A Case Based Reasoning (CBR) Approach For Accident Scenario Knowledge Management

M.S. Thesis Presentation

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April 2005
OUTLINE

• Introduction
• Literature Survey
• Research Methodology
• Results
• Conclusion & Contributions
INTRODUCTION

Motivation

The history of aviation shares the same time line as the history of aviation safety research.

The more things change, the more they stay the same. There are patterns repeating themselves throughout the history of aviation accidents (Guzzetti and Nicklas, 2003)

* Source: www.planecrashinfo.com
INTRODUCTION

Motivation

Studying the “types” of accident cases, not necessarily investigating “the” accident, has potential to contribute significantly to aviation safety research.

Identifying these patterns and using them in a hybrid expert system to assist with causal modeling of aviation accidents is the motivation for this study.
Aviation Safety Risk Management Process

AvSSP has 5 separate subprograms:
- Weather Safety Technologies
- Vehicle Safety Technologies
- System Safety Technologies
- System Vulnerability Detection
- Aircraft & System Vulnerability Mitigation

NASA Contract # NAS1-03057

Accident Categories included in the ASRM:
- Controlled Flight Into Terrain (CFIT)
- Maintenance (MAIN)
- Loss of Control (LOC)
- Runway Incursion (RI)
- Engine Failure (EF)
- General Aviation (GA)

(Luxhoj et al., 2003)
INTRODUCTION

Research Problem

Introduce an analytical approach and methodology for a conversational CBR tool.

The tool’s objective is to assist the user to identify/model the precursors (i.e., causal factors) and their interactions underlying a particular aviation accident along with some candidate NASA technologies/interventions mitigating the effect of these precursors.

Research Objective

- Develop Analytical Framework
- Develop Case Base Structure/Taxonomy
- Develop Prototype Case-Based Reasoning (CBR) System
Expert systems are computer applications that mimic a human expert’s reasoning process to assist the decision-making and problem solving. Expert systems use a knowledge base or a set of rules to respond to the inquiry.

**Expert System:** mostly tailor-made computer applications for narrowly defined problem domains.

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Expert is the one “who has made all the mistakes which can be made in a very narrow field”  

Niels Bohr

“Shallow” Knowledge

“Deep” Knowledge

Theory about the Problem Domain

Expertise of the Expert

Includes “all peculiar heuristics and shortcuts that the trained professionals have learned to use in order to perform better”  

(Klein and Methlie, 1990)
Case-based reasoning, as a paradigm for building intelligent computer systems, is based on previous observations.

*Cases serve 3 sorts of purposes in CBR systems* (Kolodner and Leake, 1996).

- Cases provide context for understanding or assessing a new situation.
- Cases provide suggestions of solutions to problems.
- Cases provide context for evaluating or criticizing suggested solutions.
LITERATURE SURVEY

Process of (CBR)

“remember and adapt”
or
“remember and compare”

Two different styles of CBR:

Problem Solving Situations,
call primarily for the use of cases to propose solutions.

Interpretive Situations,
call primarily for using cases for criticism and justification
LITERATURE SURVEY
Cases and Indexing

A case’s indexes are combinations of its important descriptors, the ones that distinguishes it from the others.

In the CBR concept, we are concerned with cutting the case library into conceptual useful pieces.

Good indexes satisfy two properties (Watson 1997):

- Abstract enough to retrieve a relevant case
- Concrete enough to be easily recognizable
LITERATURE SURVEY

Why CBR

- CBR allows a reasoner to propose solutions to problems in domains that aren’t completely understood.

- CBR gives a reasoner a means of evaluating solutions when no algorithmic method is available for evaluation.

- Cases make it possible to interpret open-ended and poorly defined concepts.

- Cases help a reasoner to focus its reasoning on important parts of a problem by pointing out what features of a problem are the crucial ones.

- Cases can warn of the potential for problems that have occurred in the past, alerting a reasoner to take actions to avoid repeating past mistakes.
RESEARCH METHODOLOGY

Aviation Safety Risk Model (ASRM) & Its Relation to the CBR Research

INDEXING & REASONING

CASE BASE

ACCIDENT CASE LIBRARY

PROBABILISTIC CAUSAL MODELING

Knowledge Acquisition from SME

Aviation System Risk Model (ASRM)

Initial Symptoms

Suggested Questions

Solution Possibilities

Prototype CBR Tool
RESEARCH METHODOLOGY

The Case Base

The initial seed is comprised of two components:

- Complete Models
- Clusters of Causal Factors
RESEARCH METHODOLOGY
Clusters of Causal Factors

