

# Checking and Comparison of WB-Graphs

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**Abstract.** Why-Because Analysis (WBA) claims to be an objective method for causal analysis of incidents in so far as different groups performing a WBA will come to more or less the same causal conclusions, modulo different construals of the list of facts which must be brought into causal relations. To determine whether this is the case or not, one must be able to compare different WBGs for similarity and difference. We consider some manipulations on WB-Graphs (WBGs) which may be used to reduce WBGs to a form in which they may be directly compared

## 1 Introduction

We shall use the graphs in Figures 7 and 8 as a running comparison. These graphs were produced by beginners at WBA, namely students in the first semester of a two-semester practical course (“Lab” course) on WBA in Fall of 2005. This was the first WBA these students had prepared. The incident description from which the analysts worked may be found in the Appendix to this note.

## 2 Identical and Non-Identical Nodes

- Some nodes in the two graphs are obviously identical. The identities are tabulated in Figure 1.
- The WBG Version 1 (V1) has 18 nodes, and WBG Version 2 (V2) has 19 nodes. 12 nodes, that is, two-thirds of either V1 or V2, are obviously identical.
- Our colleagues in IfEV Braunschweig and TU Dresden determined in their example (the Neufahrn S-Bahn collision near Munich) that about two-thirds of their nodes were intuitively identical. However, they included sets of nodes that had an m-to-n relationship: that is, the conjunction of a certain number of nodes ( $m$ ) in the first graph was equivalent to the conjunction of a certain number ( $n$ ) of nodes in their second graph.

## 3 The Precipitating Event and Logical Relations

### 3.1 Precipitating Event

Many incidents take place in a system environment in which there is a formal definition of an accident. For example, the U.S. Federal Aviation Regulations define an accident (roughly, an event which results in significant damage to an aircraft and/or deaths and/or severe injuries), similarly to the U.S. Air Force’s Class A Mishap (\$ 1m damage and/or deaths and/or severe injuries). The **precipitating event** is whatever directly caused these consequences which fulfil the definition of an accident.

A typical precipitating event would be *Aircraft collided with terrain*. One would informally identify such an event as the accident. So the notion of precipitating event coincides with the informal notion of accident. The consequences which fulfil the definition of accident are causal consequences of the precipitating event.

Figure 2 shows the precipitating event and the consequences of the 1993 Lufthansa A320 overrun accident in Warsaw. The precipitating event is node *3.1 AC hits earth bank*. This caused damage to the aircraft, which resulted in a fire which caused even more damage. It also caused the trauma death of the co-pilot, as well as the loss of consciousness of a passenger, who was overlooked during evacuation and died of asphyxiation from smoke inhalation during the fire.

G1 Index:	G1 Description	G2 Index	G2 Description
-	-	0	Accident
0	3 soldiers dead; 20 soldiers injured	1	3 soldiers killed; 20 soldiers injured
-	-	2	JDAM dropped on own soldiers
1	B52 fires JDAM with communicated coordinates	3	B52 dropped JDAM on transmitted coordinates
2	B52 receives incorrect coordinates from controller	5	B52 receives incorrect coordinates from soldiers
3	JDAM released	-	-
4	Crew did not check the coordinates	6	B52 does not verify coordinates
-	-	7	Bombing procedures
5	Transmission of incorrect coordinates	9	Soldiers transmit incorrect coordinates to B52
6	Special Forces request air support	4	Soldiers called in air strike
7	B52 active in air support in the region	8	B52 on duty
8	Determination of incorrect coordinates	10	Calculated coordinates are incorrect
9	Coordinates insufficiently checked by Special Forces	-	-
-	-	11	Procedures for air strikes
6.1	Special Forces on mission	-	-
11	Unexpected behavior of GPS device from the point of view of the soldiers	-	-
12	Assumption: Faulty instructions or violation of instructions	-	-
13	Faulty understanding of certain technical details of GPS device	14	Soldiers did not know of recalculation requirement
14	GPS device transmits own coordinates	-	-
15	Insufficient or inappropriate training	17	Air Force and Army have training problem that needs to be corrected
16	After battery change, GPS device calculates own coordinates	12	GPS device was programmed to come back to own location after battery change
17	Battery changed by controller shortly beforehand	13	Soldiers changed battery on GPS device
-	-	15	Soldiers operated GPS device
-	-	16	GPS device battery died
-	-	18	Soldiers operated under stress

Fig. 1. Comparison of Nodes

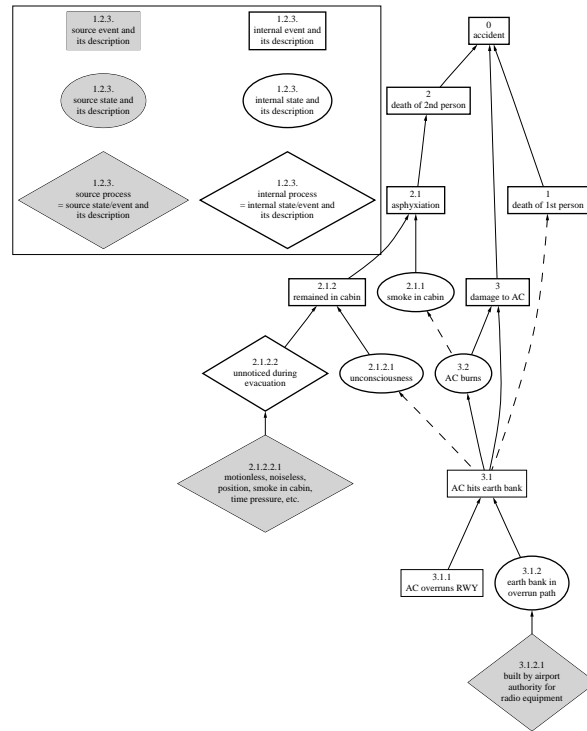
### 3.2 Identifying Logical Relations

Some nodes in V1 and V2 are logical consequences or semantic consequences of others. We say that Node  $x$  is a *semantic consequence* of Node  $y$  if and only if one can replace one or more components of Node  $x$  with semantically equivalent expressions (expressions that mean the same or similar), or same-denoting expressions (expressions that denote the same object or group of objects) such that the modified Node  $x$  becomes a logical consequence of Node  $y$ .

**V1: Figure 7** – Node 3: *JDAM released* is a logical consequence of Node 1: *B52 fires JDAM with communicated coordinates*, provided one accepts that *firing a JDAM* and *releasing a JDAM* are the same action: that is, *releasing (a JDAM)* and *firing (a JDAM)* are semantically equivalent expressions.

- Node 5: *Transmission of incorrect coordinates* is a logical consequence of Node 14: *GPS device transmits own coordinates*, provided one accepts that the phrases *own coordinates* and *incorrect coordinates* denote the same set of coordinates.

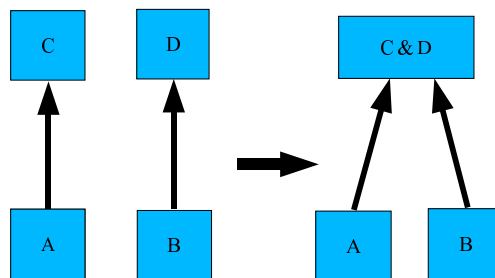
**V2: Figure 8** – Node 2: *JDAM dropped on own soldiers* is a semantic consequence of Node 3: *B52 dropped JDAM on transmitted coordinates*, provided one accepts that the phrases (*location of*) *own soldiers* and *transmitted coordinates* refer to the same set of coordinates.



**Fig. 2.** The Consequences of the Precipitating Event: The 1993 Warsaw Overrun Accident

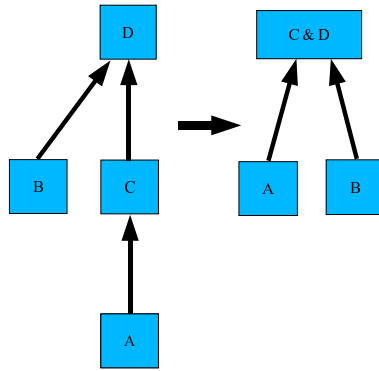
Certain nodes may be amalgamated in the following sense. One has Node  $A$  and Node  $B$  and wishes to replace these two nodes with a single node incorporating the information of both, that is, a Node  $A \mathcal{E} B$ . The question is how the in-edges (necessary causal factors; NCFs) of Nodes  $A$  and  $B$  relate to the replacement Node  $A \mathcal{E} B$ , and how the out edges of Node  $A$  (going to those nodes of which Node  $A$  is a NCF) and Node  $B$  relate to the out-edges of Node  $A \mathcal{E} B$ .

It is a theorem of the formal semantics of causality (the Lewis semantics) that any NCF of  $A$  is an NCF of  $A \mathcal{E} B$ , and similarly (of course) for  $B$ . This means that the in-edges of  $A$  and  $B$  become the in-edges of  $A \mathcal{E} B$ . This semantically-grounded graphical transformation is shown in Figure 3. A specific application of this rule which we shall be able to use in considering V1 and V2 is shown in Figure 4.



