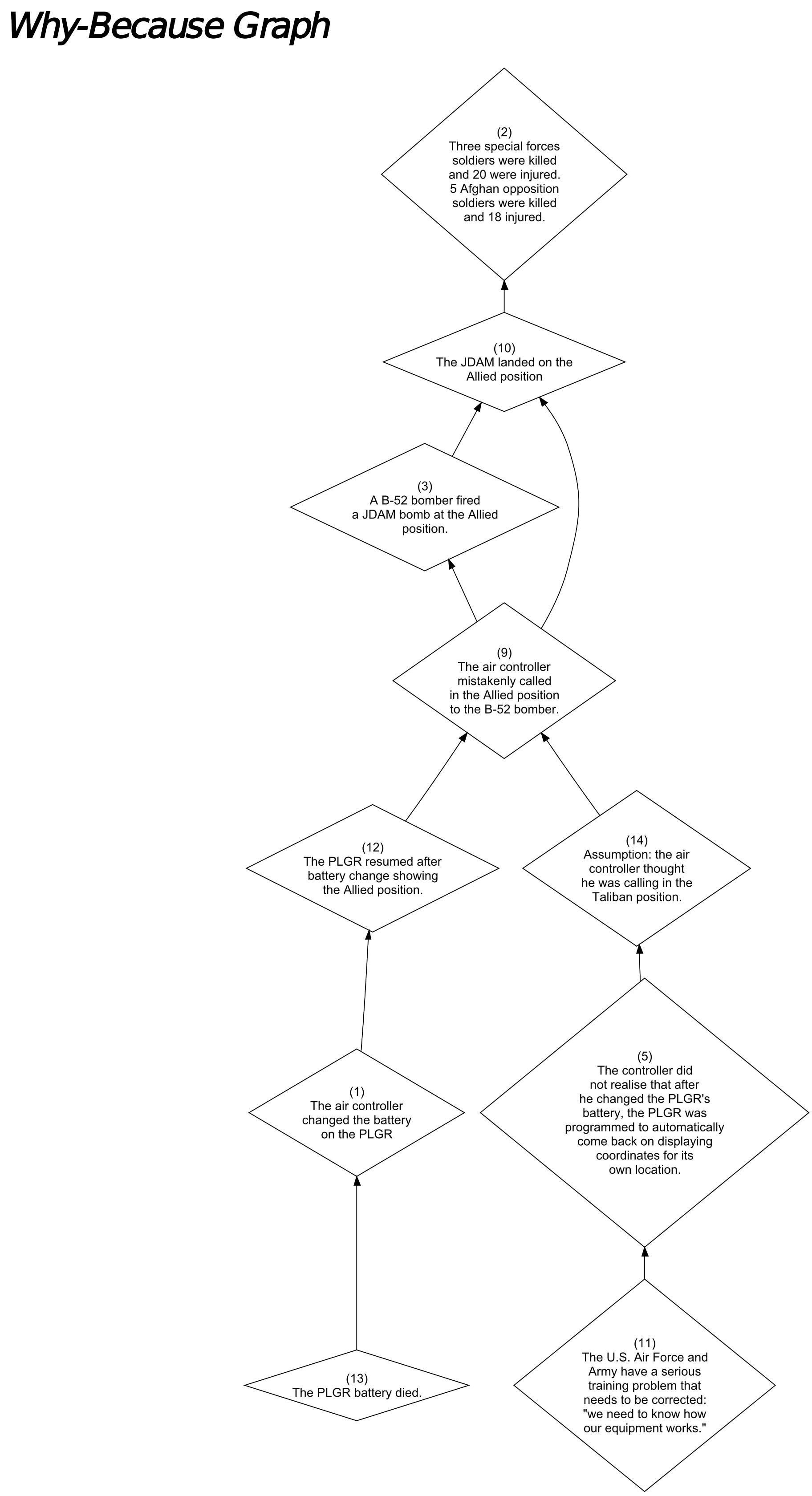
- **(14):** *Assumption: The air controller thought he was calling in the Taliban position.* Most obviously, had he realised that the PLGR reverted to own position after battery change, he would not have thought he was calling in the Taliban position (he would have realised he would be calling in his 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.* Most 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 do not (as regards the PLGR), 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.



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.
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 likely 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.

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.

