Summary of NASA Research Accomplishments 2001-2005

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Executive Summary

For the past four years, Professor Jim Luxhøj and his research team from the Center for Advanced Risk and Decision Analysis (CARDA) in the Department of Industrial and Systems Engineering at Rutgers University have been funded through the Aviation Safety and Security Program (AvSSP) from NASA to develop analytical methods and prototype tools for aviation safety risk analysis. This contract led to the development of the following research products:
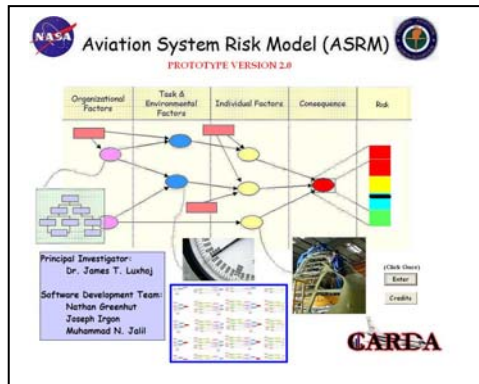
- ➢ **Aviation System Risk Model (ASRM)**
- ➢ **Post-Consequence Model (PCoM)**
- ➢ **Composite Program Assessment Score (CPAS)**
- ➢ **Bayesian Network-Uncertainty and Sensitivity Analyses (BN-USA)**
- ➢ **Case-Based Reasoner (CBR)**
- ➢ **Executive Information System (EIS)**

These prototype software tools present Artificial Intelligence and statistical methods for causal modeling, inferencing and prioritizing of aviation safety risks. The NASA research builds upon 10 years of aviation safety research with the Federal Aviation Administration (FAA). In particular, the Aviation System Risk Model (ASRM), initially developed under an FAA grant, was enhanced and further developed under the NASA contract to evaluate the projected impact upon system risk reduction of multiple new technology insertions/interventions into the National Airspace System (NAS).

Professor Luxhøj and his team published 3 journal articles and 14 conference proceedings during this 4-year period. 8 undergraduate students, 9 Masters students and 2 Ph.D. students participated in this joint government/industry/academia research during this period.

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# Summary of NASA Research Accomplishments
2001-2005

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Contract NAS1-03057

Probabilistic Decision Support for Evaluating Technology Insertion and Assessing Aviation Safety System Risk ($1,156,254), NASA Langley Research Center, Hampton, VA, Principal Investigator, March 2003 – August 2006.

Decision Support Software Prototypes

## Aviation System Risk Model (ASRM)
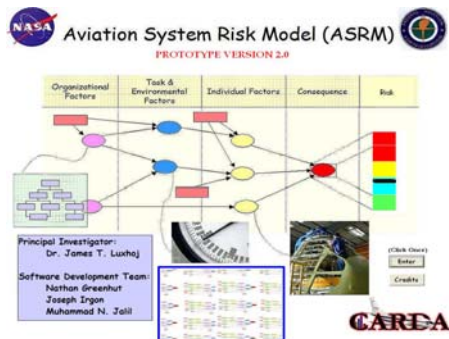
The Aviation System Risk Model (ASRM) is a software prototype that uses the flexible, probabilistic approach of Bayesian Belief Networks (BBNs) and influence diagrams to model the *complex interactions* of aviation system risk factors. The ASRM is currently being enhanced and further developed by the NASA Aviation Safety Program Office to evaluate the projected impact upon system risk reduction of multiple new technology insertions/interventions into the National Airspace System.

Post-Consequence Model (PCoM)
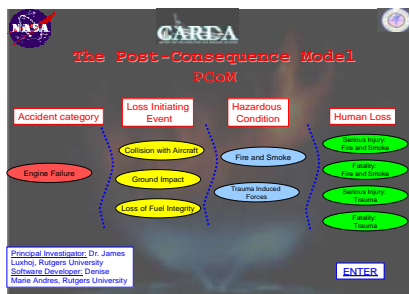
The Post-Consequence Model (PCOM) is a software prototype that uses the probabilistic approach of Bayesian Belief Networks (BBNs) and the HUGIN information technology tool to provide a severity distribution on the consequences associated with aircraft accidents, such as post-crash fire, ijuries and loss of life. New technologies aimed at severity reduction can be easily evaluated.