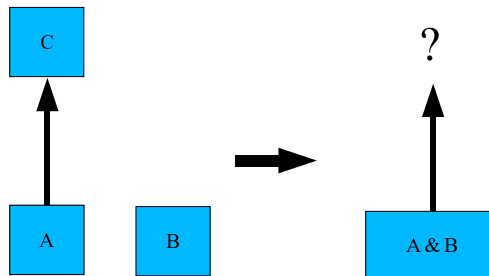
**Fig. 3.** Amalgamating In-Edges

Unfortunately, nothing much formally may be said about the out-edges of nodes  $A$  and  $B$  when one amalgamates them to a node  $A \mathcal{E} B$ . The causal connections between node  $A \mathcal{E} B$  and other nodes in the graph must be considered individually. This situation is illustrated in Figure 3.2.

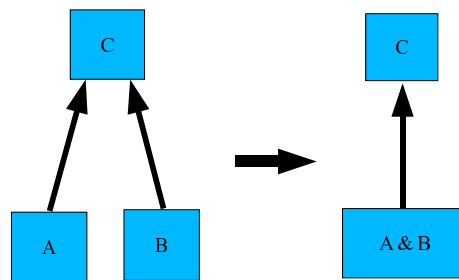


**Fig. 4.** Amalgamating In-Edges

However, if node  $A$  and node  $B$  are both NCFs of a third node  $C$ , then it follows from the Lewis semantics that  $A \& B$  will be an NCF of node  $C$  also. This situation is illustrated in Figure 3.2.



**Fig. 5.** Amalgamating Out-Edges: There is No Rule



**Fig. 6.** Amalgamating Out-Edges

#### 4 SAOIndO Form of Labels

One may compare labels more fruitfully for semantic consequence if one puts them into a standard form. One standard form for labels of nodes which denote events is the **Subject-Action-Object-Indirect-Object** form, or *SAOIndO form* for short.

In many (Indo-European) languages, one may emphasise different aspects of an event by using, say, passive voice rather than active voice of verbs (which enables one to omit the subject – the

doer – of an action), or, say, by omitting indirect objects (one kicks a ball, but omits to say at which goal). The SAOIndO form is one in which all participants of each action (event) are explicitly named:

- the doer of each action is explicit (as the sentence *subject*);
- the recipient of each action is explicit (as the sentence *object*);
- any other participants are explicit (as *indirect objects*, usually prefaced by a pronoun).

Consider for example the V1 Node 5: *Transmission of Incorrect Coordinates*. The action is *transmission*, and it is clear that it is the *incorrect coordinates* which were transmitted. But the label does not indicate who did the transmitting or who the recipients were. To put this in SAOIndO form, one has to name these participants. There some choices to make, however. It is not always unambiguous who is the subject, and *mutatis mutandis* for the other actors:

- who performed the action? Was it
  - *the soldier/controller*?
  - *the GPS device*?

One solution is to make two actions here:

- *the controller operated the GPS device to send the coordinates*
- *the GPS device sent the coordinates*

and these two events, now separated, stand in the obvious causal relation: the first is an NCF of the second.

When labels are put in SAOIndO form, it is often much easier to determine the logical relations amongst them, as well as semantic equivalences and semantic consequences.

## 5 Transparent and Opaque Contexts

It is also useful to make a distinction from philosophical logic, between different ways to make reference to objects. For example, the coordinates at which the soldiers were located are referred to as

- *coordinates*, *incorrect coordinates*, *own coordinates*, and *communicated coordinates* in V1; and
- *transmitted coordinates*, *incorrect coordinates*, *coordinates*, *calculated coordinates*, and *own location* in V2.

These phrases all refer to the same location or set of coordinates, but they emphasise different aspects of these coordinates: they were *communicated*, *incorrect*, *own* (*referred to self*), *calculated*, and *transmitted*. And they influence the semantics of the sentences in which they occur in different ways:

- *B52 receives incorrect coordinates from soldiers* implies that there was something wrong with the action; *B52 receives calculated coordinates from soldiers* has no such implication (in V2).
- *Calculated coordinates are incorrect* (V2) attributes a property to the coordinates: how did they come to have that property? Causally, the fact seems to be missing: they have that property because the coordinates of the intended target, that the soldiers were trying to calculate and transmit, were different from those they did calculate. *Calculated coordinates are not target coordinates* would have expressed that fact in a more transparent way, and would have avoided having to add this as an NCF of the node 10 in V1.
- Similarly, *Determination of incorrect coordinates* is both not in SAOIndO form and not transparent. *GPS calculates coordinates and coordinates are not target coordinates* would have rendered this fact more transparent. Note there is still a node missing: why causally did the GPS calculate these coordinates? It didn't do it all by itself. It calculated them because the soldiers were operating the device.

So it seems useful to render the SAOIndO sentences also in a form which makes the references to objects transparent. Sometimes this also gives clues to NCFs which are missing.

## 6 Reductions for Purposes of Comparison

The transformations spoken of so far have all served to regiment and beautify the WBGs, and to facilitate comparisons and identifications between nodes expressed in different ways, as well as to help correct a few causal mistakes. In so far, then, they are *information-preserving* transformations, even information-enhancing. There are some transformations which enable one to effect comparisons between WBGs, which transformations can lose information. Some examples:

- in V1, there is an assumption: Node 12: *Assumption: Faulty instructions or violation of instructions*, which is not contained in the original text but is supposed by the analyst. But it is also a leaf node: it itself has no further NCFs in the graph. V2 makes no such assumption. This marks a difference between V1 and V2, but the difference seems inconsequential to the accident itself: it arises simply because one analyst supposes something which the other analyst does not.
- in V2, the analyst found it necessary to explain causally why the battery was changed: Node 16: *GPS device battery died*. The analyst in V1 found it unnecessary. This represents a different choice of *stopping point*, which may have arisen through individual judgement or through application of a different *stopping rule*. WBA prescribes no stopping rules. Indeed, this is an area of concern in accident analysis, and research, for quite a while. The most notorious stopping rule is: stop when one discovers *pilot error*. Nowadays, considerable effort is expended into determining why (causally) a pilot made the error, or why the error was afforded by the aircraft he was operating. There is currently no consensus, nor even a small set of well-defined alternatives, concerning the validity (or even the identification) of stopping rules.
- Similarly, the analyst of V2 found it necessary to express that the soldiers were operating under stress (as well as under fire). The analyst in V1 did not find it necessary to say so.

Thus leaf nodes which appear in one WBG but not another represent a different choice of stopping rule, which WBA leaves open to the analyst. Any effective comparison of WBGs has to proceed modulo different stopping rules. Thus, leaf nodes which appear in one WBG but not in another can be omitted: this removes variants allowed by WBA. It also removes causal information from the graph to which it is applied!

One may similarly omit causal chains of nodes which stem from leaf nodes and which nodes are not present in a desired comparison graph.

## 7 Putting It All Together

### 7.1 Performing the Operations on V1 and V2

The operations described above can be applied to V1 and V2 as follows.

- V1**
- Node 3: *JDAM released* is a semantic consequence of Node 1: *B52 fires JDAM with communicated coordinates*. Since if *A* is a logical consequence of *B* fulfils the definition of *B* is an NCF of *A* (check it out in the Lewis formal semantics), the analyst has the NCF relation the wrong way round: Node 3 should follow Node 1, not the other way around. Nodes 6 and 7, NCFs of Node 3, must therefore be NCFs of Node 1, since Node 3 is “part of the meaning” of Node 1. We may omit Node 3 and subsume Nodes 6 and 7 as NCFs of Node 1. This yields the modified WBG in Figure 9.
  - The various references to the coordinates calculated and transmitted by the GPS after the battery change may be made all with one chosen phrase. I select the artificial-sounding *OwnCoords*, to attempt to avoid reading a specific non-transparent meaning into the term: it is intended to be transparent. One may also put the node labels in SAOIndO form. Further, we have remarked that in SAOIndO form, Nodes 14 and 8 come out identical, or at least so similar as not to make a causal difference. We may assimilate them both, along with their NCFs to, say, Node 8. The result of performing these three manipulations may be seen in Figure 10.

- The same rationalisation of terms may be performed with regard to the various references to *soldiers*, *Special Forces*, and *controller*, all of which terms refer to the same group, or members thereof. For the purposes of this particular analysis, there is no need to distinguish amongst members of this group (as shown by use of the general term even in instances in which it is clear that a single member of the group performed the action). I select the term *SFCon* to refer transparently to (the relevant one of) these people. Also, it becomes clear through the SAOIndO form of Node 5: *GPS transmits own coordinates to B52* that there is a NCF missing: the GPS device did this not of its own accord but because an SFCon member was operating it to do so. Thus the NCF 5.1 *SFCon commands transmission of OwnCoords* is added. The result is Figure 11.
  - I remove the leaf-node 12: *Assumption: Faulty instruction or violation of instructions*, as well as the non-event nodes 4: *B52 crew did not check OwnCoords* and 9: *OwnCoords insufficiently checked by SFCon*. In order for non-events to appear in a WBG, there must be some procedure or rule which would normally entail that certain events take place. If in the incident under analysis these events did not take place, even though they should have done so, then one may include a non-event node to say so. This is the only rule which allows inclusion of non-events. Thus when the assumption Node 12: *Assumption: Faulty instruction or violation of instructions* is removed, there is no justifying procedure anymore for the non-event nodes 4 and 9; so they must disappear as well. The result is Figure 12
  - The final operation on V1 consists in removing the Node 6.1: *Special Forces on mission*, which is a leaf node representing a different choice of stopping rule. The result is Figure 13.
- V2**
- The precipitating event is Node 1: *3 soldiers killed; 20 soldiers injured*. Thus all nodes above it, Node 0 in this case, may be removed. Node 2: *JDAM dropped on own soldiers* is also a semantic consequence of Node 3: *B52 dropped JDAM.....* (or at least it will be when the location is rendered transparent). So it may be removed. The operation follows Figures 4 and 3.2. The result is shown in Figure 14.
  - The second modification results from making transparent the references to the coordinates and the soldiers as in V1. The result is Figure 15. Note that the nodes are already in acceptable SAOindO form; an operation to render them so is unnecessary.
  - The next operation removes the non-event Node 6: *B52 does not verify OwnCoords*. The result is Figure 16.
  - The final operation removes the leaf nodes 16: *GPS device battery died* and 18: *SFCon operated under stress* which represent the different choices of stopping rules for the analyst of V2. The result is Figure 17

