

**WORKING PAPERS 2008**

<b><u>NUMBER</u></b>	<b><u>TITLE</u></b>	<b><u>AUTHOR(S)</u></b>
08-001	System Reliability Optimization Considering Uncertainty: Minimization of a Coefficient of Variance Measure	H.Tekiner/D.Coit
08-002	Component Replacement Analysis for Complex Electricity Distribution Configurations	J.Espiritu/D.Coit
08-003	Component Replacement Analysis for Radial Distribution Systems	J.Espiritu/D.Coit
08-004	Development of a Multiple Objective Genetic Algorithm for Solving Reliability Design Allocation Problems	H.Taboada/D.Coit
08-005	Development of a New Multiple Objective Prioritized Genetic Algorithm	H.Taboada/D.Coit
08-006	An ALT Proportional Hazard-Proportional Odds Model	T.Huang/E.Elsayed/T.Jiang
08-007	Multi-Objective Optimization of a Port-of-Entry Inspection Policy	C.Young/M.Li/Y.Zhu/M.Xie/ E.Elsayed/T.Asamov
08-008	Risk Analysis of Transit Vessel Traffic in the Strait of Istanbul	O.Uluscu/B.Ozbas/T.Altiok/I.Or
08-009	Approximate Analysis of Batch Ordering Policies in Distribution Inventory Systems	A.Karaman/T.Altiok
08-010	Analysis of Safety Stock Policies in De-centralized Supply Chains	M.Rawat/T.Altiok
08-011	An Approximation for Multi-server Queues with Deterministic Reneging Time	W.Xiong/T.Altiok
08-012	Transit Vessel Scheduling in the Strait of Istanbul	O.Uluscu/T.Altiok/B.Ozbas, T.Yilmaz/I.Or
08-013	On Semi-renewal Processes and Reliability Prediction	M.Tortorella
08-014	An Alternate Approach to Nonparametric Estimation with Long-term Survivors	M.Tortorella/M.Cors-Lozada
08-015	Waiting Time Approximation in Multi-Class Queueing Systems with Multiple Types of Interruptions: Modeling Congestion at Waterway Entrances	O.S.Uluscu/T.Altiok
08-016	Waiting Time Approximation in Multi-Class Queueing Systems with Multiple Types of Class-Dependent Interruptions	O.S.Uluscu/T.Altiok
08-017	Application of Multi-Dimensional Procurement Auction in Single-Period Inventory Model	P.Farahvash/T.Altiok
08-018	Risk Analysis of the Transit Vessel Traffic in the Strait of Istanbul: Executive Summary	O.S.Uluscu/T.Altiok
08-019	Life Distribution of Survivors of Qualification and Certification	M.Tortorella
08-020	A Bayesian Parallel Site Methodology with an Application to Uniformity Modeling in Semiconductor Manufacturing	J.S.Fenner/Y.Jeong/M.K.Jeong/J.C.Lu
08-021	Automatic Identification of Defect Patterns in Semiconductor Wafer Maps Using Spatial Correlogram and Dynamic Time Warping	Y.Jeong/S.J.Kim/M.K.Jeong
08-022	Robust Probabilistic Multivariate Calibration Models	F.Yi/M.K.Jeong

08-023	Recursive Support Vector Censored Regression for Nonparametric Lifetime Prediction using Degradation Paths And Failure Times in Accelerated Life Tests	J.Park/M.Jeong
08-024	Component-based Predictive Maintenance Modeling for Multi-state Systems	X.Ye/D.Coit
08-025	Multi-period Multi-objective Electricity Generation Expansion Planning Problem with Monte Carlo Simulation	H.Tekiner/D.Coit/F.Felder

## **ISE Working Paper 08-001**

### **System Reliability Optimization Considering Uncertainty: Minimization of a Coefficient of Variance Measure**

Hatice Tekiner and David W. Coit

#### **Abstract:**

System reliability optimization models considering uncertainty are reviewed and a new formulation is proposed to minimize the coefficient of variation of the system reliability estimate. The redundancy allocation problem can be described as selection of the components and system configuration to optimize some objective function(s) without violating system related constraints. In this paper, we propose a new formulation to minimize the coefficient of variance of the system reliability estimate with respect to a minimum system reliability constraint and some other system level constraints. The problem can then be converted to integer programming problem for those problem where mixing components is not allowed.

