Final Report for Period: 09/2008 - 08/2009   **Submitted on:** 12/26/2009

Principal Investigator: Paredis, Christiaan J.   **Award ID:** 0522116

Organization: GA Tech Res Corp - GIT

Submitted By:

Paredis, Christiaan - Principal Investigator

Title:

Efficient Representation and Reduction of Extreme Uncertainty in Environmentally Benign Design and Manufacture

Project Participants

Senior Personnel

Name: Paredis, Christiaan

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Bras, Bert

Worked for more than 160 Hours: Yes

Contribution to Project:

Post-doc

Graduate Student

Name: Malak, Richard

Worked for more than 160 Hours: Yes

Contribution to Project:

Is developing methods for creating parametric models that explicitly account for uncertainty so that they can be used to guide decision making during the conceptual design

Name: Duncan, Scott

Worked for more than 160 Hours: Yes

Contribution to Project:

Laid the foundation for using Info-gap Decision Theory for EBDM problems

Name: Aughenbaugh, Jason

Worked for more than 160 Hours: Yes

Contribution to Project:

Laid the foundation for using Imprecise Probabilities to support EBDM decisions under extreme uncertainty

Name: Ling, Jay

Worked for more than 160 Hours: Yes

Contribution to Project:

Developed algorithm for estimating the value of using more accurate models

Name: Roman-Morales, Felipe

Worked for more than 160 Hours: Yes

Contribution to Project:

Is developing methods for characterizing the environmental impact of manufacturing processes when the knowledge about the artifact to be manufactured is incomplete

Name: Thompson, Stephanie

Worked for more than 160 Hours: Yes

Contribution to Project:

Stephanie Thompson is a PhD student who has been supported through an NSF graduate student fellowship; as of August 1, 2008, she is supported through this project. The focus of her PhD research is on the management of uncertainty in environmentally benign design and manufacture.

Name: Lee, Benjamin

Worked for more than 160 Hours: Yes

Contribution to Project:

Developed methods and algorithms for deciding which models to refine when both monetary and time resources are limited.

Undergraduate Student

Name: Schlosser, Jeffrey

Worked for more than 160 Hours: Yes

Contribution to Project:

Developed algorithm for deciding which additional information to purchase in support of a design decision

Name: Lennard, Michael

Worked for more than 160 Hours: Yes

Contribution to Project:

Michael has been developing a case study for the lifecycle assessment of a hydraulic-hybrid car. He worked on the project for course credit in the Spring of 2008 and will be supported through a Georgia Tech Presidential Undergraduate Research Award (PURA) in the Fall of 2008.

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

Phoenix Integration

Provided free access to the ModelCenter software suite for both educational and research purposes

Applied Biomathematics Inc

Provided software support and made intellectual contributions to the development of probability boxes for design decision-making (cf. joint publication with Scott Ferson)

Ford Motor Company

Provided case studies for applying elements of the work. Specifically, elements have been applied to gear manufacturing environmental assessments. Currently, application to fuel saving technologies is also being looked into.

University of Bath

Chris Paredis spent the summer of 2009 at the University of Bath working together with Drs. Chris McMahon, Linda Newnes and Yee Mey Goh on iterative refinement of cost models -- closely related to the work on iterative refinement of environmental impact models. Funding and facilities for the stay were provided in part by the University of Bath and by the Royal Academy of Engineering through a Distinguished Visiting Fellowship awarded to Chris Paredis.

Other Collaborators or Contacts

Activities and Findings

Research and Education Activities:

The primary goal of this project is to determine which uncertainty representations and corresponding decision methods are best suited for decision-making under the extreme uncertainty common in Environmentally Benign Design and Manufacture. In addition, methods are developed to guide the efficient gathering of additional information when currently available information is insufficient to support a particular decision.

We have studied three different uncertainty representations in the context of EBDM decision-making:
1) Imprecise probabilities (specifically, probability boxes).
2) Information gaps
3) Precise probabilities (as in traditional probability theory).

We have developed a framework for managing uncertainty in EBDM decisions and design in general. We call the framework Information Economics. Based on this framework, we have developed methods for deciding which additional information or models to acquire in support of an EBDM decision. This framework has led to new insights into the design process from a decision-theoretic perspective. We have summarized these insights in a new theory called Rational Design Theory.