## 7.2 The Result: A Close Comparison

The result is that there are two differences between V1 and V2 (modulo different stopping rules):

- V1 Node 7: *B52 active in air support...* is considered by analyst 1 only to be an NCF of Node 1: *B52 fires JDAM...*, whereas in V2 the equivalent node 8: *B52 on duty* is considered also to be a NCF of Node 5: *B52 receives OwnCoords*. This represents a causal discrepancy which must be resolved: at most one of them is correct; at least one of them has simply made a causal mistake.
- V1 Nodes 11: *SFCon expects GPS device to....* and 13: *SFCON misunderstand.....* correspond somehow to V2 Node 14: *SFCon did not know of recalculation requirement*. This correspondence cannot easily be turned into a semantic equivalence by the simple rules announced above, but it is intuitively clear that not knowing something about a device, and misunderstanding its operation (expecting it to do something different) are very similar states, akin, say, to a mode confusion. However, in V1 this state is an NCF of transmission; in V2 it is an NCF of the GPS calculation itself. What are we to make of this discrepancy? Well, we can look more closely. It should be clear that knowledge, or lack of it, by SFCon is not a causal factor in why the GPS calculates what it is programmed to calculate. So in V2 the NCF arrow from Node 14: *SFCon did not know....* to 10: *GPS calculates OwnCoords....* is a causal mistake. However, it is reasonable to judge that the lack of knowledge, or false suppositions, of SFCon was a causal factor in SFCon transmitting the calculated coordinates, which were not the ones they

wished to transmit, to the B52. So V1 also has the causal influence incorrect here: Node 11: *SFCon expects...* is a NCF of Node 5.1: *SFCon commands transmission of OwnCoords*. So in the places in V1 and V2 where there is the most discrepancy, both Versions have the causal factors wrong.

After correction of the NCFs, the resulting WBGs for comparison are

- V1: Figure 18
- V2: Figure 19

We have not resolved either discrepancy fully. However, the two versions are now closely similar.

One may conclude that the graphs, which started out with two-thirds similar or identical nodes, are more similar than this simple node count would suggest. Indeed, simply looking at node labels is not enough to judge similarity of causal explanations: one could have two identical node sets and not one NCF arrow in common! By performing the regimentation and elimination operations listed, we have reached two graphs which are almost mathematically isomorphic as labelled graphs. This shows that the causal explanation proffered by the two versions is, modulo stopping rules again, almost the same. This provides evidence for the claim for objectivity of WBA.



## Appendix: Friendly Fire GPS Accident During Operation Enduring Freedom, Afghanistan

The following is an online news article by Vernon Loeb. The article was published in the Washington Post, where Loeb is a Staff Writer, on March 24th, 2002.

The incident happened during the US led Operation Enduring Freedom.

### The Incident

"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 defense 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<sup>1</sup>) at the Americans.

But the senior defense official explained yesterday that the Air Force combat controller was using a Precision Lightweight GPS Receiver, known to soldiers as a 'plugger'<sup>2</sup>, to calculate the Taliban's coordinates for a B-52 attack. The controller did not realize 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 five 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 he did not know how the Air Force would treat the incident and whether disciplinary action would be taken. But the official, a combat veteran, said he considered the incident 'an understandable mistake under the stress of operations.'

'I don't think they've made any judgments yet, but the way I would react to something like that – it is not a flagrant error, a violation of a procedure,' the official said. 'Stuff like that, truth be known, happens to all of us every day – it's just that the stakes in battle are so enormously high.'

Nonetheless, 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.'

Navy Cmdr. Ernest Duplessis, a spokesman for the U.S. Central Command, declined to comment on the friendly fire incident, saying an investigation 'has not cleared our review yet.'

In another matter, Duplessis said that U.S. forces have found within the past week a possible al Qaeda biological weapons research site that had been abandoned near Kandahar.

'There was no evidence of any chemical or biological weapons production going on there,' Duplessis said. 'But there was equipment found – it had medical supplies, commonly available laboratory equipment suitable for growing biological samples, as well as a variety of other supplies

<sup>1</sup> JDAM is a US Air Force and US Navy program to enhance general purpose bombs by integrating a guidance kit consisting of an inertial navigation system/global positioning system guidance kit

<sup>2</sup> The official military abbreviation of the Precision Lightweight GPS Receiver is PLGR; thus the name 'plugger'

like that. But I have to stress that this lab was still under construction and no samples of biological agents were found at the site.”

