**GOALI:** Efficient Simulation Techniques for Comparing Constrained Systems

### Project Participants

#### Senior Personnel

<table>
<thead>
<tr>
<th>Name</th>
<th>Worked for more than 160 Hours:</th>
<th>Contribution to Project:</th>
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<tr>
<td>Kim, Seong-Hee</td>
<td>Yes</td>
<td>She has worked on developing new variance estimators with better statistical properties --- which is critical to ensure good performance of selection procedures. She also developed a selection procedure with a tighter elimination boundary for finding the best among a number of simulated systems. She is currently working with Drs. Andradottir and Goldsman as well as Ph.D. students on the problem of finding the best alternative simulated system in the presence of a stochastic constraint and estimating the variance parameter of output data from steady-state simulations.</td>
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<tr>
<td>Goldsman, David</td>
<td>Yes</td>
<td>He has been working on improvements over existing variance estimators --- which is critical to ensure good performance of statistical selection procedures --- and developing efficient selection procedures for the problem of finding the best alternative simulated system among a number of simulated systems with or without constraints.</td>
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<tr>
<td>Andradottir, Sigrun</td>
<td>Yes</td>
<td>She has conducted research on efficient statistical selection procedures for selecting the best among a number of simulated systems in the presence of stochastic constraints. She also has been working on developing improved variance estimation techniques and stopping rules for steady-state simulations.</td>
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<tr>
<td>Diamond, Bob</td>
<td>Yes</td>
<td>Bob Diamond is a co-PI from an industrial company for discrete-event simulation software packages, which is located in San Diego, California. This project started June, 2004 and the three PI's from academia who reside in Atlanta have been working on developing variance estimation techniques with better statistical properties and efficient algorithms for finding the best among a number of simulated systems with/without stochastic constraints. Since Winter 2005, we have communicated with Bob Diamond and David Krahl (the Director of Technical Services) via email and phone in order to discuss which statistical procedure to implement into their simulation software package, Extend. We also arranged a summer internship position in his company for one of our Ph.D. students in 2006. We started regular conference call meetings with them last summer and will continue until next summer for knowledge transfer from academia to industry.</td>
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<tr>
<td>Tsui, Kwok-Leung</td>
<td>Yes</td>
<td>He works with two PIs (David Goldsman and Seong-Hee Kim) on problems related to new variance estimators for correlated data.</td>
</tr>
</tbody>
</table>
Graduate Student

Name: Batur, Demet

Worked for more than 160 Hours: Yes

Contribution to Project:
Demet Batur is a Ph.D. student of Drs. David Goldsman and Seong-Hee Kim. She has been working on developing new variance estimators and new selection procedures. She finished her Ph.D. in May, 2006.

Name: Gupta, Vivek

Worked for more than 160 Hours: Yes

Contribution to Project:
He is an advisee of Drs. Sigrun Andradottir and David Goldsman and has been working on this project since January 2005. His research concerns estimating the variance parameter of output data from steady-state simulations.

Name: Healey, Christopher

Worked for more than 160 Hours: Yes

Contribution to Project:
He is a Ph.D. student of Drs. Sigrun Andradottir, David Goldsman, and Seong-Hee Kim. He works on problems involving the performance of ranking and selection procedures in the presence of constraints.

Name: Aktaran-Kalayci, Tuba

Worked for more than 160 Hours: Yes

Contribution to Project:
She worked on developing overlapping standardized time series variance estimators. She was Dr. David Goldsman's Ph.D. student and graduated in 2006.

Name: Antonini, Claudia

Worked for more than 160 Hours: Yes

Contribution to Project:
Claudia Antonini worked on developing variance estimators for simulation using folded standardized time series.

Name: Meterelliyoaz, Melike

Worked for more than 160 Hours: Yes

Contribution to Project:
Melike Meterelliyoaz worked on variance parameter estimation methods with reuse of data.