We have implemented these methods, and applied them to several EBDM problems for validation purposes. The results have been published in conferences and journals.

Findings:

We have found that the probability-box and info-gap uncertainty representations allow one to express epistemic uncertainty explicitly and distinctly from aleatory uncertainty. Precise probabilities on the other hand force one to combine both types of uncertainty into a single probability distribution. Among the three representations, imprecise probabilities is the most expressive, allowing one to express clearly what is known and what is unknown. Traditional probability theory forces one to approximate an expression of ignorance as a least committal expression of knowledge (i.e., a maximum entropy distribution). Info-gap representations are not as expressive as imprecise probabilities because they are limited to (nested) pure intervals (although some research has investigated combining info-gaps with probability distributions).

When using these uncertainty representations for decision-making, we have found that both imprecise probabilities and info-gaps may lead to indeterminacy, that is, a situation in which the decision-maker is left with multiple alternatives that are non-dominated. All of the non-dominated alternatives could be the most preferred, but based on the available knowledge and information (or lack thereof), no single alternative can be rationally justified as being more preferred than the others in the non-dominated set. When a decision must be made, the indeterminacy must be broken by selecting one of the alternatives in the non-dominated set. When using precise (subjective) probabilities, this single choice is determined by using the maximum entropy distribution and maximizing the expected utility; it is important to recognize that this single choice is somewhat arbitrary and that it cannot completely be justified rationally. By extending the uncertainty formalism to imprecise probabilities, one can quantify the extent to which this single choice is arbitrary through the determination of the size of the set of non-dominated alternatives.

Characterizing the size of non-dominated alternatives is particularly important in the context of uncertainty management, because it indicates to what extent the decision can be improved through the gathering of additional information and knowledge.

We have demonstrated how probability boxes can be used to support decision-making in design by combining p-boxes with utility theory. Our initial findings were published in the Journal of Mechanical Design [Aughenbaugh 2006], and an application of imprecise probabilities specifically to an EBDM decision has been published at IDETC/CIE06. We have also demonstrated the use of information-gap decision theory (IGDT) in the context of EBDM decision-making, and have extended IGDT to account for multiple sources of uncertainty and multiple objectives. We have presented a comparison of the two formalisms (p-boxes and IGDT) at IDETC/CIE06.

In addition to an investigation of uncertainty representations, we have developed an Information Economic framework. Information Economics is the study of the use of information when resources are scarce. More specifically, in the context of this project, information economics helps us determine which information should be gathered and which models should be used at each step in the EBDM process. It is clearly not so that the most detailed, most accurate model or experiment is always the best ? these models or experiments also tend to be the most expensive and most time-consuming. Instead, one should try to use that information source that provides the best cost-benefit trade-off. However, determining that most valuable source is difficult because one cannot predict in advance the actual information that will be obtained from a given source. Our approach is therefore based on an iterative refinement of the information. We answer the question, given the currently available information, which additional information should be gathered (if any) to support the current decision. By relying on the availability

of an initial model (no matter how accurate or inaccurate), we can determine the relative importance of the remaining uncertainties and can weigh the expected cost of any uncertainty reduction versus the benefit in term of an improvements in the expected decision outcome. In our method, we assume that the decision maker can provide for each model or experiment what the expected uncertainty and the associated cost will be. Under these assumptions, we have developed methods that guide the decision maker towards the set of information sources (models, expert opinions, physical experiments, etc) that provide the best cost-benefit trade-off. We have presented these methods at the 2006 ASME International Mechanical Engineering Congress and Exposition and at the 2007 SAE world congress (papers by Jay Ling and Jeff Schlosser). One disadvantage of the information economic approaches introduced by student s Jay Ling and Jeff Schlosser is that one is left with indeterminacy in the (meta-level) information economic decision. (We refer to a meta-level decision because it is a decision about how to frame the design decision). To overcome the indeterminacy, we used the Hurwicz criterion, even though this criterion may sometimes lead to irrationality. Our justification was that the choice made in the design decision is only marginally sensitive to the choice made in the meta-level decision.