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

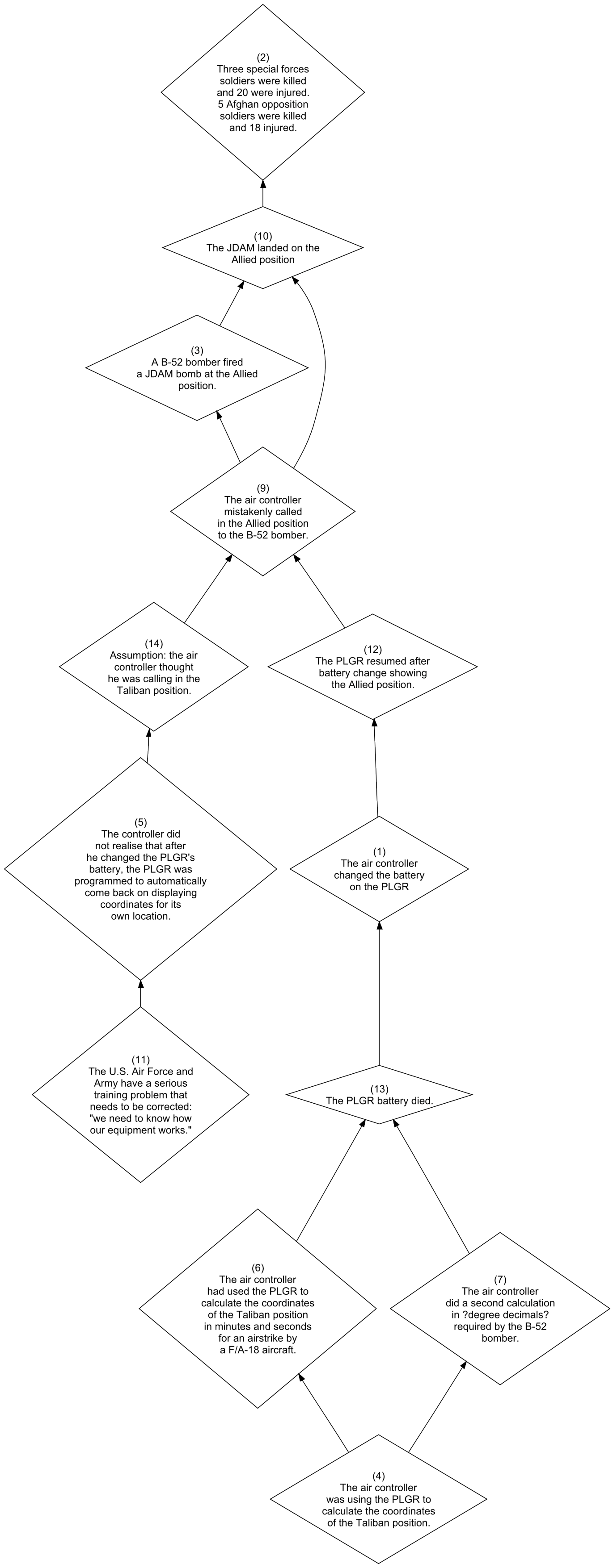
11 The U.S. Air Force and Army have a serious training problem that needs to be corrected: "we need to know how our equipment works."

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.

Why-Because Graph



Section 5: Further Analysis

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: we apply 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. For example, a narrative from which we are working may not be complete, and we may wish to consider factors that are not explicitly included therein.

Developing this theme takes us somewhat beyond the scope of the current exercise, but it is an important part of Why-Because Analysis, so I sketch it here.

I have already indicated that there may be some missing factors which may be relevant to a causal explanation. Namely, when we consider the 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. If we were to add "*standard attack procedures*" as a necessary causal factor of Factor 9, then Factor 9 becomes necessitated by the NCFs: 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; ergo the JDAM was fired at them.

We may wish to test for completeness of this sort. The **Causal Completeness Test (CCT)** asks whether a phenomenon is necessitated by the NCFs displayed. If not, we may try to formulate and add NCFs until the phenomenon is indeed necessitated by its NCFs. Applying the CCT tells us when we have enough. The appropriate formulation of missing factors takes 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 occurred because of terrestrial mechanics? I doubt it. Newtonian mechanics is part of the context within which we operate all the time on earth, so there seems good reason to assume it as part of the context of analysis.

In contrast, we may well wish to retain "standard operating procedures" explicitly as an NCF of Factor 9, because we may wish intended readers of the analysis to ask themselves whether standard operating procedures should be changed. Similarly, we may want to include a factor expressing a legal context in, say, 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.

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. At times, this has its worth: since in such a WB Graph every phenomenon is necessitated by its NCFs, it follows that there are no implicit assumptions being made for any of the individual causal connections. There are times when we indeed wish to be sure that a causal analysis is making no assumptions.

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, because inquiring rigourously after causal influence leads one 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 a necessary causal factor of the damage. Similarly, consider an operator action causally contributory to an accident. The operator could not have performed that action had heshe not been born. By the CT, again, that operator's being born is a necessary causal factor of the action that causally contributed to the accident. Working without some stopping rule will lead us to unfruitful lines of inquiry such as these. Almost all stopping rules one can usefully use will terminate an inquiry into causal factors before it arrives at the birth of accident participants.

A major reason why one might wish to go further in the friendly-fire incident analysis which we have been performing would lie in deriving countermeasures. Action could be taken on training, as intimated by the briefer, but other actions are also possible. Maybe attack procedures could be changed to require communication of the co-ordinates of the controller ordering the attack as well as the target co-ordinates. Maybe the design of the PLGR could be changed to include persistent memory for calculations. And so on.

But I stop here because the purpose of this document, to show how to perform a WBA using the SERAS® toolset, has been fulfilled.

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.