Undergraduate Student

Technician, Programmer

Name: Krahl, David

Worked for more than 160 Hours: Yes

Contribution to Project:
Mr. David Krahl is Lead Engineer and the Director of Technical Services at Imagine That, Inc. As he is responsible for block development of Extend, we have worked closely with him to develop a tool for optimization based on ranking and selection.

Other Participant

Research Experience for Undergraduates

Organizational Partners

Other Collaborators or Contacts
We have written papers with numerous other co-authors, as detailed in the findings and contributions sections of this report.
Activities and Findings

Research and Education Activities: (See PDF version submitted by PI at the end of the report)
Research and education activities are described in the attached PDF version at the end of the report.

Findings: (See PDF version submitted by PI at the end of the report)
Findings are described in the attached PDF version at the end of the report.

Training and Development:
The results related to variance estimators and constrained ranking and selection procedures have been introduced to students in our Masters and Ph.D. simulation courses. Also, the results have been introduced to the research community through tutorial papers and tutorial presentations at the Winter Simulation Conference and the INFORMS Conference.

Close collaboration with our GOALI partners Bob Diamond and David Krahl is currently ongoing to implement our procedures in the optimization tools of Extend, a real-world discrete-event computer simulation software package.

Outreach Activities:
The results were presented in a number of conferences, including the annual IIE Conference, the annual INFORMS Conference, the Winter Simulation Conference, and the NSF Grantees Conference.


`Linear Combinations of Overlapping Variance Estimators for Simulations,' Tuba Aktaran-Kalayci (presenter) and David Goldsman. INFORMS Conference, San Francisco, California, 2005.

`Finding Feasible Systems When the Number of Systems or
Constraints is Large,’ Demet Batur (presenter) and Seong-Hee Kim. INFORMS Conference, San Francisco, California, 2005.


‘Finding the Set of Feasible Systems When the Number of Systems or Constraints is Large,’ Demet Batur (presenter) and Seong-Hee Kim. 2005 Winter Simulation Conference, Orlando, Florida, 2005.


‘Exact Expected Values of Variance Estimators for Simulation,’ David Goldsman, Bogazici University (Istanbul, Turkey), March and May 2006.


‘Exact Expected Values of Variance Estimators for Simulation,’ David Goldsman, Koc University (Istanbul, Turkey), June 2006.

‘Exact Expected Values of Variance Estimators for Simulation,’ David Goldsman, Middle East Technical University (Ankara, Turkey), December 2006.


‘Linear Combinations of Variance Estimators of the Sample Mean,’ Wenchi Chiu, David Goldsman (presenter), and Wheyming Song. 2006 36th International Conference on Computers and Industrial Engineering, Taipei, Taiwan, R.O.C., 2006.


‘The Role of Simulation in Humanitarian Logistics’ (Keynote


‘Variance Estimators for Simulation Based on Data Re-use,' Christos Alexopoulos, Claudia Antonini, David Goldsman, Melike Meterelliyoza, and James R. Wilson, INFORMS Conference, Washington


Journal Publications

Christos Alexopoulos and David Goldsman, "To Batch Or Not To Batch?", ACM Transactions on Modeling and Computer Simulation, p. 76, vol. 14, (2004). Published,


Aktaran-Kalayci, T; Alexopoulos, C; Argon, NT; Goldsman, D; Wilson, JR, "Exact expected values of variance estimators for simulation", NAVAL RESEARCH LOGISTICS, p. 397, vol. 54, (2007). Published, 10.1002/nav.2021


Wenchi Chiu, David Goldsman, and Wheyming Tina Song, "Bias-Aware Linear Combinations of Variance Estimators", WSEAS Transactions on Electronics, p. 167, vol. 4, (2007). Published,


Antonini, C; Alexopoulos, C; Goldsman, D; Wilson, JR, "Area variance estimators for simulation using folded standardized time series", IIE TRANSACTIONS, p. 134, vol. 41, (2009). Published, 10.1080/0740817080233126