## **ISE Working Paper 08-002**

### **Component Replacement Analysis for Complex Electricity Distribution Configurations**

Jose F. Espiritu and David W. Coit

#### **Abstract:**

A new component replacement analysis to solve asset replacement problems for complex electricity distribution systems is developed. In the present model a Taylor series expansion is used to approximate the associated opportunity cost for each component in the system. The method is based on an interactive dynamic programming and integer programming methods to obtain optimal system-level component replacement schedules with the objective of minimizing the total Net Present Value of unmet demand, maintenance and purchase costs. The Method is applied to the Dual Element Spot Network (DESN) configuration, which is one of the most commonly used by the power industry

## **ISE Working Paper 08-003**

### **Component Replacement Analysis for Radial Distribution Systems**

Jose F. Espiritu and David W. Coit

#### **Abstract:**

A new replacement analysis methodology is developed to determine system-level component replacement schedules for radial electricity distribution configurations composed of sets of heterogeneous assets. The proposed model is an iterative combined dynamic programming and integer programming approach to obtain cost-efficient system-level component replacement schedules with the objective of minimizing the total Net Present Value of unmet demand (considering the system unavailability), maintenance and purchase costs over a finite planning horizon. There is an annual budget limiting total expenditures for maintenance and replacement costs, which limits the selection of component replacement schedules. The method is demonstrated in the replacement analysis for a radial distribution configuration.

## **ISE Working Paper 08-004**

### **Development of a Multiple Objective Genetic Algorithm for Solving Reliability Design Allocation Problems**

Heidi A. Taboada and David W. Coit

#### **Abstract:**

A new multiple objective evolutionary algorithm is proposed for solving system design allocation problems. The developed algorithm mainly differs from other MOEAs in the crossover operation performed and in the fitness assignment. In the crossover step, several offspring are created through multi-parent recombination. Thus, the mating pool contains a great amount of diversity of solutions. This disruptive nature of our proposed type of crossover, called subsystem rotation crossover (SURC) encourages the exploration of the search space. The algorithm was thoroughly tested and a performance comparison of the proposed algorithm against one of the most successful MOEAs that currently exists shows that our algorithm is more powerful to solve multi-objective redundant design allocation problems.

## **ISE Working Paper 08-005**

### **Development of a New Multiple Objective Prioritized Genetic Algorithm**

Heidi A. Taboada and David W. Coit

#### **Abstract:**

A newly developed multiple objective evolutionary algorithm is presented. MoPriGA, a multi-objective prioritized genetic algorithm, incorporates the knowledge of the decision-maker objective function preferences directly within the evolutionary algorithm. The idea behind this algorithm is to more intensely focus on the region of the Pareto set of interest to the decision-maker.