Student Stephanie Thompson reached the crucial insight that one can avoid the indecision altogether if one combines both levels of decision making. We have shifted our perspective from one in which decisions are made about the product to a perspective in which decisions are made about design tasks (i.e. about the design process as in the meta-level decisions discussed previously). This enables us to make trade-offs explicitly between improving product performance and reducing the resources used in the design process. Taking this view, it is not tolerable to reach a point of indecision caused by the indeterminacy that often results from the use of imprecise probabilities. At any point in time, designers must choose what to do next; choosing to do nothing is also a choice. Possible design tasks include refining the description of the design alternatives, performing analyses or physical tests, but also selecting a particular design alternative. Decision alternatives consist thus of design tasks rather than design configurations, and decision trees can be constructed to represent all the possible paths that a designer can take through the set of possible design tasks.

We have validated this approach by solving the decision tree for design processes consisting of a small set of design tasks. We assume that designers' beliefs about the outcomes of design tasks are captured as precise subjective probabilities. By further assuming that distributions are Gaussian, the conditional probability distributions representing the outcomes of all possible design tasks can be computed efficiently. Solving the decision trees then results in the optimal decision policy, indicating which design tasks to perform in each process step. By computing the optimal decision policy, the cost-benefit trade-off between the use of design phase resources and improvement of the designed product is evaluated. This is particularly important for EBDM decisions in which improved estimates of uncertain parameters may be very expensive and time-consuming to acquire. This new way of thinking about decision-making in design presents a stark departure from the old perspective in which decisions were made about the product. It promises to provide interesting new insights into how to manage risk by investing up-front in modeling, simulation and testing.

We have summarized the ideas on decision making as applied to the design process in Rational Design Theory (RDT ? the PhD thesis of Stephanie Thompson, to be defended in Spring 2010). We have compared Rational Design Theory with the previous work on design theory, including General Design Theory by Yoshikawa and Tomiyama, the Function-Behavior-State (FBS) work by Tomiyama, Concept-Knowledge (C-K) Theory by Hatchuel, Design Prototypes by Gero, and topological design structures by Braha and Reich. A major departure from most of these theories is that instead of building on a set-theoretic foundation, RDT is based on utility theory in which all information and knowledge is uncertain. Statements such as 'the final design must satisfy all the requirements' is meaningless from this probabilistic perspective ? no design is ever 100% guaranteed to meet a set of constraints. A consequence is that design cannot stop 'when a fully specified design alternative' has been reached. Instead, from a decision-theoretic perspective, the design process should stop (ideally) when all possible actions (analysis, refinement, etc) result in a decrease of the overall expected utility. These findings will be published in the near future.

Finally, based on an improved understanding of the role of epistemic uncertainty in the conceptual design stage, we have developed a new method for modeling the trade-offs that need to be considered for (partially defined) concepts at the early stages of design. Student Rich Malak has developed a modeling approach based on parameterized Pareto optimality that allows one to express the trade-offs for sub-systems or components in a fashion that is independent of preferences at the system level. The trade-off models represent the relationships between top-level functional and performance attributes while abstracting away the implementational details of the subsystems. This provides the opportunity to capture knowledge about broad classes of solution technologies without having to go into details ? ideal for making decisions at the early, conceptual design stage when many details are still unknown.

Training and Development:
Courses:
The ideas developed in this project have been included in a graduate level course: 'ME6105: Modeling and Simulation in Design' taught every Spring by Chris Paredis. In the course, the students go through a simulation-based design study in which they apply utility theory to make a design decision under uncertainty. Information economics is referred to throughout the course to help students understand the trade-offs between cost and benefit of models ? models for predicting physical behavior at the appropriate level of fidelity, models for expressing

uncertainty, and models for expressing multi-attribute preferences. The course is very popular with an enrolment of 30-35 on-campus MS and PhD students and 10-15 off-campus MS distance learning students (mostly practicing designers in industry). This course serves as one of the main dissemination channels of this project. Further information can be found at: http://www.srl.gatech.edu/education/ME6105.

The project ideas are also infused into a senior-level elective: 'ME4171: Environmentally Conscious Design and Manufacture' taught in the Fall by Bert Bras. In the course, the students learn about environmental impact reduction approaches, how they can be modeled and included in design decision-making. Further information can be found at: http://www.srl.gatech.edu/education/ME4171.

Basic project ideas on how uncertainty plays a role in modeling are also introduced at the undergraduate level in 'ME2016: Computing Techniques' taught every Fall by Chris Paredis. Further information can be found at: http://www.srl.gatech.edu/education/ME2016.