- Utilize patterns to boost similarity

**Pattern:** Recurring Causal Factors within Accident Suite

<table>
<thead>
<tr>
<th>Revised HFACS Failure Groups</th>
<th>CFIT Case # 3</th>
<th>CFIT Case # 2</th>
<th>CFIT Case # 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other Organizational</td>
<td></td>
<td></td>
<td>National Weather Services FAA</td>
</tr>
<tr>
<td>Unsafe Supervision</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preconditions For Unsafe Acts</td>
<td>Adverse Mental State</td>
<td>Adverse Mental State</td>
<td>Adverse Mental State</td>
</tr>
<tr>
<td>Unsafe Acts</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Causal Factors**

- Common in 2 CFIT Cases
  - Organizational Climate
  - Inadequate Supervision
  - Planned Inappropriate Operations
  - Crew Resource Management
  - Skill Based Error
  - Routine Violations
  - Adverse Physiological State

**CFIT Case#3**

**CFIT Case#2**

**CFIT Case#1**
RESEARCH METHODOLOGY
Clusters of Causal Factors

CFIT Case#3

CFIT Cluster#3

CFIT Case#2

CFIT Cluster#2
RESEARCH METHODOLOGY

Clusters of Causal Factors

CFIT Case#1

- ASRN_3
- ASRN_5
- FAA
- ORGANIZATIONAL PROCESS
- SUPERVISORY VIOLATIONS
- INADEQUATE SUPERVISION
- UNPLANNED INAPPROPRIATE OPERATIONS
- ORGANIZATIONAL CLIMATE
- PHYSICAL FAILURE

CFIT Cluster#1

- ASRN_3
- ASRN_5
- ORGANIZATIONAL PROCESS
- SUPERVISORY VIOLATIONS
- INADEQUATE SUPERVISION
- INADEQUATE SUPERVISION
- ORGANIZATIONAL CLIMATE
- PHYSICAL FAILURE

Causal factors common in all 3 cases of the CFIT accident suite:

Causal factors common in 2 cases of the CFIT accident suite:

Causal factors common in 1 case of the CFIT accident suite:
The BBN model of an accident in the ASRM may have six “causal” levels on the horizontally plane. Whereas, on the vertical plane, they have only three “descriptive” layers.
RESEARCH METHODOLOGY
Representing and Indexing ASRM Accident Cases

The ASRM BBN model of the Cali Case (without the technologies / interventions).

The descriptiveness of the case model is proportional to the number of its levels in the descriptive plane.
RESEARCH METHODOLOGY

Improving the Descriptiveness & Developing a Vocabulary for Indexing

Some Findings:

The FMS logic, at the time of the accident, was not able to retain the fixes the airplane’s position and those the airplane is proceeding towards, following the execution of a command to the FMS to proceed direct to a fix. The approach charts used by the flightcrew do not show graphically the high terrain on either side of the descent. There was discrepancy between approach charts and FMS presentation for the same approach that can hinder the ability of the pilots to execute an instrument approach. The speedbrake design does not permit automatic retraction that would operate during windshear and GPWS maneuvers, or other situations demanding maximum thrust and climb capability.
## RESEARCH METHODOLOGY

Improving the Descriptiveness & Developing a Vocabulary for Indexing

<table>
<thead>
<tr>
<th>TECHNOLOGICAL ENVIRONMENT</th>
<th>CHECKLIST LAYOUT</th>
<th>DISPLAY/ INTERFACE CHARACTERISTICS</th>
<th>EQUIPMENT/CONTROLS DESIGN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Approach Charts</strong></td>
<td><strong>Flight Management Computer (FMS)</strong></td>
<td><strong>Speed Brakes</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Attribute 1: Approach Chart Layout</strong></td>
<td><strong>Attribute 3: FMS Logic</strong></td>
<td><strong>Attribute 4: automatic retraction during windshear and GPWS maneuvers</strong></td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
<td><strong>Attribute 2: Consistency between FMS and approach charts</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The level of descriptive detail reached by the attribute model approach of the prototype CBR tool as opposed to the systemwise approach of the BBN models of the ASRM.
RESEARCH METHODOLOGY

INDEXING ACCIDENT CASES
From Several Attributes Models to A Domain Model

Preconditions of Unsafe Acts
- Environmental Factors
  - Technological Environment
- Checklist Layout
  - Approach Charts
- Attribute 1: Approach Chart Layout
- Attribute 2: Consistency between FMS and approach charts
- Equipment/Controls Design
- Speed Brakes