## **ISE Working Paper 08-006**

### **An ALT Proportional Hazard-Proportional Odds Model**

T. Huang, E. A. Elsayed and T. Jiang

#### **Abstract:**

Accelerated life testing (ALT) is used to obtain failure data of products in a short time period in order to extrapolate the reliability and lifetime of the products under normal conditions. Estimation of the reliability and lifetime is based on models, which can be classified as parametric and non-parametric models. Non-parametric models are commonly used because of the distribution-free property. Proportional hazard model (PHM) and proportional odds model (POM) are two widely used non-parametric models for reliability prediction based on ALT data. These two models perform well if the underlying distributions are Weibull and log-logistic respectively. However, in some situations the failure time data may be obtained from a mixed population and using PHM or POM will result in inaccurate estimates of the reliability at normal operating conditions. In this paper, we develop a proportional hazard-proportional odds (PH-PO) model in order to obtain more accurate estimation for both mixed and non-mixed populations when the failure time distributions follow Weibull and log-logistic or a mix of the two. This PH-PO model is based on a parameter family, which makes proportional hazard model, and proportional odds model special cases of the proposed model. Baseline function and stress effect function of the PH-PO model are determined and maximum likelihood function is defined for parameter estimation. The performance of the PH-PO model is verified numerically using simulated data. The results show that in general the PH-PO model gives more accurate estimations of the reliability.

## ISE Working Paper 08-007

### Multi-Objective Optimization of a Port-of-Entry Inspection Policy

Christina M. Young, Mingyu Li, Yada Zhu, Minge Xie,  
Elsayed A. Elsayed and Tsvetan Asamov

#### Abstract:

At the port-of-entry containers are inspected through a specific sequence of sensor stations to detect the presence of nuclear materials, biological and chemical agents, and other illegal cargo. The inspection policy, which includes the sequence in which sensors are applied and the threshold levels used at the inspection stations, affects the probability of misclassifying a container as well as the cost and time spent in inspection. In this paper we consider a system operating with a Boolean decision function combining station results and present a multi-objective optimization approach to determine the optimal sensor arrangement and threshold levels while considering cost and time. The total cost includes cost incurred by misclassification errors and the total expected cost of inspection, while the time represents the total expected time a container spends in the inspection system. An example which applies the approach in a theoretical inspection system is presented.

## ISE Working Paper 08-008

### Risk Analysis of Transit Vessel Traffic In the Strait of Istanbul

Ozgecan S. Uluscu, Birnur Ozbas, Tayfur Altiok and Ilhan Or

#### Abstract:

The Strait of Istanbul, the narrow waterway separating Europe from Asia, holds a strategic importance in maritime transportation as it links the Black Sea to the Mediterranean. It is considered one of the world's most dangerous waterways to navigate. Over 50,000 transit vessels pass through the Strait annually, 20% of which carry dangerous cargo.

We have developed a mathematical risk model to analyze the risks involved in the transit vessel traffic system in the Strait of Istanbul. Vessel traffic operations and data were analyzed and a simulation model was developed to mimic and study the system behavior. Geographical conditions, current vessel-entrance scheduling/sequencing practices mimicking Turkish Straits Vessel Traffic Services' decisions to coordinate vessel traffic in both directions were modeled and implemented in the simulation model using a scheduling algorithm.

Risk analysis was performed by incorporating a probabilistic accident risk model into the simulation model. A mathematical risk model was developed based on probabilistic arguments and historical data as well as subject-matter expert opinions. We have also performed a scenario analysis to evaluate the behavior of the accident risks. This analysis allowed us to investigate the impact of various factors on the risk profile of the Strait. These factors included vessel arrivals, scheduling policies, pilotage, overtaking, and local traffic density. Policy suggestions were made based on findings of the study.

## **ISE Working Paper 08-009**

### **Approximate Analysis of Batch Ordering Policies In Distribution Inventory Systems**

Abdullah Karaman and Tayfur Altiok

#### **Abstract:**

We have considered a distribution inventory system with one warehouse and several retailers. Customer demand arrives at the retailers and the material flow between echelons is driven by reorder point/order quantity inventory control policies. Our objective is to calculate the long-run inventory statistics. The challenge in this system is to characterize the demand arrival process at the warehouse. A similar example is a queue to which the arrival process is the superposition of separate arrival streams, each of whose inter-arrival times is of Erlang distribution. We present a methodology to characterize such arrival streams as Markovian processes. We extend the methodology to phase-type arrival streams as well.