Alexopoulos, C; Argon, NT; Goldsman, D; Tokol, G; Wilson, JR, "Overlapping variance estimators for simulation", OPERATIONS RESEARCH, p. 1090, vol. 55, (2007). Published, 10.1287/opre.1070.047

Alexopoulos, C; Argon, NT; Goldsman, D; Steiger, NM; Tokol, G; Wilson, JR, "Efficient computation of overlapping variance estimators for simulation", INFORMS JOURNAL ON COMPUTING, p. 314, vol. 19, (2007). Published, 10.12

Aktaran-Kalayci, T; Goldsman, D; Wilson, JR, "Linear combinations of overlapping variance estimators for simulation", OPERATIONS RESEARCH LETTERS, p. 439, vol. 35, (2007). Published, 10.1016/j.orl.2006.08.00
Alexopoulos, C; Andradottir, S; Argon, NT; Goldsman, D, "Replicated batch means variance estimators in the presence of an initial transient", ACM TRANSACTIONS ON MODELING AND COMPUTER SIMULATION, p. 317, vol. 16, (2006). Published,


Kim, SH; Alexopoulos, C; Tsui, KL; Wilson, JR, "A distribution-free tabular CUSUM chart for autocorrelated data", IIE TRANSACTIONS, p. 317, vol. 39, (2007). Published, 10.1080/0740817060074394


Books or Other One-time Publications


Tuba Aktaran-Kalayci, Christos Alexopoulos, David Goldsman, and James R. Wilson, "Optimal Linear Combinations of Overlapping Variance Estimators for Steady-State Simulation", (2009). Book, Published
Editor(s): C. Alexopoulos, D. Goldsman, and J. R. Wilson
Collection: Advancing the Frontiers of Simulation: A Festschrift in Honor of George Samuel Fishman
Bibliography: Springer, Heidelberg, Germany

Web/Internet Site

Other Specific Products

Product Type:
Software (or netware)

Product Description:
This software is to implement overlapping standardized time series variance estimators due to Alexopoulos, Argon, Goldsman, Tokol and Wilson (2006) and Alexopoulos, Argon, Goldsman, Steiger, Tokol and Wilson (2006) in an easy way for general use. User's manual is also available.

Sharing Information:

Contributions within Discipline:
Here we summarize contributions of our work.

1. From the 1st Year

Christos Alexopoulos and David Goldsman} (2004).  ```To Batch Or Not To Batch?``` ACM Transactions on Modeling and Computer Simulation, 14:76--114. [This paper won the 2007 INFORMS Simulation Society Outstanding Simulation Publication Award.]

Contributions: The paper systematically investigates the two most popular methods used in simulation output analysis. It gives explicit conditions under which the method of batch means is superior to that of independent replications.


Contributions: The paper introduces the new idea of combining the multiple replications and batch means methods for output analysis in steady-state simulation.

Contributions: This paper extends work due to Zhu et al. (2004) by accounting for (i) unknown and unequal variances and (ii) correlation across systems due to, e.g., the use of common random numbers.


Contributions: The new estimators developed in the paper allow for more efficient estimation of the variance of the sample mean, a quantity that ought to be reported as part of any study involving estimation of the underlying population mean.


Contributions: This paper provides state-of-the-art procedures for the comparison-with-a-standard problem popular in simulation. In addition, the procedures can be further extended to check the feasibility of simulated systems in the presence of stochastic constraints on some secondary performance measures.


Contributions: The findings in this paper can be adapted to study the asymptotic behavior of a number of sequential ranking-and-selection procedures involving continuation regions of various shapes. Specifically, our work provides tools to help in the development of asymptotically valid selection procedures for steady-state simulations.


Contributions: On the theory side of things, we believe that this is the most efficient and stable sequential confidence interval procedure in the literature. On the applied side, we provide pseudo-code for the algorithm, as well as executable code so that users can run the algorithm easily on their own.