Domain Model
- Environmental Factors
  - Technological Environment
- Display/Interface Characteristics
  - Flight Management Computer (FMS)
- Checklist Layout
  - Approach Charts
- Attribute: FMS Logic
- Attribute 1: Automatic retraction during windshear and GPWS maneuvers
- Attribute 2: Consistency between FMS and approach charts
- Equipment/Controls Design
- Speed Brakes

Attribute Model 1
- Preconditions of Unsafe Acts
  - Environmental Factors
- Approaches Layout
- Attribute 1: Speed Brakes
- Attribute 2: Consistency between FMS and approach charts

Attribute Model 2
- Preconditions of Unsafe Acts
  - Environmental Factors
- Display/Interface Characteristics
- Checklist Layout
  - Approach Charts
- Attribute: FMS Logic
- Attribute 1: Automatic retraction during windshear and GPWS maneuvers
- Attribute 2: Consistency between FMS and approach charts
- Equipment/Controls Design
- Speed Brakes

Domain Model
- Environmental Factors
  - Technological Environment
- Display/Interface Characteristics
- Checklist Layout
  - Approach Charts
- Attribute: FMS Logic
- Attribute 1: Automatic retraction during windshear and GPWS maneuvers
- Attribute 2: Consistency between FMS and approach charts
- Equipment/Controls Design
- Speed Brakes
RESEARCH METHODOLOGY
Indexing the Accident Cases into the Case Base

[Diagram showing a model with preconditions of unsafe acts, environmental factors, technological environment, display/interface characteristics, flight management computer (FMS), checklist layout, approach charts, equipment/controls design, and speed brakes.]

- CFIT Case 1
- CFIT Case 2
- CFIT Case 3
RESULTS
Composition of the Case Base

INITIAL SEED
15 Accidents
15 Clusters

CFIT Accident Suite:
• 3 Accident Models
  • 3 Clusters

LOC Accident Suite:
• 3 Accident Models
  • 3 Clusters

MAIN Accident Suite:
• 4 Accident Models
  • 4 Clusters

RI Accident Suite:
• 3 Accident Models
  • 3 Clusters

EF Accident Suite:
• 2 Accident Models
  • 2 Clusters

GA Accident Suite
1 LOC Accident
1 EF Accident
{ Not Included in the Initial Seed }
RESULTS

The Prototype CBR Tool

- Did the management authorize an unqualified crew for flight?
- Was the decision of the captain to fly VFR a contributing factor?
- Were the airplane flying at an altitude lower than it was permitted to operate at in VFR operating procedures?
- Did the captain have a careless attitude and take unnecessary risks?
- Was the flightcrew fatigued and did they want to end the trip as soon as possible?
- Did the captain's active personal life distract him from his professional duties?
- Were there any factors, such as short sleep periods or early morning flight, present that could have led to fatigue?
- Was the captain mentally fatigued?
- Did the flight crew fail to stay on the assigned frequency and request radio traffic advisory service?
- Did the flight crew have the required experience and/or complete required flight operations?
- Did the management personnel fail to track the performance of the flight crew?

The accident occurred on July 25 near Palawan Bay, at an altitude of 150 feet, and was attributed to an instrument flight crew fatigued by a long flight trip.

The flight crew was operating in the northern portion of the flight route, maintaining visual flight. The captain mistakenly continued to use the northern portion of the flight route, believing it was the correct altitude.

Due to difficulties before the flight, the captain continued to have such difficulties before the flight, and the procedures for screening and training were inadequate because FAA regulations were not examined and maintained in accordance with approved procedures.

In summary, the system and the training of the flight crew were inadequate, and the aircraft's systems were not properly maintained due to the accident.

The investigation was conducted under the FAA's mandatory accident reporting system.
RESULTS
Information Provided Within The Solution Possibility
Validating Expert Systems

Major problems encountered in validating expert system performance (O'Keefe et al., 1987)

- What to validate,
- What to validate against,
- What to validate with,
- When to validate,
- How to control the cost of validation,
- How to control bias, and
- How to cope with multiple results.

Validation Methods

- Qualitative
- Quantitative

Solution Possibilities (Cases retrieved by the tool)

Experts knowledge

Accident Cases outside of the Initial Seed
Validation of the Prototype CBR Tools Performance

FACE VALIDATION: subjectively compare systems performance against human expert performance.