## **ISE Working Paper 08-010**

### **Analysis of Safety Stock Policies in De-centralized Supply Chains**

Mustafa Rawat and Tayfur Altiok

#### **Abstract:**

The nineties have witnessed substantial progress in supply chain management with many organizations realizing that supply chain initiatives have increased their competitiveness, reduced inventory, and improved their ability to meet customer demand. The challenges in managing supply chains are to ensure product availability and the ability to respond to market signals through accurate demand forecasts. Global competitiveness, faster product development, shorter product life and recent advances in information technology have placed increasing attention on the development of better approaches to manage supply chains. In this research, we model a multi-stage supply chain network representing a typical manufacturing/distribution environment made up of stores, distribution centers and manufacturing facilities. The stores sell different product types and replenish them from distribution centers. Customer orders arrive at the stores and are satisfied from the available on-hand inventory. Daily review of inventory is employed at all echelons in this study. If the inventory level falls below a predetermined level, orders are placed to bring it up to its target level. A similar inventory control activity is maintained at the distribution centers. Production at the plants is carried out on an order-by-order basis. Three policies of inventory control are introduced, and compared based on their performances in customer service level and the average inventory on hand.

## **ISE Working Paper 08-011**

### **An Approximation for Multi-server Queues With Deterministic Reneging Time**

Wei Xiong and Tayfur Altıok

#### **Abstract:**

In this paper, we studied multi-server queue with Poisson arrivals, general service time distribution, and deterministic renegeing times. This work was motivated by the timeout mechanism used in managing application servers in transaction processing environments. In such systems, a customer who stays in the queue longer than the timeout period is lost. We proposed a scaling approach, and a fast and accurate approximation for the expected waiting time in the queue.

## **ISE Working Paper 08-012**

### **Transit Vessel Scheduling in the Strait of Istanbul**

Ozgecan S. Uluscu, Tayfur Altıok, Birnur Ozbas, Tuba Yilmaz and Ilhan Or

#### **Abstract:**

Managing the transit vessel traffic in the Strait of Istanbul is a highly complex operation since vessels, weather and water conditions, and a set of regulations affect its operation significantly. At the present time, the VTS (Vessel Traffic Services) operators manage the traffic based on some fundamental rules. After discussions with the VTS, in this report, we present a mathematical formulation of the scheduling process currently in place and validate it by comparing its results with scheduling decisions made by the operators in some days of 2005. The results are highly promising. The proposed algorithm can be slightly altered and used in traffic scheduling in other waterways as well. The fundamental philosophy of the algorithm is to schedule the vessels with highest waiting time first while giving priority to large vessels carrying dangerous cargo. Our goal has been to incorporate the algorithm into a simulation model designed to be used for risk analysis purposes.

## ISE Working Paper 08-013

### On Semi-Renewal Processes and Reliability Prediction

Michael Tortorella

#### Abstract:

We analyze the notion of “reliability prediction” by studying a special type of point process for which the connection of future to past can be explicitly displayed. In this type of process, the *semi-renewal process*, all finite-dimensional distributions are completely determined by the distribution of the time to the first event in the process. The theory provides a heretofore unappreciated unification of the two most commonly used reliability prediction models for maintained systems, namely, the renewal and nonhomogeneous Poisson processes. We show that familiar results from renewal theory extend and generalize to semi-renewal processes.

## ISE Working Paper 08-014

### An Alternate Approach to Nonparametric Estimation with Long-term Survivors

Michael Tortorella and Marco Cors-Lozada

#### Abstract:

The Kaplan-Meier estimator is a simple and widely used nonparametric method for estimating a survivor function from univariate, ungrouped data containing right-censored observations. When some nonzero proportion of the population will never experience the event in question, all such “long-term survivors” in the population will contribute a right-censored observation to any data set in which they fall, regardless how long the study may be conducted. In this case, an estimate of the survivor function at infinity should be greater than zero to reflect the proportion of long-term survivors, or “immunes,” in the population. As a rule, the Kaplan-Meier estimator will indeed be positive at infinity whenever at least one right-censored observation is recorded at the last observation time. We are led to inquire whether the K-M estimate at infinity is too large, though, because the long-term survivors are never at risk, while the K-M estimator makes no distinction in the risk set between members who are truly at risk and members who will never experience the event in question and so should not be considered at risk at any time.

