Assurance Cases for Medical Devices

Charles B. Weinstock

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Today’s Presenter

Chuck Weinstock has been with SEI for more than 25 years. He is currently a senior member of the technical staff in the System of Systems Software Assurance Initiative within the SEI's Research, Technology, and System Solutions program. With his colleague John Goodenough, Weinstock authored the 2009 SEI technical note *Towards an Assurance Case Practice for Medical Devices*. He has been active in the dependable computing field since the late 1970's when he worked at SRI International on the SIFT fault-tolerant computer. He earned a bachelor's degree in mathematics, a master of science degree in industrial engineering, and a doctorate in computer science, all from Carnegie Mellon University.
Software in Medical Devices

An ever increasing percentage of medical device functionality is provided by software.

- The industry is experiencing the problems which arise when hardware-intensive systems become software-intensive systems.

Specific concerns for medical devices include:

- Patient privacy (including HIPAA regulations)
- Safety
- Regulatory

A desire for more frequent “plug-and-play” (networked) use of the devices makes the problems particularly interesting.

- The patient is sometimes the network
The SEI and Medical Devices

SEI begins working with assurance cases

Initial FDA/SEI contact

Medical device project (with FDA …)

Project report issued

FDA draft guidance issued

2003 2004 2005 2006 2007 2008 2009 2010

AdvaMed workshop

AdvaMed software conference

AdvaMed workshop

Overview of the Talk

The assurance "problem"
The assurance case
Recent FDA guidance regarding assurance
Goal structuring notation with an example
Assurance case patterns and archetypes
Tooling for assurance cases
Concluding thoughts
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Polling Question 1

Why are you attending this webinar?

1. My company has an immediate need to use assurance cases for a medical device
2. My company has an immediate need to use assurance cases, but not necessarily for a medical device
3. I’ve heard about assurance cases and want to find out more about them
4. Other
**Assurance**

*Justified confidence* that a system will function as intended in its environment of use

Why should we have confidence?

What evidence is there to support this confidence?

Why do we believe the evidence?

It is not enough to provide evidence without an explanation of its significance
Assurance

Justified confidence that a system will function as intended in its environment of use

“as intended” by the system’s users as they are actually using it

• Different usage patterns are possible by different sets of users

This includes evaluating mitigations of possible causes of critical failures

• Minimize impact of unusual (or unexpected) operational conditions

• Minimize impact of vulnerabilities that can be exploited by hostile entities, especially in networked environments
Assurance

Justified confidence that a system will function as intended in its environment of use

The actual environment of use
The System Assurance Problem

Systems are getting more complex and more dependent on software

- Reaching sound conclusions about safety, reliability, etc. is getting harder

Traditional methods for evaluating dependable behavior (e.g., safety) are increasingly inadequate

- Too costly (in time and money) to test complex systems well
- Testing is not the best way of showing impact of subtle, but critical errors
- Test results, by themselves, do not show that a system has been well engineered to run adequately under untested conditions
  - FDA: “A convincing argument must be made as to why [the] engineering approach is sufficient”

We need better means of justifying confidence that a system will behave as intended
Recognition of the Assurance Problem

National Defense Industrial Association (NDIA) Top Software Issues (August 2006)

- Testing, by itself, doesn’t assure the system (NDIA 5)
- Component level assurance (if possible) does not imply system level assurance. Exhaustive testing is not feasible. (NDIA 6)


- Assurance that a system is dependable requires the construction and evaluation of a “dependability case” (claims, argument, evidence, expertise)
- For testing to be a credible component of a [case for dependability], the relation between testing and properties claimed will need to be explicitly justified

Approaches to Establish Confidence in Systems

Standards-Based

• Evaluate developer competence based on conformance to process standards
• Examples: DO 178B for avionics safety, Common Criteria for security

Product-Based

• An “assurance case” approach based upon:
  ✓ Claims about product behavior supported by evidence based on product analysis
  ✓ Evidence linked to claims by an argument
• Example: Safety case
Polling Question 2

Have you or your company experienced situations where assurance techniques such as testing have proven inadequate?

1. Yes
2. No
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Assurance Cases

An assurance case presents a claim that a system is acceptably safe, secure, reliable, etc. in a given context along with supporting evidence.
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An assurance case links the claim to the evidence with a supporting argument.
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An assurance case presents a claim that a system is acceptably safe, secure, reliable, etc. in a given context along with supporting evidence.

An assurance case links the claim to the evidence with a supporting argument.