Composite Program Assessment Score (CPAS)
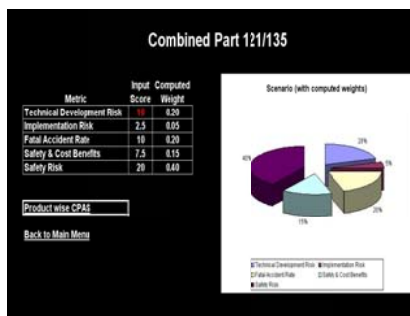
The Composite Program Assessment Score (CPAS) software prototype supports the evaluation of multiple metrics, scuh as Technical Development Risk, Implementation Risk, Safety Risk, Accident Rate and Cost/Benefit. The scores from the five metrics may be weighted by decision makers and combined into an aggregate score. The software contains "filters" to provide analyses by Part 121/135 and by product "suite". A portfolio prioritization graph is displayed.

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Bayesian Network-Uncertainty and Sensitivity Analysis (BN-USA)
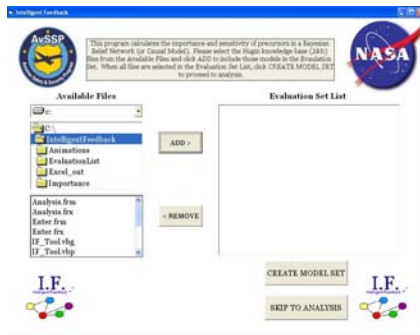
The Bayesian Network-Uncertainty and Sensitivity Analyses (BN-USA) software prototype facilitates the exploration of structural and reponse uncertainty in the ASRM models. The software facilitates the computation of pairwise importance measures that results in a rank ordering of the most important precursors. In addition, the BN-USA software also supports sensitivity analyses of the impact of precursors upon consequence probability. The BN-USA also has the capability to assist with new technology exploration.

Case-Based Reasoner (CBR)
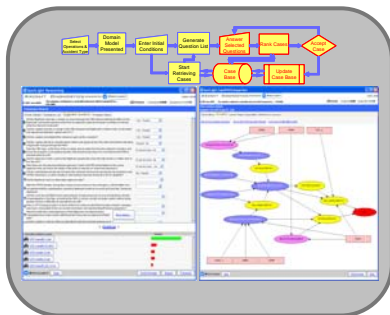
The Case Based Reasoner (CBR) is constructed using the 17 ASRMs dealing with Loss of Control, Engine Failure, Runway Incursion, Controlled Flight Into Terrain and Maintenance-related accidents. Through a series of dialog boxes, the user answers questions regarding the causal factors involved in an aircraft accident. The CBR then searches the case base for the most closely matching cases and reports a rank ordering. These cases may be retrieved as offered as "solution possibilities" with suggested technology and procedural mitigations.

Executive Information System (EIS)

The Executive Information System (EIS) is the repository for the software prototypes of the ASRM, PCoM, CPAS and BN-USA. In addition, the EIS also offers a number of varied executive displays of ASRM output.

Refereed Journal Publications (Total = 3)

1. Andres, Denise M., James T. Luxhøj, and David W. Coit, "Modeling of Human-System Risk and Safety: Aviation Case Studies as Exemplars," Human Factors and Aerospace Safety *(to appear 2006).*

2. Kardes, Erim, and James T. Luxhøj, "A Hierarchical Probabilistic Approach for Risk Assessments of an Aviation Safety Product Portfolio," Air Traffic Control Quarterly, Vol. 13, No. 3 (2005), pp. 279-308.

3. Jalil, Muhammad, James T. Luxhøj, and David W. Coit, "A Bayesian Framework to Assess the Impact of Advanced Aviation Technologies on Post-Crash Human and Aircraft Survivability," Human Factors and Aerospace Safety, Vol. 4, No. 2 (2004), pp. 101-130.

Conference Proceedings (Total = 14)

4. Luxhøj, James T. and David W. Coit, "Modeling Low Probability/High Consequence Events: An Aviation Safety Risk Model," The Annual Reliability and Maintainability Symposium, Newport Beach, CA, January 23-26, 2006 *(Invited Paper – to appear).*

5. Bareither, Chad and James T. Luxhøj, "Model Validation and Exploration of New Concepts in Aviation Safety," Proceedings of the AIAA's 5th Annual Aviation Technology, Integration, and Operations (ATIO) Technical Forum, Arlington, VA, September 26-28, 2005.

6. Oztekin, Ahmet and James T. Luxhøj, "A Case-Based Reasoning (CBR) Approach for Accident Scenario Knowledge Management," International Society of Air Safety Investigators (ISASI) Seminar, Fort Worth, Texas, September 12-16, 2005.

7. Luxhøj, James T., "Model-Based Reasoning for Aviation Safety Risk Assessments," SAE World Aerospace Congress, Dallas/Fort Worth, Texas, October 3-6, 2005 (selected to appear in the SAE 2005 Transactions).