Research Training:
This project has impacted a large number of graduate students (7). Besides the two students for which we budgeted, additional contributions to the project have been made by students who received NSF graduate student fellowships before the start of the project (Jason Aughenbaugh and Felipe Roman), as well as by two students who received a fellowship as a direct result of their involvement in the project (Jay Ling and Jeff Schlosser). Stephanie Thompson who received an NSF fellowship during her MS studies switched advisors and has been working on the project also.
The proposal submission and the project research were specifically motivated by the ideas developed by Jason Aughenbaugh (received PhD in August 2006 for his work on imprecise probabilities in EBDM) and Scott Duncan (received PhD in December 2007 for his work on Info-Gap Decision Theory in EBDM). Jay Ling (received MS in May 2006) laid the foundation for uncertainty management based on the principles of Information Economics. Stephanie Thompson who is close to defending her PhD thesis has extended the information economic concepts into Rational Design Theory. Finally, Richard Malak extended these ideas towards the development of predictive trade-off models. Richard graduated in the Fall of 2009 and is currently an assistant professor at Texas A&M University.

We would like to highlight the work by the undergraduate student, Jeff Schlosser. Jeff further developed the work by MS student Jay Ling into a strategy for reducing uncertainty in situation where multiple information gathering options are considered simultaneously (i.e., reducing multiple sources of uncertainty based on physical experiments, expert opinion, or simulations). Jeff received a President's Undergraduate Research Award from Georgia Tech and an NSF Graduate Research Fellowship in the Spring of 2007. The paper in which he reported his research findings was published at the SAE World Congress and in the SAE Transactions, Journal of Passenger Cars ? Mechanical Systems. Jeff graduated in May 2007 and started the MS/PhD program at Stanford University in the Fall of 2007 (he was also accepted with a full research assistantship at Georgia Tech, MIT and UC Berkeley). His 5-semester involvement in the project contributed significantly to his development as an engineer and researcher.

Outreach Activities:
In September 2006, Jason Aughenbaugh and Chris Paredis collaborated with Zissimos Mourelatos on the organization of a workshop on Uncertainty Representation in Robust and Reliability-Based Design. The workshop was closely related to this project and served as a dissemination channel of our findings towards the broader engineering design community. The workshop objectives and topics were phrased as follows:
'In this workshop, several different uncertainty representations for robust and reliability-based design will be evaluated and compared. Experienced researchers will present different approaches towards uncertainty representation and decision making under uncertainty, addressing specific criteria for determining the suitability of these representations in the context of design. Such criteria include among others: clarity in the semantics of the uncertainty representation, rigor and consistency of the underlying mathematical formalism, ease of computation, and suitability for decision making. The intent of the workshop is to spawn a discussion among researchers interested in uncertainty in design ? a discussion that focuses on the interpretation of different uncertainty representations and how they can and should be used in support of design decision making. In the current literature, much of the focus in robust and reliability-based design is on improving the computational efficiency of specific analysis and optimization algorithms. As more researchers become interested and involved in this area, it is important that the community does not lose track of the basic concepts and philosophies underlying these algorithms. Currently, little attention is being paid to some of the fundamental philosophical differences that still exist within the community. In this workshop, these different perspectives will be presented, compared, evaluated, and discussed, with the intent to increase awareness and understanding of these sometimes complex issues.'
The workshop was attended by more than 30 researchers from around the world. Further information can be found at: http://www.srl.gatech.edu/Members/cparedis/Workshop.

In August 2008, Chris Paredis collaborated with Petter Krus (Link?ping University) on the organization of a workshop on predictive modeling in systems design, as part of the 2008 IDETC/CIE conference. Student Rich Malak presented research on trade-off modeling that resulted from this project. More than 25 people participated in discussions on the value and challenges of using predictive models in early design when uncertainty is large. The research team used this workshop to disseminate their research findings to the broader community.