**ISE Working Paper 08-015**

**Waiting Time Approximation in Multi-Class Queueing Systems  
with Multiple Types of Interruptions:  
Modeling Congestion at Waterway Entrances**

Ozgecan S. Uluscu and Tayfur Altioek

**Abstract:**

We consider a single-server queue subject to multiple types of operation-independent interruptions motivated by operations and vessel queueing at entrances of waterways. A case in point is the Strait of Istanbul. We are using waiting-time arguments and service completion time analysis to obtain the expected waiting time of a customer (vessel) in the aforementioned queue with  $n$  classes of customers and  $k$  possibly simultaneous and class-independent service interruptions. In this paper, we generalize the single-class queueing model presented in the previous work and consider multiple classes of customers with non-preemptive priority service structure.

**ISE Working Paper 08-016**

**Waiting Time Approximation in Multi-Class Queueing Systems  
with Multiple Types of Class-Dependent Interruptions**

Ozgecan S. Uluscu and Tayfur Altioek

**Abstract:**

We consider a single-server queue subject to multiple types of operation-independent and class-dependent interruptions motivated by operations and vessel queueing at entrances of waterways. A case in point is the Istanbul Strait. We are using waiting-time arguments and service completion time analysis to obtain the expected waiting time of a customer (vessel) in the aforementioned queue with two classes of customers and  $k$  possibly simultaneous and class-dependent service interruptions. In this paper, we generalize the queueing model with multiple types of class-independent interruptions presented in the previous work and consider class-dependent service interruptions.

## **ISE Working Paper 08-017**

### **Application of Multi-Dimensional Procurement Auction In Single-Period Inventory Model**

Pooya Farahvash and Tayfur Altioek

#### **Abstract:**

Procurement is one of the major activities in the Manufacturing Resource Planning (MRP II), which is closely coupled with inventory management. Any improvement in this area will have a direct impact on the performance of the entire supply chain. Auction mechanism can be a successful procurement method when there are several potential suppliers available. In this work we consider a single-period inventory model when the selection of the supplier is done through a reverse auction and bids consist of several attributes, namely price, shortage quantity and lead time. The multi-dimensionality of the bid increases the complexity of the underlying problem and thus, we used an approximate approach that provides us with a means to determine an estimate for the optimal inventory decision variable, in this case the target level. This estimate is needed for the initiation of the auction and the procurement process. The Monte-Carlo simulation method was used to investigate the goodness of the approximate analytical method.

## **ISE Working Paper 08-018**

### **Risk Analysis of the Transit Vessel Traffic in the Strait of Istanbul**

Ozgecan Uluscu and Tayfur Altioek

#### **Abstract:**

The Strait of Istanbul, the narrow waterway separating Europe from Asia, holds a strategic importance in maritime transportation as it links the Black Sea to the Mediterranean. It is considered as one of the world's most congested and difficult-to-navigate waterways. Over 50,000 transit vessels pass through the Strait annually, roughly 20% of which carry dangerous cargo.

In this study, we have analyzed safety risks pertaining to transit vessel maritime traffic in the Strait of Istanbul and proposed ways to mitigate them without causing additional vessel delays. Actual vessel traffic operations and data were studied and a simulation model was developed to mimic the operation with its geographical and weather dynamics. Safety risk analysis was performed by incorporating a probabilistic accident risk model into the simulation model. A mathematical risk model was developed based on probabilistic arguments regarding instigators, situations, accidents, consequences and historical data as well as subject-matter expert opinions. Scenario analysis was carried out to study the behavior of the accident risks, with respect to changes in the surrounding geographical, meteorological and traffic conditions. This analysis allowed us to investigate the impact of various factors on the risk profile of the Strait. These factors included vessel arrival rates, scheduling pilotage and overtaking policies, and local traffic conditions.