8. Luxhøj, James T., "Aviation Safety in Practice: Applying Principles and Tools to Measure Risk Reduction," Safety Across High-Consequence Industries, Saint Louis University, St. Louis, Missouri, September 20-22, 2005.

9. Greenhut, Nathan, R., Bareither, Chad, and James T. Luxhøj, "Feedback Support for GAP Analysis of Aviation Technologies," 11th International Conference on Industry, Engineering, and Management Systems, Cocoa Beach, FL, March 15-17, 2005.

10. Oztekin Ahmet and James T. Luxhøj, "A Case-Based Reasoning (CBR) Approach for Representing and Indexing Aviation Accidents," 9th World Multi-Conference on Systems, Cybernetics and Infomatics, Orlando, FL, July 10-13, 2005, pp. 340-345 *(Best Paper Award for the Management Information Systems session).*

11. Luxhøj, James T. and David W. Coit, "Towards Safer Skies: A Probabilistic Approach to Risk Assessment of New Aviation safety Products," European Safety and Reliability Conference (ESREL), Tri City, Poland, June 27-30, 2005.

12. Greenhut, Nathan, and James T. Luxhøj, "Graphical Interface Enhancements for an Aviation Technology Integration Executive Information System," Proceedings of the AIAA's 4th Annual Aviation Technology, Integration, and Operations (ATIO) Technical Forum, Chicago, IL, September 20-22, 2004.

13. Greenhut, Nathan, and James T. Luxhøj, "GAP Analysis of Developed Models for an Aviation Technologies Decision Support System," <u>10th International Conference on Industry, Engineering, and Management Systems</u>, Cocoa Beach. FL, March 15-17, 2004.

14. Kuturu, Ram, and James T. Luxhøj, "Decision Support for Conditional Probability Elicitation in Bayesian Belief Networks (BBNs)," <u>10th International Conference on Industry, Engineering, and Management Systems</u>, Cocoa Beach. FL, March 15-17, 2004.

15. Kardes, Erim, and James T. Luxhøj, "An Object Oriented Stochastic Approach for Risk Modeling of Advanced Aviation Safety Technology Products," <u>10th International Conference on Industry, Engineering, and Management Systems</u>, Cocoa Beach, FL, March 15-17, 2004.

16. Luxhøj, James T., "Probabilistic Causal Analysis for System Safety Risk Assessments in Commercial Air Transport," <u>Proceedings of the Workshop on Investigating and Reporting of Incidents and Accidents (IRIA)</u>, September 16-19, 2003, Williamsburg, VA.

17. Luxhøj, James T., Muhammad Jalil, and Sharon Monica Jones, "A Risk-Based Decision Support Tool for Evaluating Aviation Technology Integration in the National Airspace System," <u>Proceedings of the AIAA's 3<u>rd</u> Annual Aviation Technology, Integration, and Operations (ATIO) Technical Forum</u>, Denver, Colorado, November 17-19, 2003.

18. Luxhøj, James T., "Probabilistic Risk Modeling and Evaluation of Advanced Technology Insertion for Commercial Aviation," <u>Industrial Engineering Research Conference</u>, Portland, OR, May 18-20, 2003.

Submitted Papers

Kardes, Erim, and James T. Luxhøj, "The Use of Representative Indices in Hierarchical Influence Diagram Modeling: A Case Study," <u>International Journal of Reliability, Quality, and Safety Engineering</u>

Ammarapala, Veeris, and James T. Luxhøj, "A Collaborative Multi-Criteria Decision Making Technique for Aviation Risk Factor Prioritization," <u>Human Factors and Aerospace Safety</u>

Lechner, Kathleen, James T. Luxhøj and Stephen Eisenhawer, "Systematic Creation of Bayesian Belief Networks and Their Relationship to Logic-Evolved Decision Models," <u>Industrial Engineering Research Conference</u>, May 20-24, 2006, Orlando, FL.

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Sharma, Varun, David W. Coit, and James T. Luxhøj, "Determination of a Composite Program Assessment Score (CPAS) for Prioritization of a Technology Portfolio," <u>Industrial Engineering Research Conference</u>, May 20-24, 2006, Orlando, FL.

Luxhøj, James T., "Risk Assessment for Aviation Safety Product Development," <u>Flexible Automation and Intelligent Manufacturing (FAIM) Conference</u>, University of Limerick, Ireland, June 26-28, 2006.

Presentations

Greenhut, Nathan and James T. Luxhøj, "What-If" and Sensitivity Analysis for the Aviation System Risk Model (ASRM), <u>Industrial Engineering Research Conference</u>, Atlanta, GA, May 14-18, 2005..