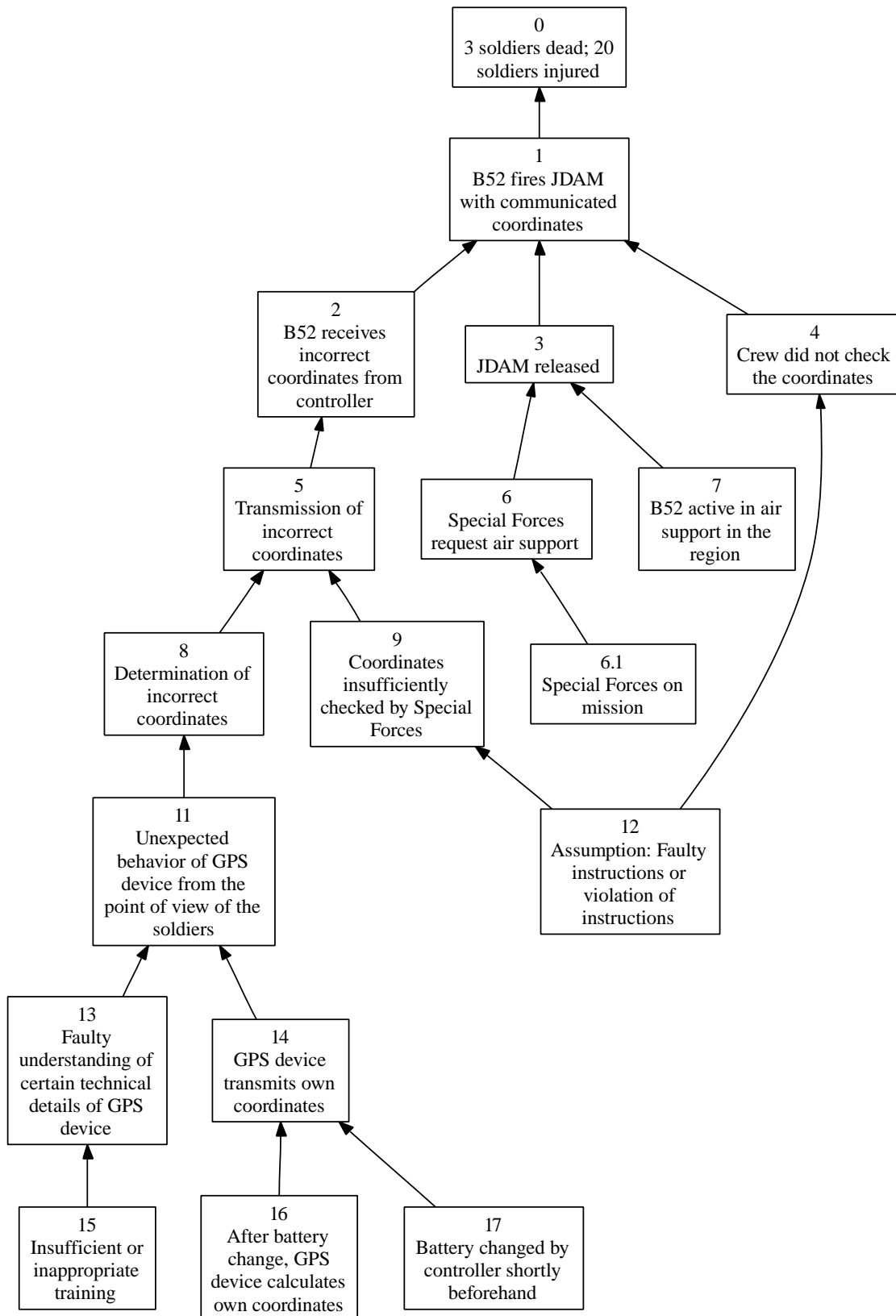


Fig. 7. The GPS Friendly Fire Incident: Version 1

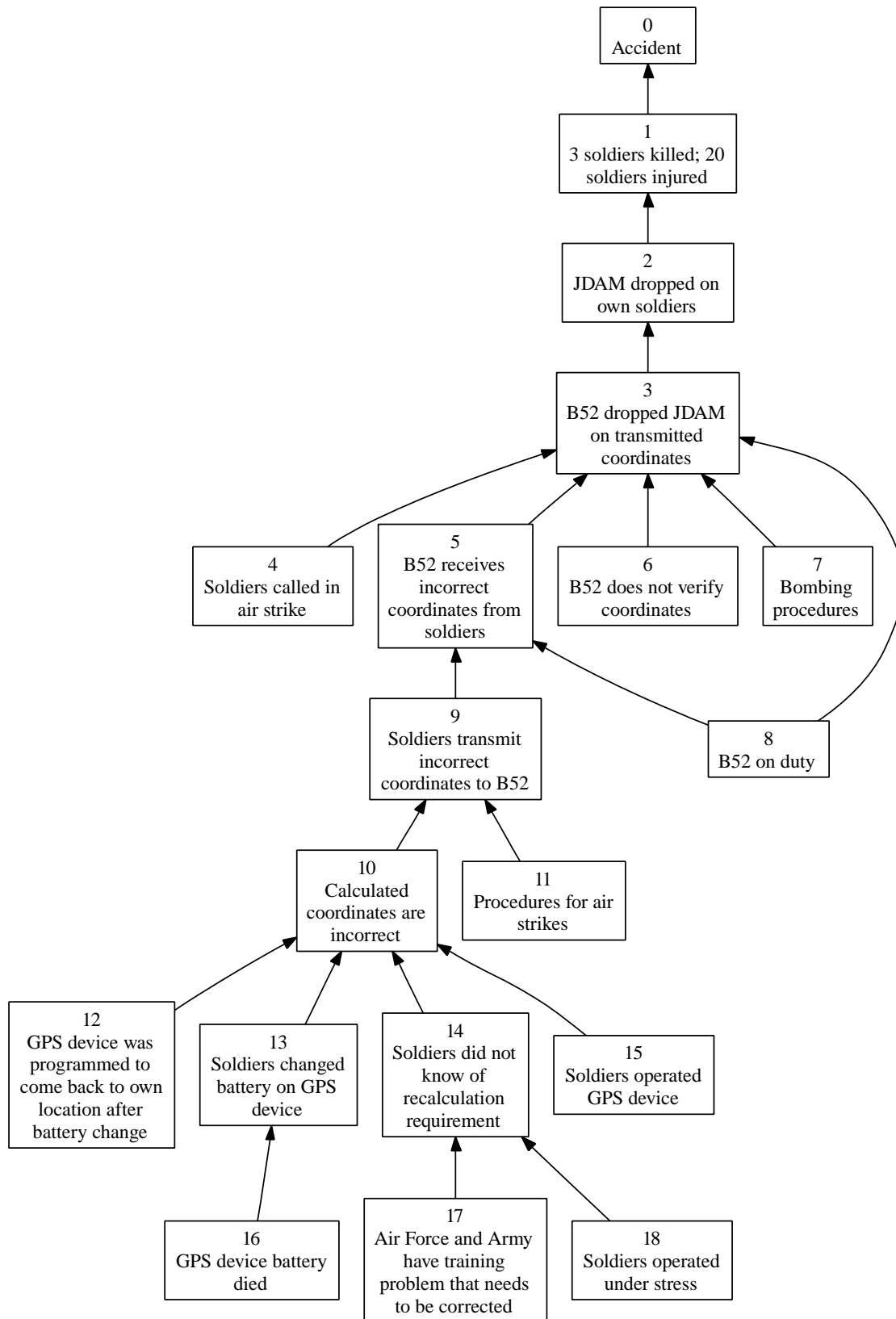


Fig. 8. The GPS Friendly Fire Incident: Version 2