Journal Publications

J.M. Aughenbaugh, C.J.J. Paredis, "The Value of Using Imprecise Probabilities in Engineering Design", Journal of Mechanical Design, p. 969, vol. 128, (2006). Published,

J.M. Ling, J.M. Aughenbaugh, C.J.J. Paredis, "Managing the Collection of Information under Uncertainty Using Information Economics", Journal of Mechanical Design, p. 980, vol. 128, (2006). Published,

S. Duncan, C.J.J. Paredis, and B. Bras, "An Approach to Robust Decision Making under Severe Uncertainty in Life-Cycle Design", International Journal of Sustainable Design, p. 45, vol. 1, (2008). Published,

S. Duncan, C.J.J. Paredis, and B. Bras, "Applying Information-Gap Decision Theory to a Design Problem having Severe Uncertainty", SAE 2006 Transactions, Journal of Materials and Manufacturing, p. 01-0273, vol. , (2007). Published,

S.J. Rekuc, J.M. Aughenbaugh, M. Bruns, and C.J.J. Paredis, "Eliminating Design Alternatives Based on Imprecise Information", SAE 2006 Transactions, Journal of Materials and Manufacturing, p. 01-0272, vol. , (2007). Published,

J. Schlosser, C.J.J. Paredis, "Managing Multiple Sources of Epistemic Uncertainty in Engineering Decision Making", SAE 2007 Transactions, Journal of Passenger Cars ? Mechanical Systems, p. 2007-01-1, vol. , (2007). Published,

J.M. Aughenbaugh, C.J.J. Paredis, "Probability Bounds Analysis as a General Approach to Sensitivity Analysis in Decision Making under Uncertainty", SAE 2007 Transactions, Journal of Passenger Cars ? Mechanical Systems, p. 2007-01-1, vol. , (2007). Published,

R.J. Malak Jr, J.M. Aughenbaugh, C.J.J. Paredis, "Multi-Attribute Utility Analysis in Set-Based Conceptual Design", Computer Aided Design, p. 217, vol. 41(3), (2008). Published, 10.1016/j.cad.2008.06.004

Reap, J; Roman, F; Duncan, S; Bras, B, "A survey of unresolved problems in life cycle assessment", INTERNATIONAL JOURNAL OF LIFE CYCLE ASSESSMENT, p. 374, vol. 13, (2008). Published, 10.1007/s11367-008-0009-

Reap, J; Roman, F; Duncan, S; Bras, B, "A survey of unresolved problems in life cycle assessment - Part 1: goal and scope and inventory analysis", INTERNATIONAL JOURNAL OF LIFE CYCLE ASSESSMENT, p. 290, vol. 13, (2008). Published, 10.1007/s11367-008-0008-

Stephanie C. Thompson, Christiaan J.J. Paredis, "An Investigation into the Decision Analysis of Design Process Decisions", Journal of Mechanical Design, p. , vol. , (2010). Submitted,

Richard J. Malak, Jr., Lina Tucker, Christiaan J.J. Paredis, "Compositional Modeling of Fluid Power Systems Using Predictive Tradeoff Models", International Journal of Fluid Power, p. 45, vol. 10 (2), (2009). Published,

Books or Other One-time Publications

J.M. Aughenbaugh, "Managing Uncertainty in Engineering Design Using Imprecise Probabilities and Principles of Information Economics", (2006). Thesis, Published
Bibliography: PhD Dissertation. G.W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology.

J.M. Ling, "Managing Information Collection in Simulation-Based Design", (2006). Thesis, Published
Bibliography: MS Thesis. G.W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology.

J.M. Aughenbaugh, J.M. Ling, and C.J.J. Paredis, "The Use of Imprecise Probabilities to Estimate the Value of Information in Design", (2005). Paper in Proceedings, Published
Collection: Proceedings of the 2005 ASME International Mechanical Engineering Congress and Exposition
Bibliography: paper no. IMECE2005-81181, Orlando, FL, November 5-11

S. Duncan, C.J.J. Paredis, and B. Bras, "Applying Information-Gap Decision Theory to a Design Problem having Severe Uncertainty", (2006). Paper in Proceedings, Published
Collection: Proceedings of the SAE 2006 World Congress
Bibliography: paper no. 2006-01-0273, Detroit, Michigan, April 3-6

S.J. Rekuc, J.M. Aughenbaugh, M. Bruns, and C.J.J. Paredis, "Eliminating Design Alternatives Based on Imprecise Information", (2006). Paper in Proceedings, Published
Collection: Proceedings of the SAE 2006 World Congress
Bibliography: paper no. 2006-01-0272, Detroit, Michigan, April 3-6