In general, the argument is broken down hierarchically:

- Claims, argument, sub-claims, sub-arguments, evidence
- Easy to show graphically, although can be done in document structure (e.g., sub-section numbering)
The Argument Carefully Links Claims to Evidence

Important to “carry” the reader with you through the argument

- Not lose them in the details
- Not force them to make big leaps
The Argument Carefully Links Claims to Evidence

Important to “carry” the reader with you through the argument

• Not lose them in the details
• Not force them to make big leaps

Need sufficient, judiciously placed stepping stones

Not all arguments need the same number of stepping stones

The FDA is finding insufficient “stepping stones” in current submissions
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4. Goal structuring notation with an example
5. Assurance case patterns and archetypes
6. Tooling for assurance cases
7. Concluding thoughts
What is an infusion pump?

An infusion pump injects continuously or periodically, drugs, nutrients, or other injectable fluids into the circulatory system.

All infusion pumps require caregiver programming of the rate of injection and the length of time to deliver the fluid.

More complex pumps take into account the specific drugs being infused, the weight/age of the patient, and the hospital setting.

Some pumps allow the patient to control part of the injection process (e.g., to inject more painkiller).

Correct functioning of the pump is critical to the proper care of the patient.
FDA Guidance on Infusion Pumps

FDA draft guidance issued in April 2010 was intended to improve the quality of infusion pumps and reduce the number of recalls and Medical Device Reports.

- Demonstration of substantial equivalence via the use of an assurance case
  - Hazard areas of particular concern include: operational, environmental, electrical, hardware, software, mechanical, biological, chemical, and use
  - Information security: confidentiality, integrity, availability, and accountability
  - Risks to health: underdose, air embolism, overdose, incorrect therapy, etc.
  - Design and development decisions that bear on safety and effectiveness

http://www.fda.gov/MedicalDevices/DeviceRegulationandGuidance/GuidanceDocuments/ucm206153.htm
What is a Safety Argument

• This infusion pump is safe because
  – The safety requirements are defined in my
    • Safety requirements analysis, derived requirements ...
    • Legislation, policy ...
• The safety requirements are met through our
  – Safety analysis of design, use ...
  – Hazard management through problem reporting
  – Observing failures are at a ‘safe’ level
  – Appropriate quantity, quality and rigor of evidence
• Safety management continues to be adequate because we have
  – SMS
  – staff competence
  – ongoing independent scrutiny ...

http://www.fda.gov/downloads/MedicalDevices/NewsEvents/WorkshopsConferences/UCM219685.pdf
Assurance Cases for Safety

A means of justifying confidence that a system will be safe

- Augments testing where testing by itself is inadequate or too costly
  - Cannot demonstrate system safety/security/performance solely by testing
  - The FDA no longer wants to rely primarily on a hazard analysis and just test results to show that hazards have been adequately mitigated

Used extensively in developing safety-critical systems (in Europe)

Increasing interest in US

- FDA Infusion Pump Guidance [draft]
- ISO 15026-2 “Assurance Case” [under development]
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Goal Structuring Notation (GSN)

Was developed to help organize and structure Safety Cases in a readily reviewable form.

Has been successfully used for over a decade to document safety cases for aircraft avionics, rail signaling, air traffic control, and nuclear reactor shutdown.

Shows how **claims** are broken down into sub-claims, and eventually supported by **evidence** while making clear the argumentation **strategies** adopted, the rationale for the approach (**assumptions, justifications**) and the **context** in which claims are stated.
Example: Partial Requirements

5. Power and Battery Operations

5.1. Battery voltage

5.1.1. An active battery voltage shall be measured for the pump throughout its operation.

5.1.2. The active battery voltage shall be calculated as an average of 10 consecutive battery voltage readings.

5.1.3. The amount of battery life remaining shall be calculated as a function of the active battery voltage.

5.1.4. If the battery life remaining is less than 15 minutes, the pump shall issue a Low battery alarm.

5.1.5. The low battery alarm shall be silenced when the pump is connected to an external power supply.

5.1.6. If the battery life remaining is less than 5 minutes, the pump shall issue a Battery depleted alarm.
### Example: Partial Hazard Analysis

1. **Operational Hazards**

<table>
<thead>
<tr>
<th>HID</th>
<th>Hazard</th>
<th>Pump Type</th>
<th>Cause</th>
<th>Action</th>
<th>Mitigated by</th>
<th>Safety Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Overinfusion</td>
<td>All</td>
<td>Programmed flow rate too high</td>
<td>Alarm(); Log()</td>
<td>Drug library</td>
<td>1.1, 1.4.4, 1.4.11</td>
</tr>
<tr>
<td>1.2</td>
<td>Overinfusion</td>
<td>All</td>
<td>Dose limit exceeded due to too many bolus requests</td>
<td>Alarm(); Log()</td>
<td>Flow sensor</td>
<td>1.4, 3.4.6</td>
</tr>
<tr>
<td>1.3</td>
<td>Overinfusion</td>
<td>All</td>
<td>(Programmed) Bolus volume/concentration too high</td>
<td>Alarm(); Log()</td>
<td>Drug library</td>
<td>1.4, 3.4.6</td>
</tr>
<tr>
<td>1.4</td>
<td>Overinfusion/Underinfusion</td>
<td>All</td>
<td>Incorrect drug concentration specified</td>
<td>Alarm(); Log()</td>
<td>Barcode scanner</td>
<td>1.1, 6.1.3, 6.1.4</td>
</tr>
</tbody>
</table>