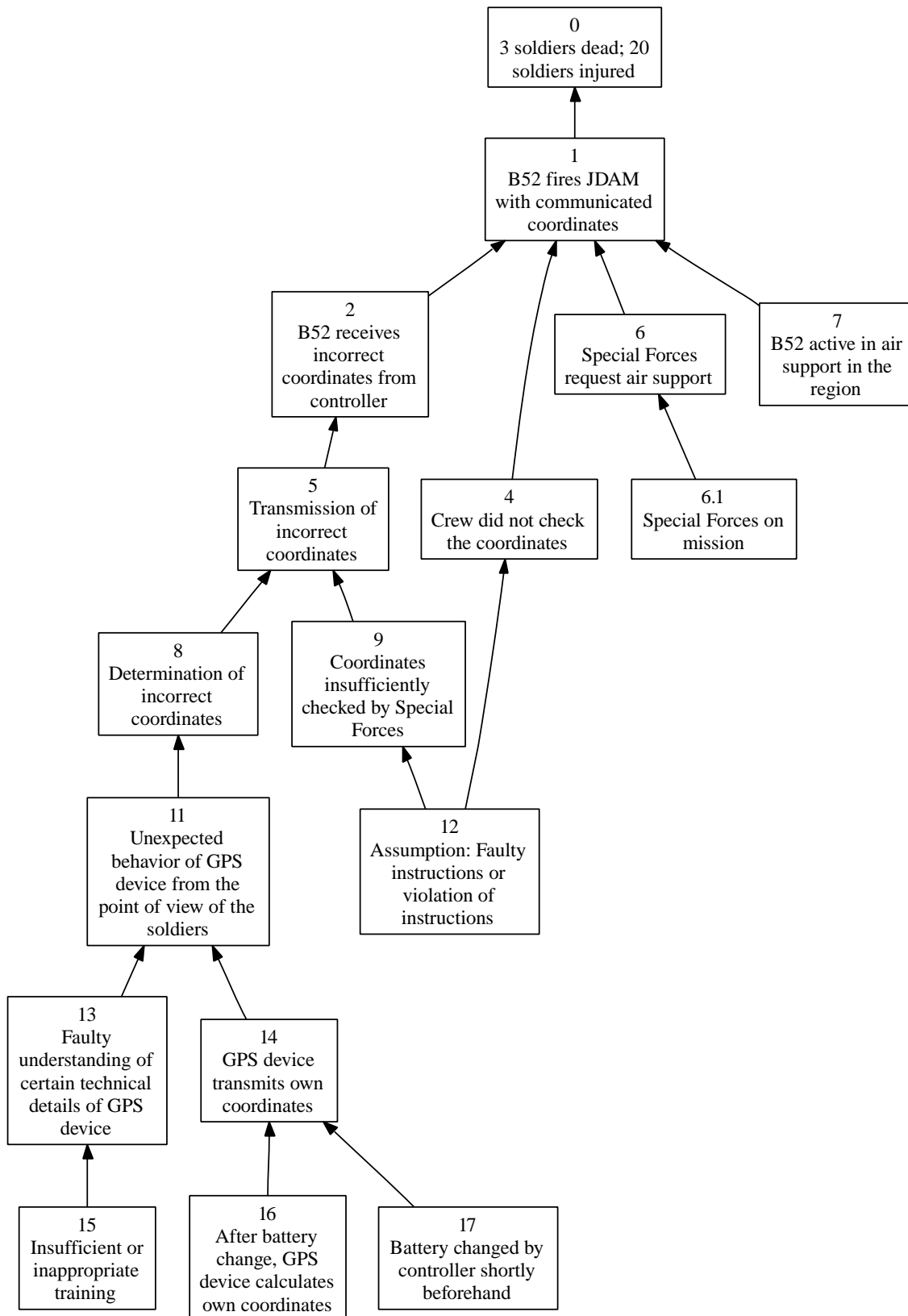


Fig. 9. V1 Modification 1

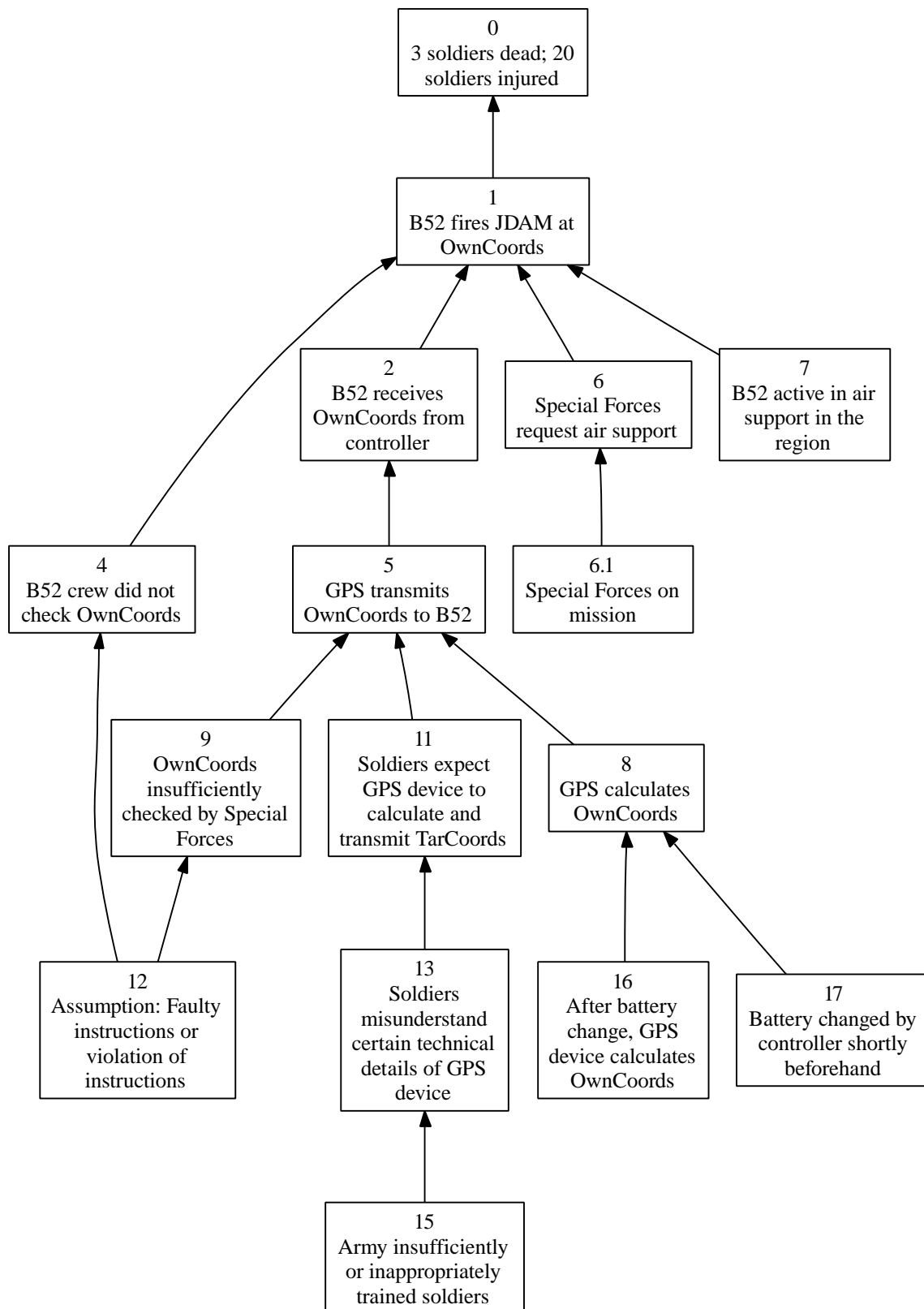


Fig. 10. V1 Modification 2

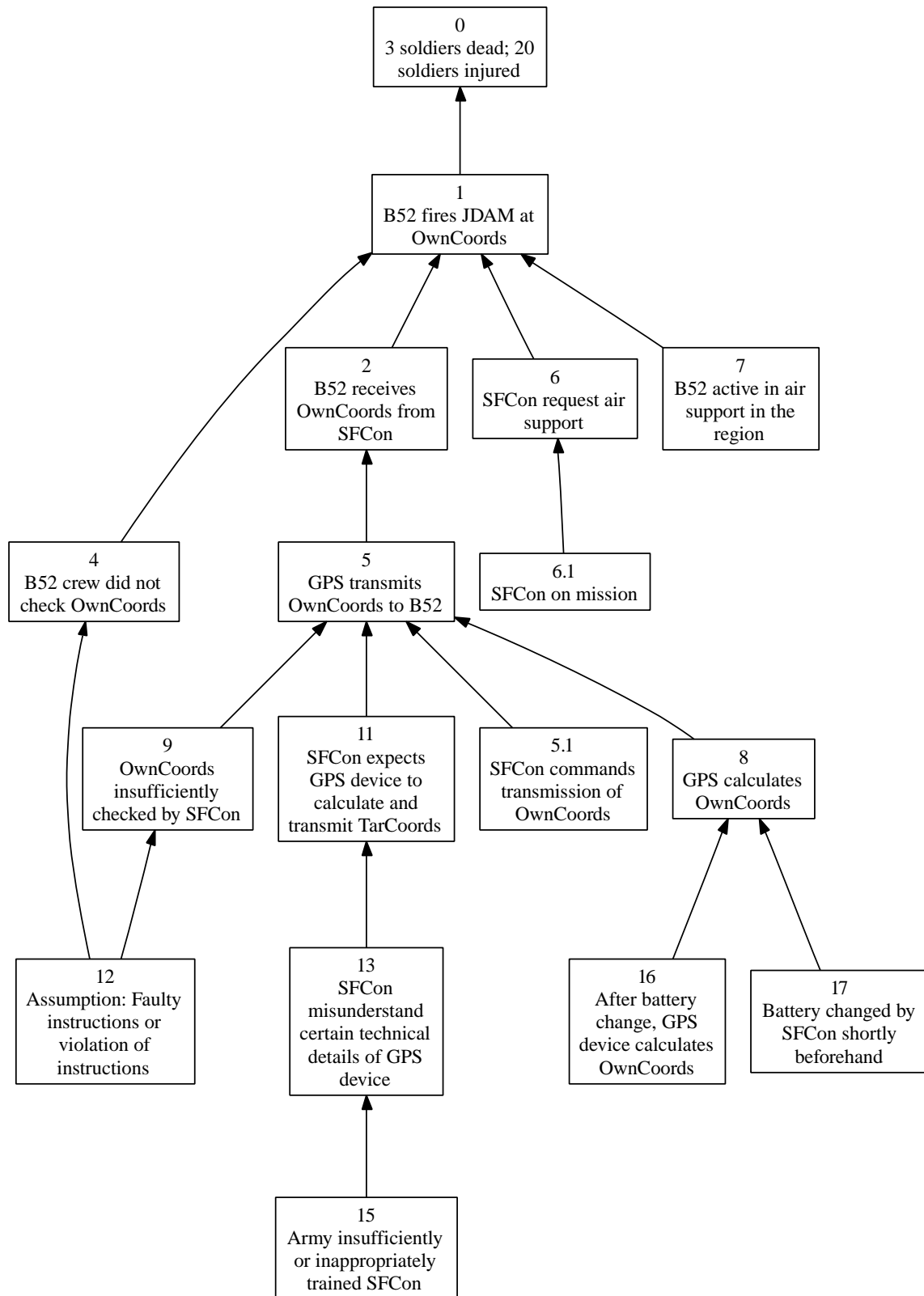


Fig. 11. V1 Modification 3