Bareither, Chad, Nathan Greenhut, and James T. Luxhøj, "Probabilisitc Risk Modeling and Advanced Sensitivity Analyses with Belief Networks," <u>Industrial Engineering Research Conference</u>, Atlanta, GA, May 14-18, 2005.

Andres, Denise, and James T. Luxhøj, "Severity Assessment Using the Post-Consequence Outcome Model (PcoM)," <u>Industrial Engineering Research Conference</u>, Atlanta, GA, May 14-18, 2005.

Greenhut, Nathan, Luxhøj, James T. and David W. Coit, "Using an Integer Program with Birnbaum's Importance Measures for Risk Prioritization of an Aviation Technology Portfolio," <u>INFORMS Annual Conference</u>, October 2004 *(presented by N. Greenhut).*

Luxhøj, James T., "Building a Safety Risk Management System: A Proof-of-Concept Prototype"
-   6th Annual FAA/NASA Risk Analysis and Safety Performance Measurements in Aviation Workshop," Washington, DC, August 16-20, 2004 *(Invited Presentation)*

Luxhøj, James T, "The Science and Art of Safety Risk Assessments for the Aviation Industry"
-   presented at the INFORMS Conference on OR/MS in Practice: Applying Science to the Art of Business, Cambridge, MA, April 25-27, 2004 *(Invited Presentation)*

Luxhøj, James T, "Probabilistic Risk Decision Support Research"
-   presented at the FAA Office of System Safety, June 9, 2004
-   presented at the FAA Technical Center, Pomona, NJ, June 3, 2003
-   presented at the National Institute of Aerospace (NIA), NASA Langley Research Center, Hampton, VA, May 29, 2003

Luxhøj, James T., "Probabilistic Decision Support for Evaluating Aviation Safety Program (AvSP) Technologies"
-   presented to the Rutgers Undergraduate Education Advisory Council, March 26, 2003 (with Kimberlee Kauffeld)

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Luxhøj, James T., Session Chair and Participant, "NASA Panel: Risk Analysis in Aviation Safety," Annual Meeting of the Transportation Research Forum, The George Washington University, Washington, DC, March 6-8, 2003.

Luxhøj, James T., "Human Error Modeling and Safety Risk Management for Commercial Aviation"
- presented at the Global Aviation Information Network (GAIN) Asia-Pacific Regional Conference, Tokyo, Japan, November 14-15, 2002 (with Scott Shappell)

Luxhøj, James T., "Aviation Safety Risk Management Schemes in the US and their Future Perspectives"
- presented at Waseda University, Department of Industrial and Management Systems Engineering, Tokyo, Japan, November 13, 2002 *(Invited Presentation)*

Luxhøj, James T.,"Probabilistic Decision Support to Evaluate Technology Insertion"
- presented at the 4th National Workshop on Risk Analysis and Safety Performance Measurements in Aviation, Tropicana Casino and Resort, Atlantic City, NJ, August 29, 2002

M.S. Theses

Muhammad Naiman Jalil, *A Probabilistic Decision Support System (PDSS) for Evaluating the Impact of Technology Insertion on Aviation Safety System Risk* (October 2003)
Erim Kardes, *Hierarchical Bayesian Belief Networks for Advanced Safety Risk Modeling* (May 2004) (Ph.D. student, ISE, University of Southern California)
Ahmet Emre Oztekin, *A Case-Based Reasoning (CBR) Approach to Accident Scenario Knowledge Acquisition* (May 2005)
Ryan Dickey, *Analytic Modeling and Prioritization of Emergent Aviation Safety Risks,* NASA Graduate Student Researchers Program (GSRP) ($24,000), NASA Langley Research Center, Hampton, VA, July 1, 2003 – June 30, 2004. (left Rutgers to accept a financial analyst position with Barclay Bank)
Nathan Greenhut, *An Executive Information System (EIS) for Complex Aviation System Risk Modeling (*May 2005) NASA Graduate Student Researchers Program (GSRP) ($24,000), NASA Langley Research Center, Hampton, VA, July 1, 2004 – June 30,
Denise Andres, *Development of a Post-Consequence Model for Aircraft Accident Severity Assessment* (May 2005) (Supply Chain Analyst, Johnson & Johnson, NJ)
Chad Bareither, *Uncertainty Resolution and Advanced Technology Concept Exploration in Binary-Node Bayesian Belief Networks* (degree expected January 2006)
Varun Sharma, *Development of a Composite Program Assessment Score for an Advanced Technology Portfolio Prioritization* (degree expected May 2006)
Katherine Lechner, *Systematic Creation of Bayesian Belief Networks: Relationship with Logic-Evolved Decision Models* (degree expected May 2007)