2. **Environmental Hazards**

<table>
<thead>
<tr>
<th>HID</th>
<th>Hazard</th>
<th>Pump Type</th>
<th>Cause</th>
<th>Action</th>
<th>Mitigated by</th>
<th>Safety Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Failure to operate/ Pump malfunction</td>
<td>All</td>
<td>Temperature /Humidity/ Air pressure too high or too low</td>
<td></td>
<td></td>
<td>7.1</td>
</tr>
<tr>
<td>2.2</td>
<td>Contamination</td>
<td>FRN</td>
<td>Contamination due to spillage / exposure to toxins</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. **Electrical Hazards**

<table>
<thead>
<tr>
<th>HID</th>
<th>Hazard</th>
<th>Pump Type</th>
<th>Cause</th>
<th>Action</th>
<th>Mitigated by</th>
<th>Safety Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Overheating</td>
<td>FRN</td>
<td>Incorrect or loose interconnections between devices – channel error;</td>
<td>Alarm(); Log()</td>
<td></td>
<td>7.1.2</td>
</tr>
<tr>
<td>3.2</td>
<td>Overheating</td>
<td>FRN</td>
<td>Supply processor charge too high; Insufficient cooling/faulty heat sink; Unintended magnet quench</td>
<td>Alarm(); Log()</td>
<td></td>
<td>7.1.2, 7.3</td>
</tr>
<tr>
<td>3.3</td>
<td>Charge Error</td>
<td>All</td>
<td>Battery could not be charged</td>
<td>Alarm(); Log()</td>
<td></td>
<td>4.1.8</td>
</tr>
<tr>
<td>3.4</td>
<td>Supply Voltage Error</td>
<td>FRN</td>
<td>Supply voltage too high; Supply voltage too low; Battery voltage exceeds limits</td>
<td></td>
<td></td>
<td>7.3</td>
</tr>
<tr>
<td>3.5</td>
<td>Battery Failure</td>
<td>FRN</td>
<td>Battery voltage too low; Battery depleted</td>
<td>Alarm(); Log()</td>
<td></td>
<td>4.1, 5.1</td>
</tr>
</tbody>
</table>

Source: Hazard Analysis for the Generic Infusion Pump (University of Pennsylvania)
Example: Battery Exhaustion – Part One

- **Cx1**: Hazards: over infusion, under infusion, ...

- **S1**: Argue over hazards to safe pump operation

- **S2**: Argue over hazards causing over infusion

- **S3**: Argue over hazards causing under infusion

- **Cx4**: Hazards: exhaustion of battery power, occlusion of line, faulty pump calibration, ...

- **C2**: The battery exhaustion hazard has been adequately mitigated

- **C1**: Pump is safe for use on patients
Example: Battery Exhaustion – Part Two

C2
The battery exhaustion hazard has been adequately mitigated

C3
Caregiver is notified sufficiently soon (but not too soon) prior to battery exhaustion

Cx3
A late warning won't give the caregiver time to stop current activities and plug the pump in. An early warning may be ignored. This depends on the clinical setting.

C4
When operating on battery power, visual and auditory alarms are launched at least \( x \) minutes prior to battery exhaustion but no more than \( x+y \) minutes prior

S4
Argue over hazards causing failure to notify caregiver in a timely manner

Cx2
Caregiver doesn't notice alarm; amount of warning time too little for the anticipated clinical setting

C5
Visual and auditory alarms are loud enough to be heard and identified in the anticipated clinical setting

C6
\( x \) minutes warning prior to battery exhaustion is sufficient time to allow corrective action in the anticipated clinical setting
Two Ways to Structure: Arguing by Hazards to Safety

- **C1** Pump is safe
- **S1** Argue over hazards
- **C2** Environmental hazards have been mitigated
  - **C3** Environmental hazards to overdose have been mitigated
  - **C4** Environmental hazards to air embolism have been mitigated
- **C5** Software hazards have been mitigated
  - **C6** Software hazards to overdose have been mitigated
  - **C7** Software hazards to air embolism have been mitigated
- **Cx1** Hazards: environmental, software, etc.
Two Ways to Structure: Arguing by Risks to Health