## **ISE Working Paper 08-019**

### **Life Distribution of Survivors of Qualification and Certification**

Michael Tortorella

#### **Abstract:**

System reliability modeling is performed using the life distributions of components comprising the system. For undersea system products, components undergo qualification and certification programs that change the nature of the initial population. In particular, components that survive qualification and certification have a different life distribution than that of the initial population (that is, the population before qualification and certification are performed). For an undersea system reliability model, it is important to use the correct life distribution so that the results of the modeling will faithfully reflect what to expect in service. The purpose of this note is to describe how the life distribution of a population is changed by the qualification and certification procedures.

## **ISE Working Paper 08-020**

### **A Bayesian Parallel Site Methodology with an Application to Uniformity Modeling in Semiconductor Manufacturing**

Joel S. Fenner, Young-Seon Jeong, Myong K. Jeong and Jye-Chyi Lu

#### **Abstract:**

The increasing use of standard machines in manufacturing processes provides opportunities for sharing information from similar operations to improve the accuracy of process-model characterization for supporting root-cause analysis and process monitoring activities. This article researches how to integrate data from parallel sites that are alike in some ways but dissimilar in others. The parallel sites could be several machines that accomplish the same process step, several industrial locations that produce the same product, or even several different time windows for the same machine. The proposed Bayesian parallel-site model flexibly allows for the compromise between pooling the data completely and treating sites as completely unrelated. One of the key features in our hierarchical model is the quasi-common parameters that are different from site to site, but have some commonality between sites. The similarities between the individual quasi-common parameters are modeled through common global hyperparameters which determine the prior distribution for quasi-common parameters. The case study on the uniformity modeling (across the different dies on a silicon wafer, across slots in a furnace, etc.) illustrates how the hierarchy of a Bayesian model can be used to incorporate correlation structure. The Bayesian approach provides the flexibility for handling many other possible parallel data source scenarios that one might encounter in many applications.

## ISE Working Paper 08-021

### Automatic Identification of Defect Patterns In Semiconductor Wafer Maps using Spatial Correlogram and Dynamic Time Warping

Young-Seon Jeong, Seong-Jyb Kim and Myong K. Jeong

#### Abstract:

A wafer map is a graphical illustration of the locations of defective chips on a wafer. Defective chips are likely to exhibit a spatial dependence across the wafer map, which contains useful information on the process of integrated circuit (IC) fabrication. An analysis of wafer map data helps to better understand ongoing process problems. This paper proposes a new methodology in which spatial correlogram is used for the detection of the presence of spatial autocorrelations and for the classification of defect patterns on the wafer map. After the detection of spatial autocorrelation based on our proposed spatial randomness test using spatial correlogram, the dynamic time warping algorithm which provides non-linear alignments between two sequences to find optimal warping path is adopted for the automatic classification of spatial patterns based on spatial correlogram. We also develop generalized join-count (JC) based statistic and then propose a procedure to determine the optimal weights of JC-based statistics. The proposed method is illustrated using real-life examples and simulated data sets. The experimental results show that our method is robust to random noise and has a robust performance regardless of defect location and size.

## ISE Working Paper 08-022

### Robust Probabilistic Multivariate Calibration Models

Yi Fang and Myong K. Jeong

#### Abstract:

In this paper we propose a robust probabilistic multivariate calibration (RPMC) model in an attempt to identify linear relationships between two sets of observed variables contaminated with outliers. Instead of the Gaussian assumptions that predominate in classical statistical models, RPMC is closely related with the multivariate Student's t-distribution over noises and latent variables. As a result, RPMC lowers the effect of outlying data points by regulating the thickness of the distribution tails. RPMC is essentially a robustified version of the supervised probabilistic principal component analysis (SPPCA) that recently emerged. We show that RPMC encompasses probabilistic PCA and SPPCA as limiting cases. We also derive an efficient EM algorithm for parameter estimation in RPMC. Based on the probabilistic description of latent variables, we present a procedure for the detection of outliers. The experimental results from both simulated examples and real life datasets show the effectiveness and robustness of the proposed approach.