2. From the 2nd Year
Tuba Aktaran-Kalayci and David Goldsman (2005). "Linear

Contributions: This paper generalizes standardized time series estimators that have been proposed in the literature. The estimators proposed in the paper exploit a great deal of the possible information they can get from a given data set and, therefore, are (to date) the most efficient standardized time series estimators based on batching.


Contributions: The idea of using overlapping batches is applied to standardized time series estimators.


Contributions: Efficient algorithms to avoid heavy additional computational efforts in computing overlapping standardized time series estimators are proposed. Software and a user's manual for general and easy use are made available via the web. In addition, the paper shows how to use standardized time series estimates in constructing certain confidence intervals.


Contributions: We present statistically valid selection procedures that can handle a general stochastic constraint. This is the first work in this area that has been done in the literature.


Contributions: Procedures presented in the paper will serve as a critical step to move from optimization with one stochastic constraint to optimization with multiple stochastic constraints,
which is the ultimate goal of this ongoing grant.


Contributions: The paper shows that the idea of variance updating can be very useful --- even in the context of ranking and selection problems involving terminating simulations --- with little loss in the probability of correct selection.

3. From the 3rd Year


Contributions: For a wide variety of cases, the exact expected values of variance estimators for steady-state simulation can be calculated for any sample size.


Contributions: The variance parameter estimators proposed in the paper exploit more information from a given data set than other estimators proposed in the simulation literature. The result is a class of new estimators with low bias and low variance.


Contributions: Our expressions explicitly show how a simulation's transient mean function affects variance estimator performance. In some cases, the replicated batch means estimator is a good compromise choice with respect to bias and variance. However, care must be taken to avoid an excessive number of replications when the transient function is pervasive.

Contributions: By providing a way to avoid negative values of Cramer-von Mises (CvM) variance estimators, one can use CvM estimators safely in many applications, including estimating variance parameters in ranking and selection procedures.

4. From the 4th Year


Contributions: This proceedings paper expands on the earlier results from our Aktaran-Kalayci et al. (2007) Operations Research Letters article (listed in the Contributions from the 3rd Year).


Contributions: This proceedings paper gives some additional results above and beyond those in the Alexopoulos, et al. (2006) ACM TOMACS paper. Specifically, we obtain performance properties of replicated batch means under more general assumptions than heretofore considered.


Contributions: This paper defines a new problem, namely, constrained ranking and selection and provides creative and new approaches to solve the problem.


Contributions: We look at an entirely new class of variance parameter estimators that effectively re-use data from simulations. The new estimators are asymptotically more efficient than benchmark estimators such as batch means or certain standardized time series estimators.

Contributions: This paper is the proceedings version of the Antonini et al. (2008) IIE Transactions paper on the same subject.


Contributions: This paper proposes a novel approach to variance estimation for computer simulation output. Namely, we attempt to minimize the variance of a linear combination of estimators subject to a bias constraint.


Contributions: This paper is the proceedings version of the Healey, Kim, and Goldsman (2009) listed in the contributions from the 5th year.


Contributions: This tutorial provides directions of future research in ranking and selection and explains the importance of our research dealing with constrained ranking and selection.

5. From the 5th Year


Contributions: With a little extra computational work, we can obtain a variance estimator with better statistical properties than standardized time series area or Cramer--von Mises estimators.

Contributions: This paper provides statistical procedures for feasibility detection when the number of constraints on a secondary performance measure is larger than one.


Contributions: This paper studies (i) the significance of statistical properties of estimators for the asymptotic variance parameter in steady-state simulation and (ii) why research involving variance estimators for steady-state simulations needs to be continued.


Contributions: We provide fine-tuned expected value and variance results for a new class of folded estimators; and we show that the new folded estimators perform as advertised by theory.


Contributions: We derive optimal linear combinations of a large class of variance parameter estimators. We show that these estimators outperform others in the literature with only minor additional computational costs.