C1
Pump is safe

S1
Argue over risks to health

C2
Risks to overdose have been mitigated

C3
Environmental hazards to overdose have been mitigated

C4
Software hazards to overdose have been mitigated

C5
Risk of air embolism has been mitigated

C6
Environmental hazards to air embolism have been mitigated

C7
Software hazards to air embolism have been mitigated

Cx1
Risks to health: overdose, air embolism, etc.
Assurance Case Benefits

Improves comprehension of existing arguments

Improves discussion and reduces time-to-agreement on what evidence is needed and what the evidence means

(Having identified argument structure up front) focuses activities towards the specific end-objectives

Recognition and exploitation of successful (convincing) arguments becomes possible (assurance case patterns)

Supports monitoring of project progress towards successful certification

When problems arise it helps with diagnosis

When new functionality is added it can quickly pinpoint needed new evidence (and identify existing evidence that need not be reconsidered)
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Patterns and Archetypes

An assurance case pattern is a reusable template that captures acceptable ways of structuring a generic argument.

- Parameterized.
- Saves development time and money.
- For the FDA, saves valuable evaluation time.

A library of assurance case archetypes (patterns representing fragments of arguments) would have significant benefits:

- Guidance for the medical device manufacturer as to the proper argument and, perhaps more importantly, the required evidence.
- Ease the transition of the community to the widespread use of assurance cases.
- As long as the archetype argument applies the manufacturer and the FDA could treat the evidence as a check list.
Keyboard Archetype

C1
Entry errors caused by keypad design are mitigated

C2
The keypad layout mitigates against multiple simultaneous key presses by a single finger

C3
The keypad adopts existing best practices for HCI design

C4
Keys are unambiguously marked so that it is clear what action they control

C5
The keypad design mitigates against "bounce"

Ev 1
Keypad layout information and design document

Ev 2
Assurance case showing keypad conformance to HCI design standards

Ev 3
Key markings that are clearly unambiguous (to the reviewer)

Ev 4
Keypad design document including "bounce" assurance case

Ev 5
Test results for keypad hardware and software

Ev 6
Error logs showing little or no problems related to "bounce"

C6
The incidence of problems traced to keypad bounce is non-existent or acceptably low
Using the Archetype

A manufacturer developing a device with a keypad that conforms to the keypad archetype can:

• Assert that the keypad archetype argument applies
• Provide a checklist of evidence (with the evidence to back it up of course)
  ✓ The keypad design has proper spacing
  ✓ The keypad conforms to best HCI practice
  ✓ The key markings are easily readable and unambiguous
  ✓ The keypad design avoids “bounce”
  ✓ A history that they keypad (or similar keypads) are trouble-free

The FDA can review the device without ever looking at the argument, but has it available if necessary.
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Tooling

Goal structured assurance cases can be done with a word processor, but they are easier to follow when presented graphically. We’ve used three tools to produce assurance cases:

1. Mindmanager (or similar) is very good for brainstorming.

   - Argue over hazards
     - Environmental
       - Air embolism
     - Software
       - Overdose
   - Pump is safe
Goal structured assurance cases can be done with a word processor, but they are easier to follow when presented graphically. We’ve used three tools to produce assurance cases:

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2. GSNCASEmaker is a set of unsupported Visio macros.
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2. GSNCASEmaker is a set of unsupported Visio macros.

3. ASCE (Adelard Safety Case Editor) is a supported standalone tool.
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Implications for manufacturers

- The Safety Case will evolve over the life of the system

- While the structure of the Safety Case will broadly remain constant,
  - the status of the evidence will change, e.g., planned test coverage will be replaced by evidence of test results
  - the relative weight of the arguments may change, e.g., compliance with a process standard might be replaced by proven in use

- Therefore plan for multiple reports
  - Obtain agreement on the argument structure first
  - Use identification of evidence as management tool
Final Thoughts

Assurance case must

• Integrate design analyses focused on hazards and FMEA
• Be reviewable

Assurance case evaluation criteria are currently subjective

• Need more data on which subtle defects are worth analysis efforts
• Need more understanding of what makes reliability arguments sound

Assurance case patterns hold promise of capturing valid arguments and guiding reliability improvement efforts
Conclusions

Within conventional assurance reports the ‘chain of argument’ can often get lost

- But the argument is more important than the document!

Assurance cases have been found to be a useful basis for mapping out and evolving the structure of the arguments

- Provides a roadmap for a document or set of documents
- Provides a basis for discussion among engineers and between developers and assessors
- Creating outline arguments at the beginning of a project helps show progress towards a complete solution
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