S. Duncan, C.J.J. Paredis, and B. Bras, "An Approach to Robust Decision Making under Severe Uncertainty in Life-Cycle Design", (2006). Paper in Proceedings, Published
Collection: Proceedings of The 13th CIRP International Conference on Life Cycle Engineering (LCE2006)
Bibliography: Leuven, Belgium, May 31-June 2

S. Duncan, J.M. Aughenbaugh, C.J.J. Paredis, and B. Bras, "Considering the Info-Gap Approach to Robust Decisions Under Severe Uncertainty in the Context of Environmentally Benign Design", (2006). Paper in Proceedings, Published
Collection: Proceedings of IDETC/CIE 2006
Bibliography: paper no. DETC2006-99486, Philadelphia, PA

J. M. Aughenbaugh, S. Duncan, C.J.J. Paredis, and B. Bras, "A Comparison of Probability Bounds Analysis and Decision Analysis in Environmentally Benign Design and Manufacture", (2006). Paper in Proceedings, Published
Collection: Proceedings of IDETC/CIE 2006
Bibliography: paper no. DETC2006-99230, Philadelphia, PA

M. Bruns, and C.J.J. Paredis, "Numerical Methods for Propagating Imprecise Uncertainty", (2006). Paper in Proceedings, Published
Collection: Proceedings of IDETC/CIE 2006
Bibliography: paper no. DETC2006-99237, Philadelphia, PA

J.M. Ling, and C.J.J. Paredis, "An Information Economic Approach for Model Selection in Engineering Design", (2006). Paper in Proceedings, Published
Collection: Proceedings of the 2006 ASME International Mechanical Engineering Congress and Exposition
Bibliography: paper no. IMECE2006-14535, Chicago, IL, November 5-10

M. Bruns, C.J.J. Paredis, and S. Ferson, "Computational Methods for Decision Making Based on Imprecise Information", (2006). Paper in Proceedings, Published
Collection: Proceedings of the 2006 Reliable Engineering Computing Workshop (REC?06)
Bibliography: Savannah, GA, February 22-24

J.M. Aughenbaugh and C.J.J. Paredis, "Why are Intervals and Imprecision Important in Engineering Design?", (2006). Paper in Proceedings, Published
Collection: Proceedings of the 2006 Reliable Engineering Computing Workshop (REC?06)
Bibliography: Savannah, GA, February 22-24

C.J.J. Paredis and B. Bras,, "Managing Uncertainty in Environmentally Benign Design and Manufacture", (2006). Paper in Proceedings, Published
Collection: 2006 NSF Design, Service, and Manufacturing Grantees and Research Conference
Bibliography: St. Louis, MO, July 24-27

J.M. Aughenbaugh, and C.J.J. Paredis, "Probability Bounds Analysis as a General Approach to Sensitivity Analysis in Decision Making under Uncertainty", (2007). Paper in Proceedings, Published
Collection: Proceedings of the SAE 2007 World Congress
Bibliography: paper no. 2007-01-1480, Detroit, Michigan, April 16-19

J. Schlosser, and C.J.J. Paredis, "Managing Multiple Sources of Epistemic Uncertainty in Engineering Decision Making", (2007). Paper in Proceedings, Published
Collection: Proceedings of the SAE 2007 World Congress
Bibliography: paper no. 2007-01-1481, Detroit, Michigan, April 16-19

S.J. Duncan, "Including Severe Uncertainty into Environmentally Benign Life Cycle Design Using Information-Gap Decision Theory", (2007). Book, Published
Bibliography: PhD thesis. G.W. Woodruff School of Mechanical Engineering. Georgia Institute of Technology.