Contributions to Other Disciplines:
New variance estimators for autocorrelated data from our work further alleviate the difficulties in obtaining a good variance estimate prior to performing any statistical process control procedure in quality control.

In addition to the first two papers published last year, the third paper was submitted to IIE Transactions in 2008:


Contributions to Human Resource Development:
Four female PhD students were graduated: one is currently an assistant professor at a university, two are post-docs in universities, and one is a former assistant professor and currently in industry. These women have certainly helped bolster underrepresented groups in education and industry. Dr. Goldsman also gave numerous lectures to high school math teachers for probability and statistics and is helping to develop a new OR-based 12th grade math course for the state of Georgia.

Contributions to Resources for Research and Education:
Free software for variance estimators for steady-state simulation has been developed, and it is accessible on the internet for any researchers or educators. This will help researchers and educators understand the implementation and performance of variance estimators for stationary autocorrelated data.

Contributions Beyond Science and Engineering:
Our procedures for constrained ranking and selection can provide more practically meaningful solutions for a complicated decision-making process, including environmental management. For example, one PI is collaborating with researchers in environmental engineering and they show that uncertainty should be considered in determining the most cost-effective design of a seawater desalination plant; and constrained ranking and selection procedures could provide a useful decision-making tool to find the most cost-effective design.

Conference Proceedings

Alexopoulos, C;Andradottir, S;Argon, NT;Goldsman, D, Replicated batch means for steady-state simulations with initial transients, "DEC 09-12, 2007", PROCEEDINGS OF THE 2007 WINTER SIMULATION CONFERENCE, VOLS 1-5, : 296-300 2007


Antonini, C;Alexopoulos, C;Goldsman, D;Wilson, JR, Folded standardized time series area variance estimators for simulation, "DEC 09-12, 2007", PROCEEDINGS OF THE 2007 WINTER SIMULATION CONFERENCE, VOLS 1-5, : 434-441 2007


Categories for which nothing is reported:

Organizational Partners
Any Web/Internet Site
Activities

The performance of statistical selection procedures, especially for steady-state simulation, depends highly on the quality of variance estimates. The three co-PIs have worked on improvements of existing variance estimators, to produce estimators with better statistical properties — that is, low bias and low variance — for output data from steady-state simulations. In particular, we have investigated:

1. the method of replicated batch means — whether it is better to conduct one long run, or multiple smaller runs, or a compromise between the two extremes;
2. ASAP3, a new sequential procedure for confidence interval estimation;
3. new “overlapping” estimators based on standardized time series for the variance parameter of a stationary stochastic process;
4. analysis of the computational effort to produce overlapping standardized time series estimators and the use of their asymptotic distribution to construct confidence intervals via those estimators;
5. linear combinations of nonoverlapping standardized time series area estimators;
6. linear combinations of overlapping standardized time series area estimators;
7. combining nonoverlapping standardized time series area and Cramér–von Mises variance estimators — resulting in Durbin–Watson type variance estimators — to achieve low bias and low variance;
8. improved jackknifed versions of Durbin–Watson type estimators for the asymptotic variance parameter;
9. linear combinations of overlapping standardized time series area and Cramér–von Mises estimators;
10. overlapping versions of the jackknifed version of the Durbin–Watson estimator for the asymptotic variance parameter;
11. new “folded” standardized time series area and Cramér–von Mises estimators for the asymptotic variance parameter;
12. (ongoing) linear regression of various variance estimators to produce a new linear combination estimator having lower bias and variance;
13. (ongoing) the connection between standardized time series and spectral estimators; and
14. (ongoing) the determination of a warm-up period in steady-state simulation using spectral estimators.