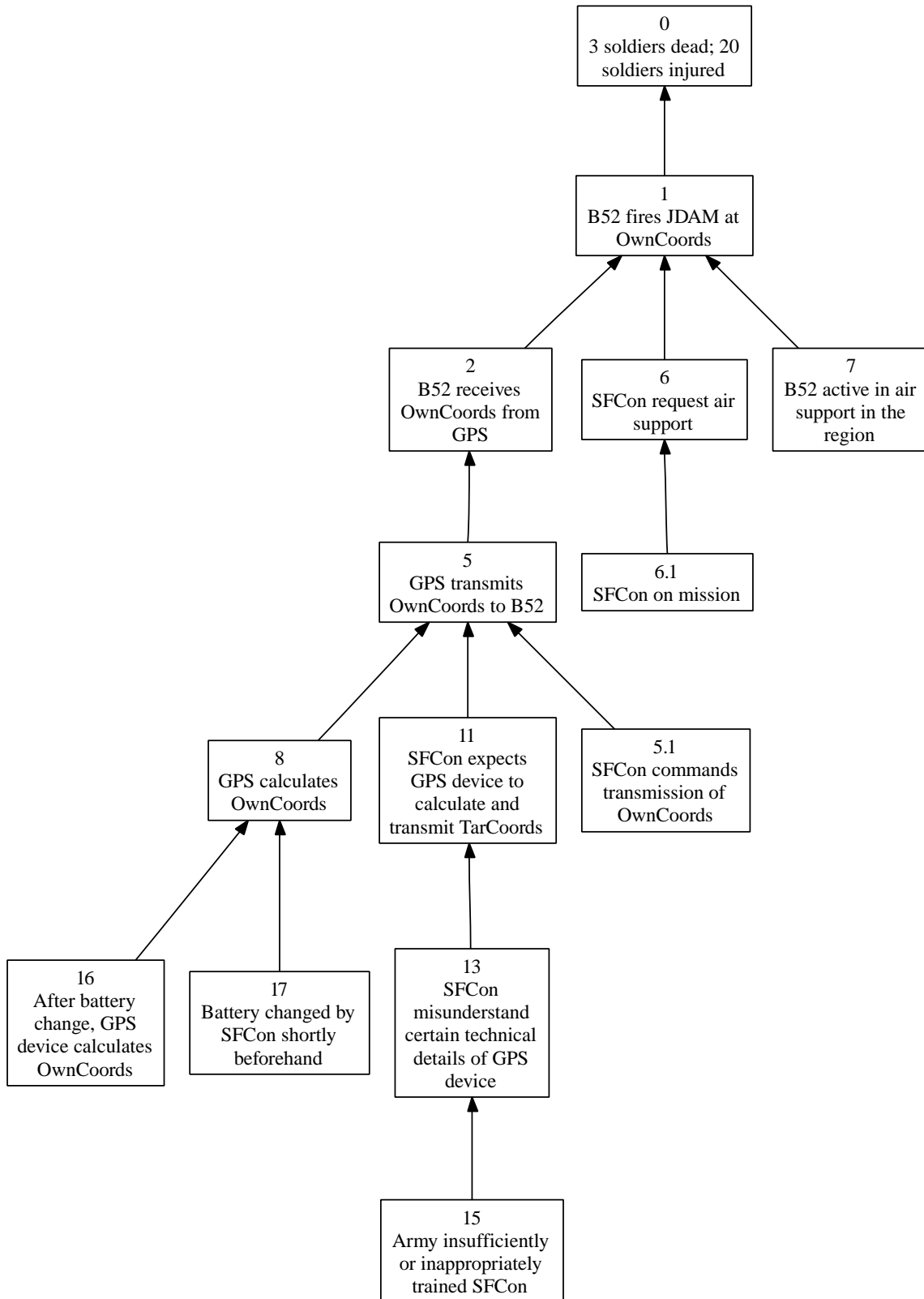


Fig. 12. V1 Modification 4



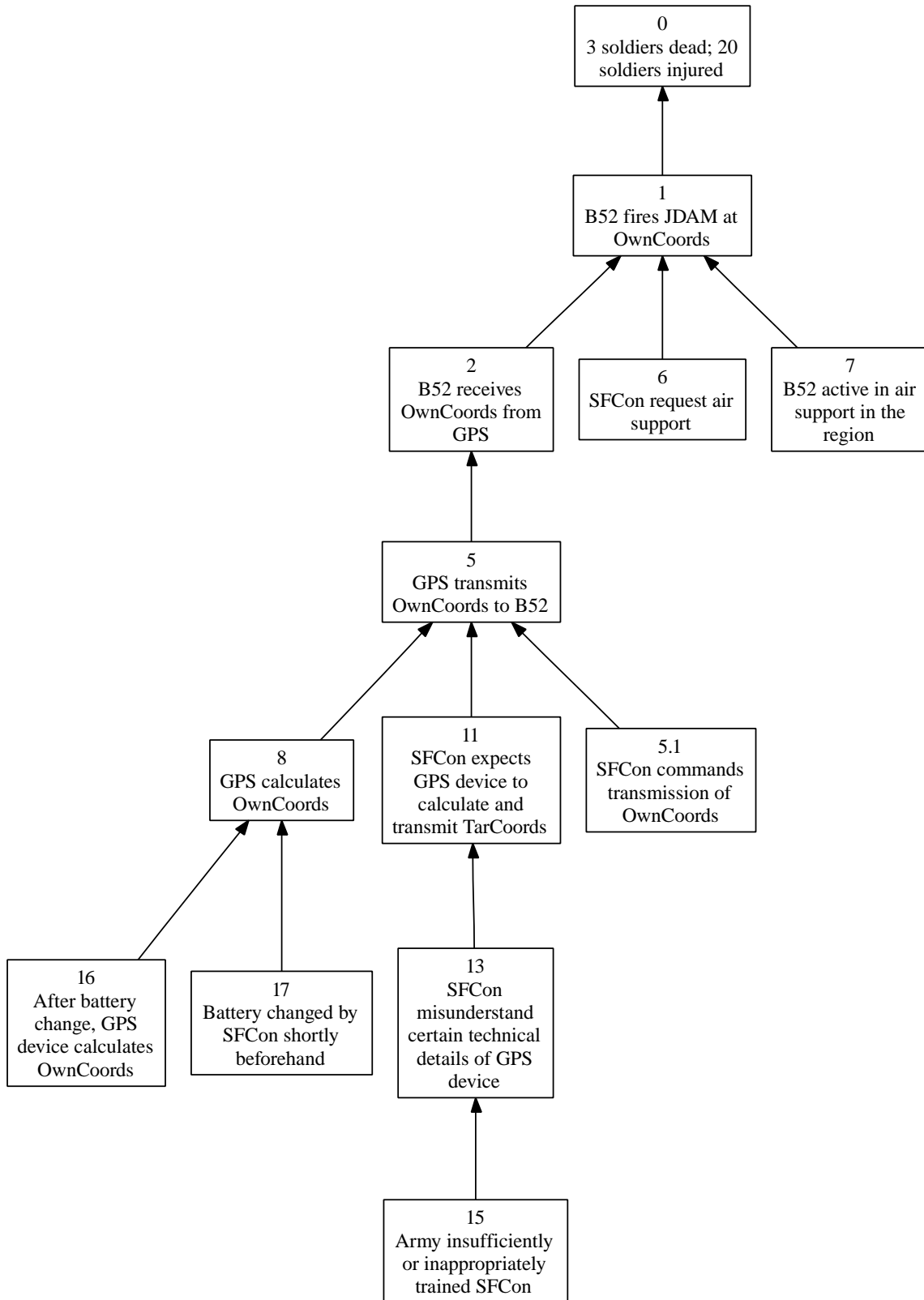


Fig. 13. V1 Modification 5

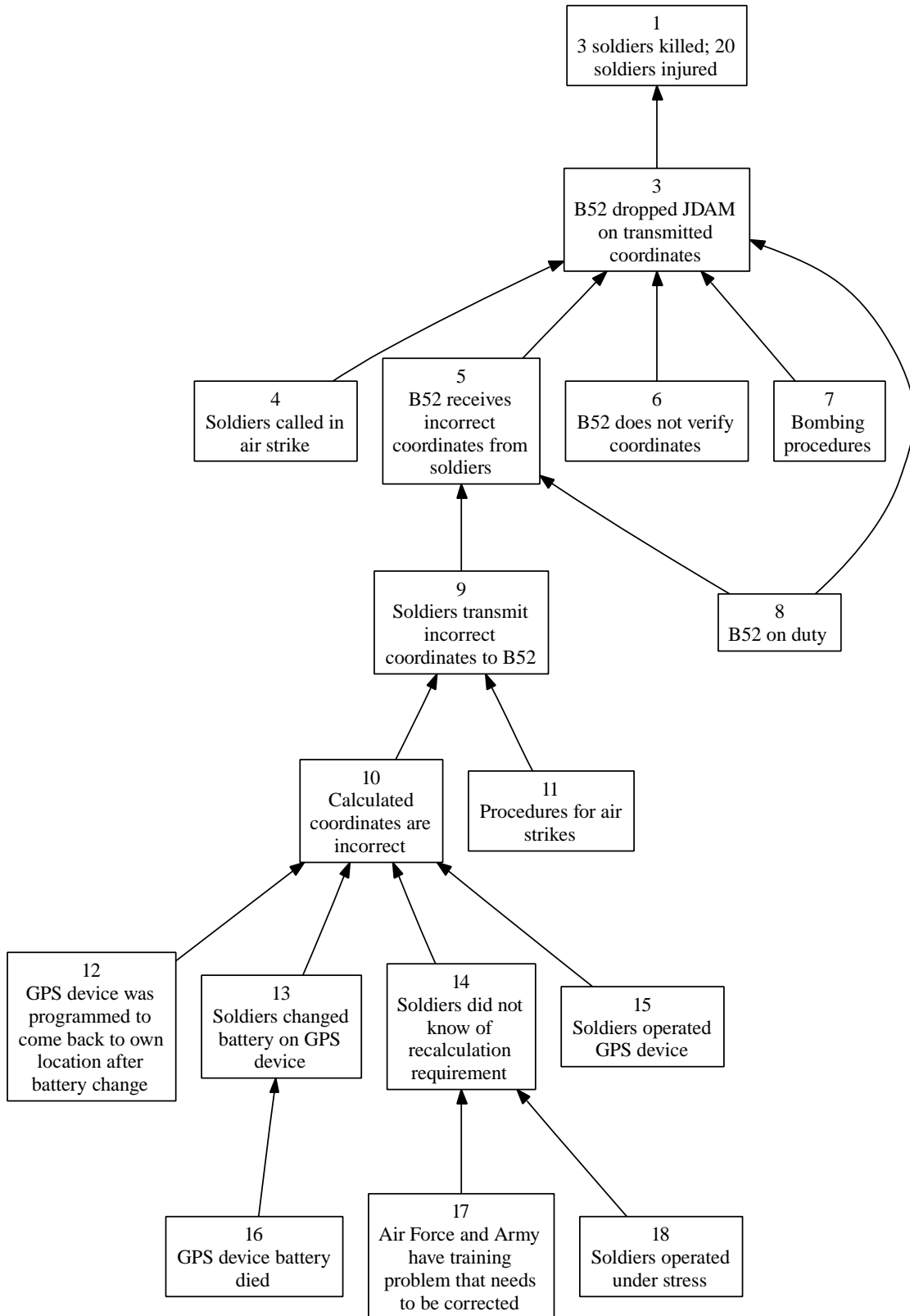