Richard J. Malak, Jr.
Christiaan J.J. Paredis, "Using Support Vector Machines to Formalize the Valid Input Domain of Models in Data-Driven Predictive Modeling for Systems Design", (2009). Conference Proceeding, Published
Collection: Proceedings of the ASME 2009 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference (IDETC/CIE 2009)
Bibliography: August 30 - September 2; DETC2009-87376

Richard J. Malak, Jr., "Using Parameterized Efficient Sets to Model Alternatives for Systems Design Decisions", (2008). Thesis, Published
Bibliography: Ph.D. Thesis

Stephanie C. Thompson
Christiaan J.J. Paredis, "A Process-Centric Problem Formulation for Decision-Based Design", (2009). Conference Proceeding, Published
Collection: Proceedings of the ASME 2009 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference (IDETC/CIE 2009)
Bibliography: August 30 - September 2, DETC2009-87421

Benjamin D. Lee
Christiaan J.J. Paredis, "Accounting for the Duration of Analyses in Design Process Decisions", (   ). Conference Proceeding, Submitted
Collection: Proceedings of the 2010 SAE World Congress
Bibliography: under review

Web/Internet Site

URL(s):
http://www.srl.gatech.edu/research/nsfebdm
Description:
Provides project overview, participants and publications

Other Specific Products

Contributions

Contributions within Discipline:
At the early stages of design, information about environmental impact is often very sparse while gathering additional information can be time-consuming and expensive. This poses the question of how one best proceeds in gathering the right kind of and right amount of information to support a decision in the context of Environmentally Benign Design and Manufacture.

Our approach is to develop a method for incrementally determining which information is worthwhile collecting. For different mathematical representations of uncertainty, we determine how a decision can be made most economically through computational experiments in which the costs and benefits of information are evaluated objectively.

Our research has demonstrated that when uncertainty is extreme, info-gap decision theory can, at low cost, identify decision problems in which there is a clearly preferred, robust alternative. Similarly, when uncertainty is large, imprecise probabilities allow for better design decisions because they include an inherent sensitivity analysis that allows designers to determine when additional information gathering is warranted.

We have performed computational experiments with detailed models of the design process to establish a ground-truth for trading off the cost of gathering additional information in support of a design decision with the corresponding improvements in design outcomes. These models bridge the gap between decision-making using imprecise probabilities and traditional utility-theory approaches by focusing on making decision about the design process rather than directly about the design artifact. We have summarized the insights from these experiments in Rational Design Theory.

Contributions to Other Disciplines:

Decision making is a very common activity that plays a pivotal role in almost any kind of problem solving. As a result, many other disciplines involve similar problems in which decisions need to be made under extreme uncertainty. The algorithms and methods developed specifically in the context of EBDM problems are expected to transfer readily to other domains in which decision-making plays an important role.

Contributions to Human Resource Development:

The project has provided so far an opportunity for nine students to develop their research skills at the undergraduate, MS, and PhD levels. One of the PhD graduates (Richard Malak) is currently an assistant Professor at Texas A&M University. The project has also contributed to course material to which hundreds of students have been exposed. These students learned about Environmentally Benign Design and Manufacture and about the role of uncertainty in modeling and decision-making in EBDM.

Contributions to Resources for Research and Education:

Contributions Beyond Science and Engineering:

The idea of probability boxes as an uncertainty representation was first introduced by Scott Ferson and Lev Ginzburg, the principal stakeholders in small company called Applied Biomathematics. Drs. Ferson and Ginzburg are both biologists and spun off their company from SUNY Stonybrook. The focus of Applied Biomathematics has traditionally been on environmental risk assessment (hence their work on probability boxes). Through their interactions with Chris Paredis, they have recognized the potential for probability boxes to be used in support of design decision-making. In response, they submitted a proposal and received funding through the NASA SBIR program. With this funding, they are developing software (based on their previous RiskCalc tool) for uncertainty analysis in collaborative design; a beta-version of the software (as an MS Excel plug-in) will be made available at no charge to academic users in August 2008. Chris Paredis has been a consultant on the second phase of this SBIR project until Spring 2009.

Conference Proceedings

Malak, RJ;Paredis, CJJ, Using parameterized Pareto sets to model design concepts, "NOV 11-15, 2007", PROCEEDINGS OF THE ASME INTERNATIONAL MECHANICAL ENGINEERING CONGRESS AND EXPOSITION 2007, VOL 3, : 215-228 2008

Duncan, SJ;Paredis, CJJ;Bras, B, Applying info-gap theory to remanufacturing process selection affected by severe uncertainty, "NOV 11-15, 2007", PROCEEDINGS OF THE ASME INTERNATIONAL MECHANICAL ENGINEERING CONGRESS AND EXPOSITION 2007, VOL 15, : 293-300 2008

Categories for which nothing is reported:

Any Product

Contributions: To Any Resources for Research and Education