## ISE Working Paper 08-023

### Recursive Support Vector Censored Regression for Nonparametric Lifetime Prediction using Degradation Paths and Failure Times in Accelerated Life Tests

Jong In Park and Myong K. Jeong

#### Abstract:

Accelerated life tests (ALTs) are widely used in many applications for the time-effective assessment of products. Statistical analysis of the performance degradation paths of the products combined with actual failure times have the competence to provide more accurate lifetime estimates. We propose two nonparametric methods for analyzing the ALT data where the degradation paths and failure times are combined to estimate the lifetime of the product: the scale-accelerated degradation path model and recursive support vector regression. The proposed methods represent a novel approach in that functional forms describing the degradation paths need not be specified and the stress-life relationship need not even be assumed in order to extrapolate the lifetimes. A real-life example of an accelerated degradation test in which multi-stresses are employed to expedite a secondary rechargeable battery's failure during test intervals is presented to illustrate the proposed methods. The results demonstrate the efficiency of the proposed methods in predicting the lifetimes from accelerated test data.

## ISE Working Paper 08-024

### Component-based Predictive Maintenance Modeling for Multi-state Systems

Xiaodao Ye and David W. Coit

#### Abstract:

Component-level predictive maintenance schedules are developed to maximize multi-state system lifetime, considering degrading component multi-state behavior. To maximize the system time-to-replacement, the predictive maintenance schedule is based on individual component performance degradation trends, system performance requirements and component maintenance thresholds. This work is an extension of earlier published research using system-level predictive maintenance. Compared with the system-perspective predictive maintenance model for multi-state system, this model has several advantages. We studied a set of different configuration flow transmission water pipe multi-state systems through both a component and system perspective and compared the results. The conclusion is that the system-perspective model has an advantage when dealing with pure parallel systems; however for other types of system configurations, component-perspective model can provide more efficient maintenance to prolong the estimated lifetime of components and to save maintenance costs. We use a Markov Chain model to obtain the time-dependent state probability for all states of each component, and the universal generating function methodology is used to evaluate the performance of each component and the system. For the examples, a numerical search is used to determine the values of individual component maintenance thresholds to maximize the lifetime of overall system.

## ISE Working Paper 08-025

# Multi-period Multi-objective Electricity Generation Expansion Planning Problem with Monte Carlo Simulation

Hatice Tekiner, David W. Coit and Frank A. Felder

### Abstract:

A new approach to the electricity generation expansion problem is proposed to minimize simultaneously multiple objectives, such as cost and air emissions, including CO<sub>2</sub> and NO<sub>x</sub>, over a long term planning horizon. In this problem, system expansion decisions are made to select the type of power generation, such as coal, nuclear, wind, etc., where the new generation asset should be located, and at which time period expansion should take place. We are able to find a Pareto front for the multi-objective generation expansion planning problem that explicitly considers availability of the system components over the planning horizon and operational dispatching decisions. Monte Carlo simulation is used to generate numerous scenarios based on the component availabilities and anticipated demand for energy. The problem is then formulated as a mixed integer linear program, and optimal solutions are found based on the simulated scenarios with a combined objective function considering the multiple problem objectives. The different objectives are combined using dimensionless weights and a Pareto front can be determined by varying these weights. The mathematical model is demonstrated on an example problem with interesting results indicating how expansion decisions vary depending on whether minimizing cost or minimizing greenhouse gas emissions or pollutants is given higher priority.