Fig. 14. V2 Modification 1

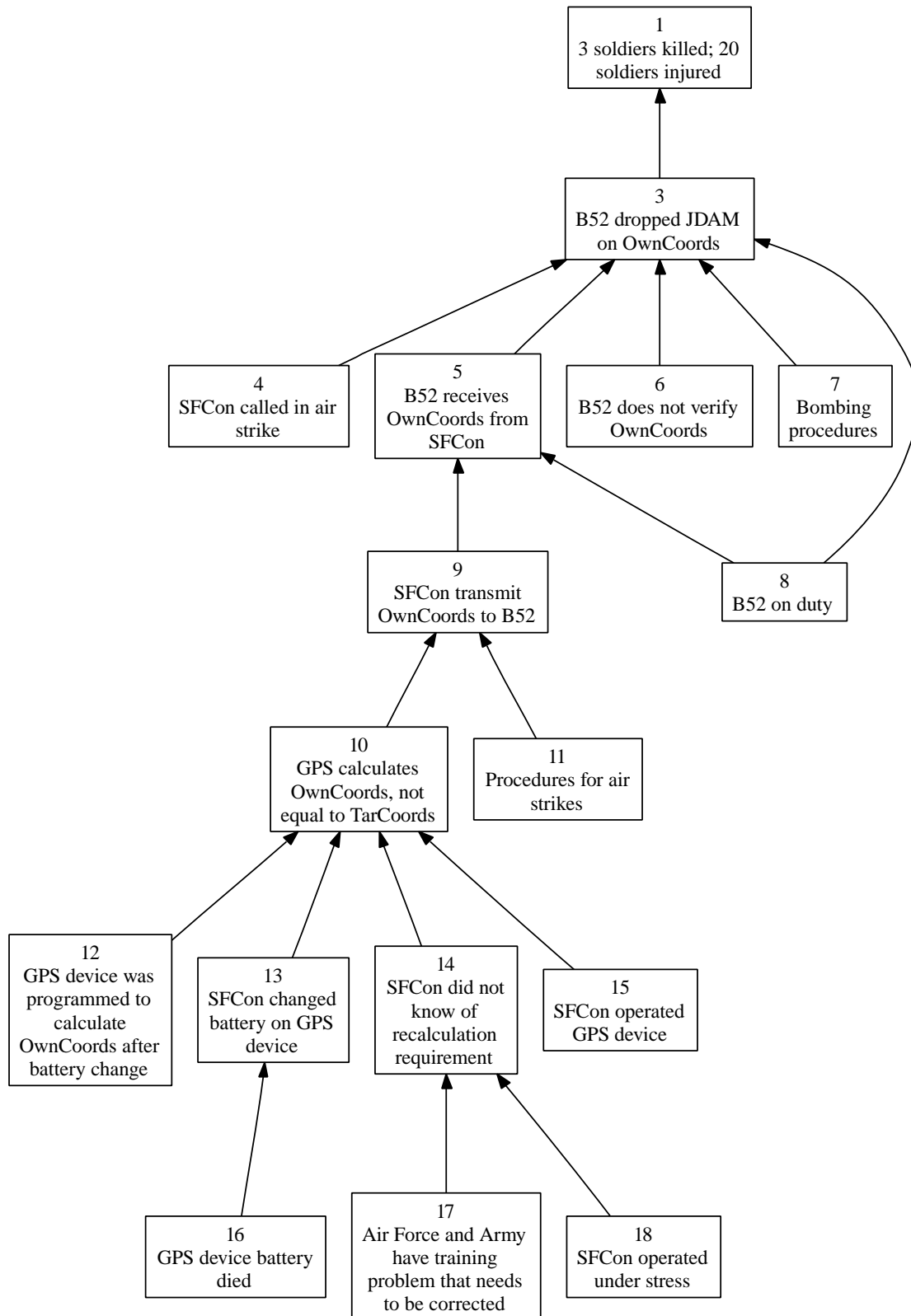


Fig. 15. V2 Modification 2

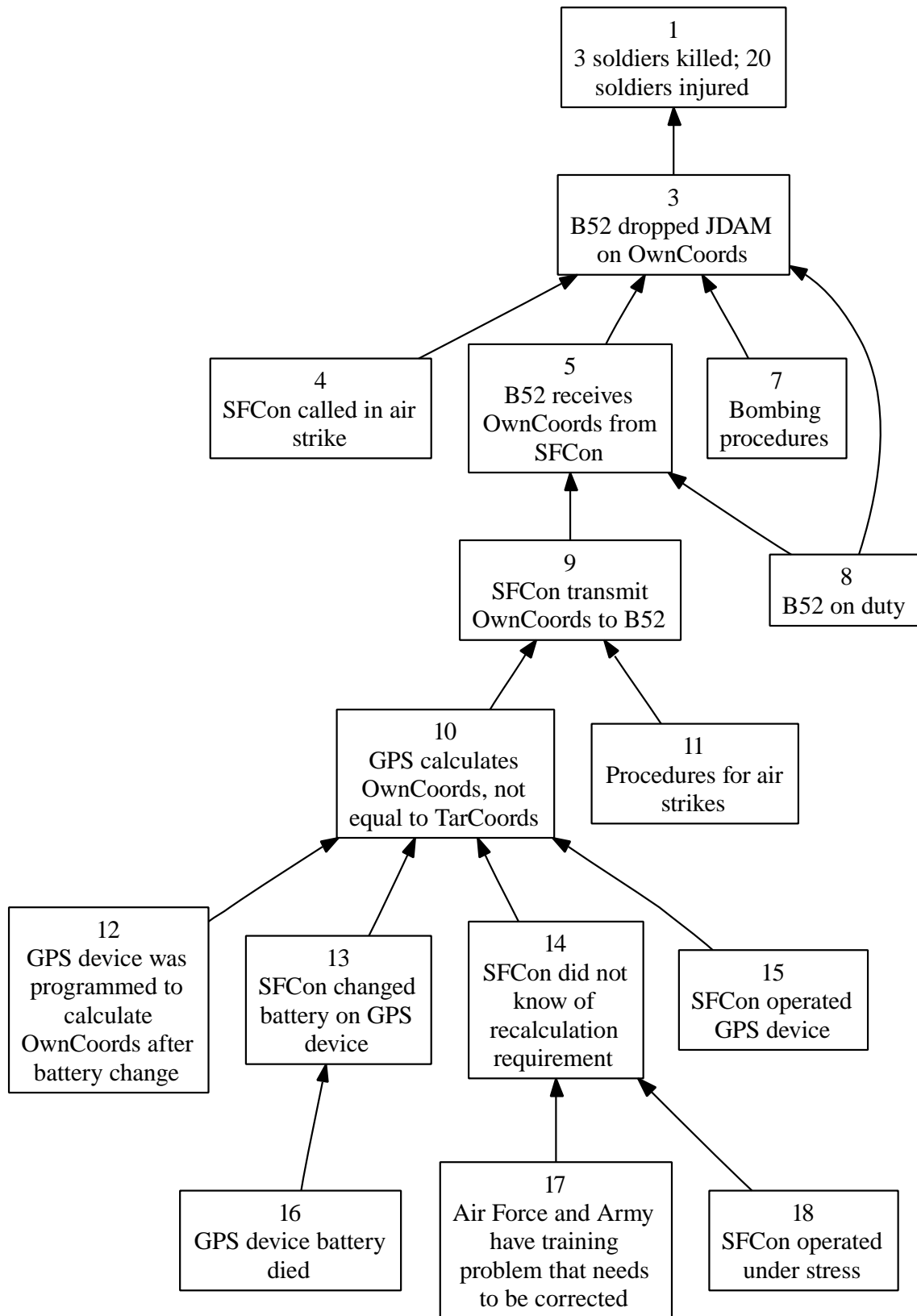


Fig. 16. V2 Modification 3