Analytical Approach of ASRM
- Select Operations & Accident Type
- Domain Model
- Present
- Enter Initial Conditions
- Answer Selected Questions
- Generate Question List
- Rank Cases
- Start Retrieving Cases
- Case Base
- Accept Case
- Update Case Base

Prototype CBR Tool
- Causal Model Retrieved from Case Base
- Causal Model Built by ASRM Process
- Test Case Selected from NTSB Database

Human Expert Performance
- But Infeasible
- Compare System Performance
Evaluation of the Prototype CBR Tool
Semi-Formal Qualitative Evaluation Method for the CBR Tool

Test Case Selected from NTSB Database

Study the Test Case with Experts

Prototype CBR Tool

Run the Tool with Experts

Relevancy of Causal Factors

Relevancy of NASA Products

CAUSAL FACTOR RELEVANCY SCALE

Ideal

10

All causal factors in the retrieved case are relevant

Relevant

5

Half of the causal factors in the retrieved case are relevant

Not Relevant

0

No causal factors in the retrieved case are relevant

TECHNOLOGY RELEVANCY SCALE

Ideal

10

All technologies in the retrieved case are relevant

Relevant

5

Half of the technologies in the retrieved case are relevant

Not Relevant

0

No technologies in the retrieved case are relevant

Experts evaluate the veracity of the proposed case

Causal Model Retrieved from Case Base
Review Session
With 2 SMEs from FAA FSDO (Pittsburg)

Test Case from NTSB Database

Experts Reviewed Test Case & Contributing Factors

IN-FLIGHT COLLISION WITH TERRAIN
Date of the Accident: April 22, 1992
Operator: Tomy International, Inc.
Scenic Air Tours
Aircraft: Beech E18S

Accident Synopsis
• Under the provisions of on-demand air taxi operations of FAR Part 135 and under VFR.
• The pilot and eight passengers aboard sustained fatal injuries.
• The airplane was destroyed by impact forces and postcrash fire.

IMC prevailed at the time and location of the accident.

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Experts Reviewed Test Case & Contributing Factors

After 3 Initial Symptoms & 5 Questions

Top-Ranked Solution Possibility: CFIT Cluster #1

SMEs Evaluated the Veracity

Causal Factors in the Solution Possibility

<table>
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<tr>
<th>Causal Factors in the Solution Possibility</th>
<th>SMEs Subjective Judgment about NTSB Tech Factors</th>
<th>NASA Technologies in the Solution Possibility</th>
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<tbody>
<tr>
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<td>Relevant</td>
<td>Relevant</td>
</tr>
<tr>
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<td>Relevant</td>
<td>Relevant</td>
<td>Relevant</td>
</tr>
<tr>
<td>Inadequate Supervision</td>
<td>Not Relevant</td>
<td>Relevant</td>
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<td>Decision Error</td>
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Top-Ranked Solution Possibility: CFIT Cluster #1

After 3 Initial Symptoms & 5 Questions

SMEs Evaluated the Veracity

Causal Factors in the Solution Possibility

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Review Session
SMEs Evaluated Veracity of The Solution Possibility

Causal Factors in the Solution Possibility

<table>
<thead>
<tr>
<th>Causal Factor</th>
<th>SMEs Subjective Judgment About Individual Causal Factors</th>
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<tbody>
<tr>
<td>Organizational Process</td>
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<td>Inadequate Supervision</td>
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<td>Crew Resource Management</td>
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</table>

CAUSAL FACTOR RELEVANCY SCALE

Ideal 10

SME 1: Relevant 5

SME 2: Not Relevant 0

NASA Technologies in the Solution Possibility

<table>
<thead>
<tr>
<th>Technologies</th>
<th>SMEs Subjective Judgment About NASA Technologies</th>
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</thead>
<tbody>
<tr>
<td>ASMM-3</td>
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<tr>
<td>ASMM-6</td>
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<td>SWAP-5</td>
<td>Relevant</td>
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</tr>
<tr>
<td>SVS-1, 4</td>
<td>Relevant</td>
</tr>
</tbody>
</table>

TECHNOLOGY RELEVANCY SCALE

Ideal 10

SME 1: Relevant 5

SME 2: Not Relevant 0
Conclusions and Contributions

• An analytical method for indexing & representing aviation accident into a case base
• A novel CBR approach for Accident Scenario Knowledge Management
• A prototype CBR system

Publications

• Oztekin, A., and Luxhoj, J. T., “A Case-Based Reasoning (CBR) Approach for Representing and Indexing Aviation Accidents” to be presented in WMSCI, Orlando, July 2005
• Oztekin, A., and Luxhoj, J. T., “A Case-Based Reasoning (CBR) Approach for Accident Scenario Knowledge Management” submitted to ISASI, Fort Worth, TX, Sept. 2005