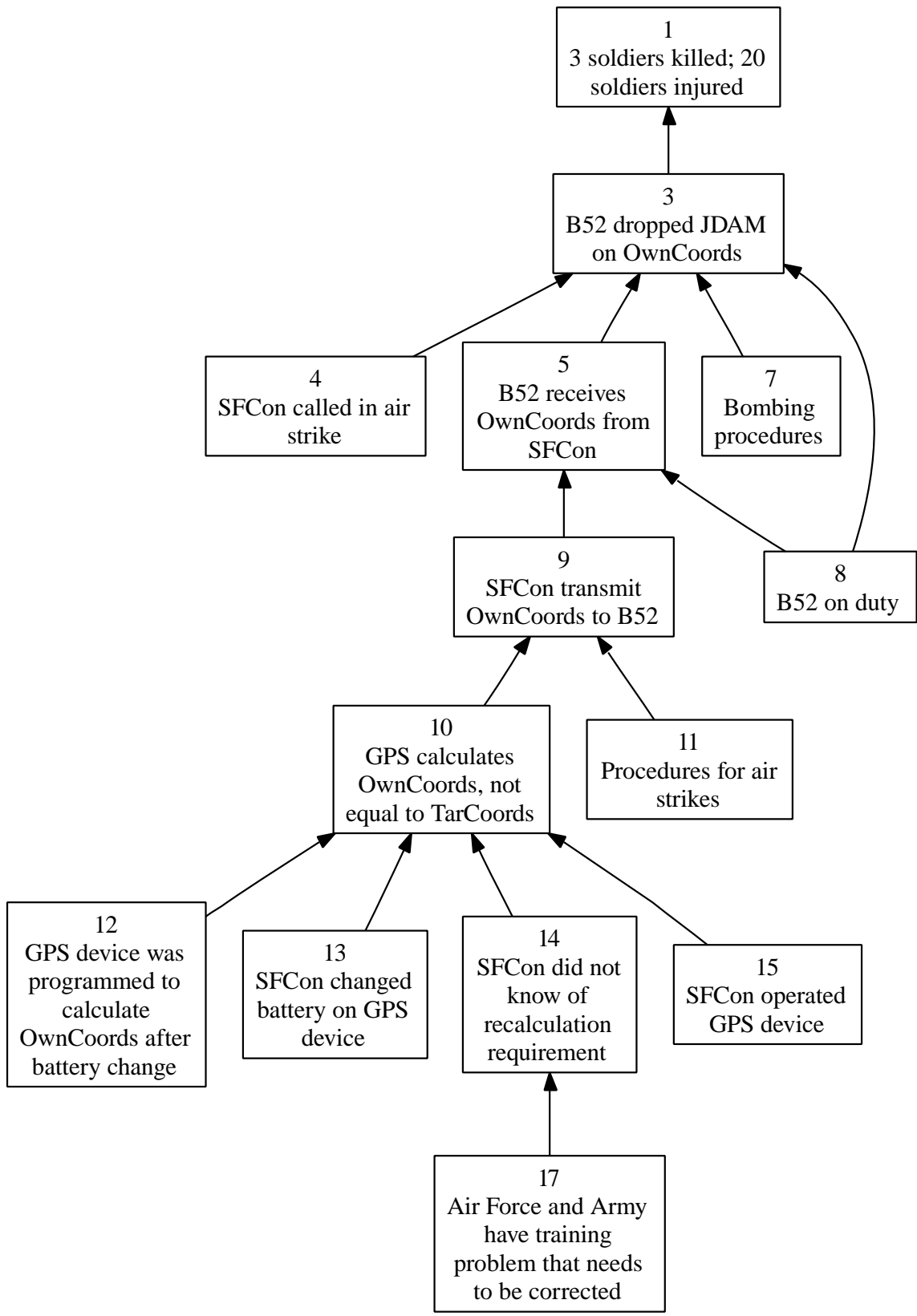


Fig. 17. V2 Modification 4

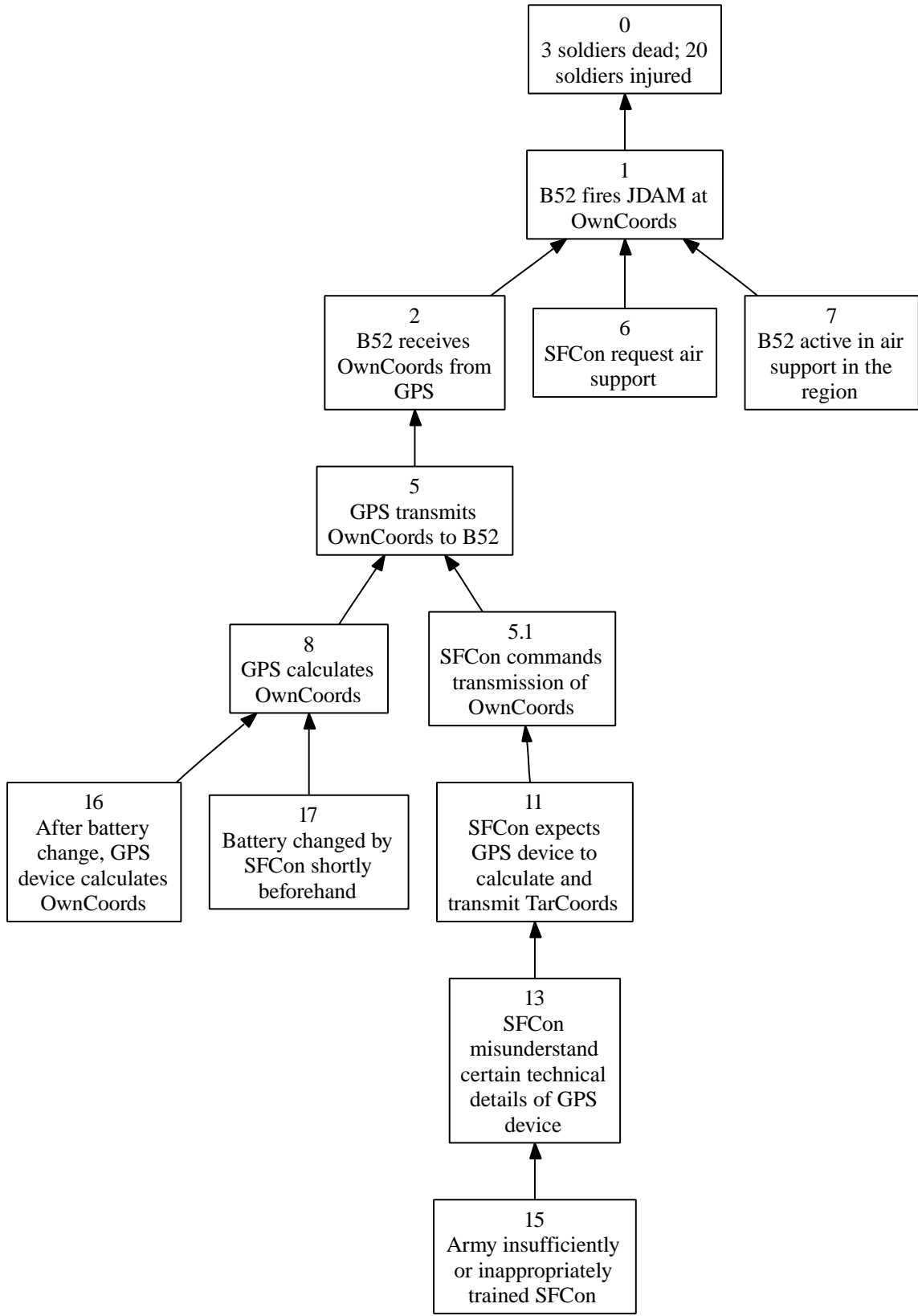


Fig. 18. V1 Final Corrected

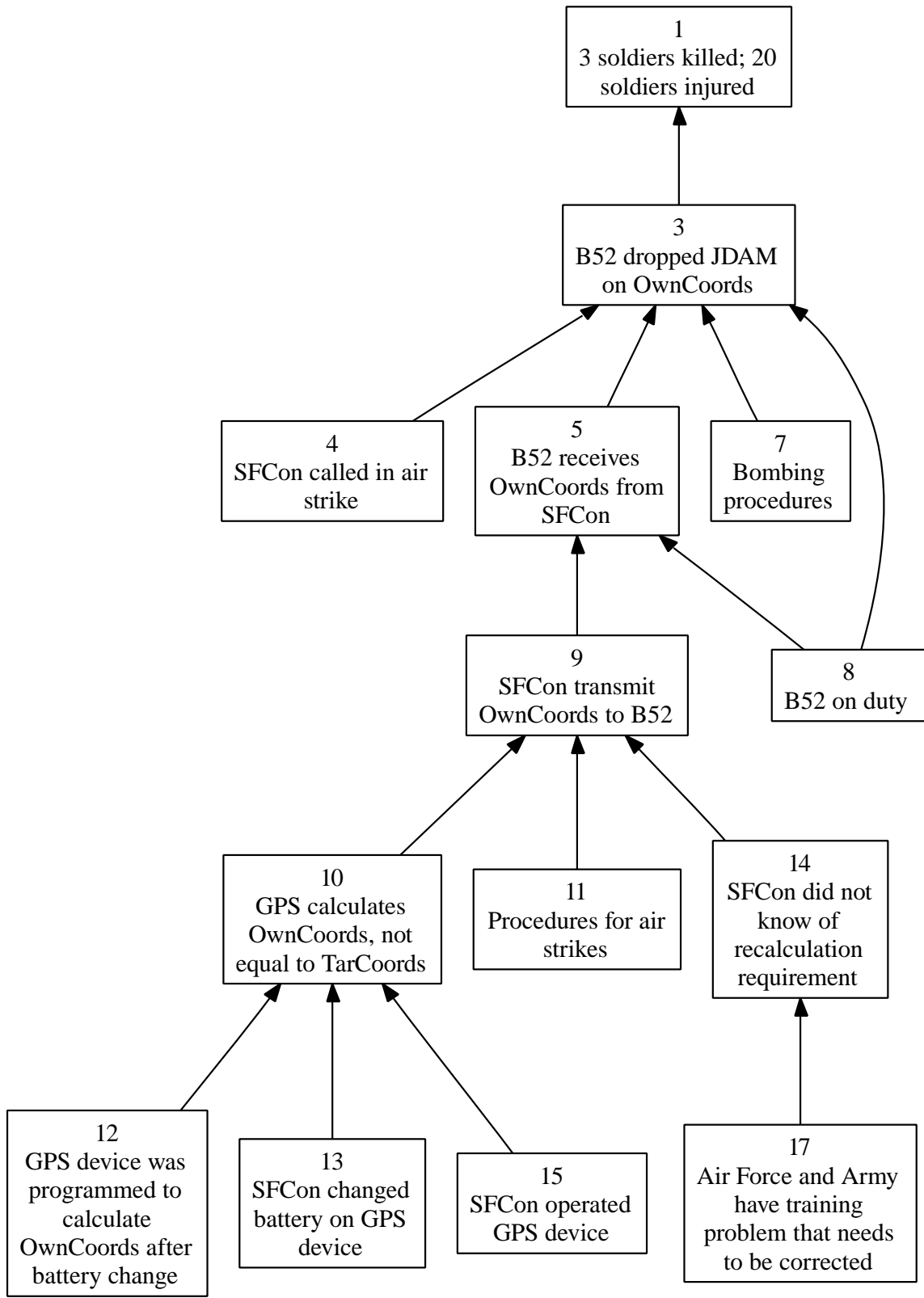


Fig. 19. V2 Final Corrected