In addition, variance estimators feed into the main problem under study, namely, the development of new selection procedures in the presence of stochastic constraints. To this end, we have investigated

1. a selection procedure for comparing a number of alternative simulated systems with a standard, which can be extended to checking the feasibility of systems;
2. new selection procedures using a parabolic elimination boundary;

3. a new procedure to check feasibility in the presence of a stochastic constraint;

4. the performance of a procedure with variance updates on independent and identically distributed data with normal or Bernoulli marginals;

5. new procedures that find a set of feasible or near-feasible systems and then choose the best among those systems in the set in the presence of one stochastic constraint;

6. procedures that find a set of feasible or near-feasible systems among a finite number of simulated systems in the presence of multiple stochastic constraints;

7. the performance of ranking and selection procedures specially designed for steady-state simulation with new variance estimators;

8. developing procedures to check feasibility in the presence of multiple stochastic constraints;

9. (ongoing) presenting the idea of dormancy for constrained ranking and selection procedures, where a system becomes dormant (pausing sampling) when it is found to be inferior to a system whose feasibility is not known yet and the system turns back to competition when the superior system turns out to be infeasible; and

10. (ongoing) developing procedures for constrained ranking and selection in the presence of multiple stochastic constraints with the use of common random numbers.

One Ph.D. student finished her Ph.D. in 2004 with a thesis titled “Ranking and Selection Procedures for Bernoulli and Multinomial Data” and two Ph.D. students finished in 2006 with theses titled “Variance Estimation in Steady-State Simulation, Selecting the Best System, and Determining a Set of Feasible Systems via Simulation” and “Steady-state Analyses: Variance Estimation in Simulations and Dynamic Pricing in Service Systems”. One Ph.D. student finished in 2007 with a thesis titled “Variance Parameter Estimation Methods with Re-Use of Data”. Two Ph.D. students (Vivek Gupta and Christopher Healey) are currently working on topics related to this project.
Findings

From the 1st Year


  Findings: In this paper, we compare the method of batch means to that of independent replications in the context of steady-state simulation output analysis. In particular, is it better to conduct one long run (and use batch means) or to conduct multiple smaller runs (independent replications)? We find that independent replications performs well when the underlying observations are, indeed, in steady-state. Unfortunately, independent replications falls apart in the presence of a mild transient in the output stream. Therefore, we recommend the use of batch means in most practical applications in which steady-state analysis is deemed appropriate.


  Findings: We present and analyze a new output analysis method for steady-state simulation called the replicated batch means method that combines two well known output analysis techniques, namely the multiple replications and batch means methods. We also present new methods for initializing the replications in steady-state simulation. Numerical results show that the replicated batch means method, implemented with a good initialization technique and number of replications, is a promising method for steady-state simulation output analysis.


  Findings: This paper extends findings from Zhu et al. 2004. In particular, we generalize selection procedures with a parabolic boundary; and we consider the more-realistic case involving unknown variances. Selection procedures with a parabolic elimination boundary show better performance over existing selection procedures with a triangular boundary, especially when the number of systems is large and common random numbers are employed. Therefore, when the number of systems is very large — which is the case of interest for this grant — the new procedures seem preferable.


  Findings: We study estimators for the variance of the sample mean from a stationary stochastic process. In particular, we combine two different estimators arising from the method of standardized time series — namely, the so-called area and Cramér–von Mises estimators. We find that the combined estimators have the same low bias as their constituents, but lower variance. We demonstrate the efficacy of the new estimators using exact and Monte Carlo examples.


  Findings: We develop statistically valid fully sequential procedures for the problem of finding systems whose expected performance measures are larger or smaller than a single system —
referred to as a standard — and, if there are any, finding the one with the largest or smallest performance. The procedures are appropriate for use in the simulation environment since they account for (i) unknown/unequal variances and (ii) dependence across systems due to, e.g., the use of techniques such as common random numbers. We find that the new procedures are a great deal more efficient than existing procedures.


  Findings: Given a sequence of functions converging to a realization of the relevant Brownian motion process on the unit interval, we show that the corresponding sequence of boundary-hitting points converges almost surely to the boundary-hitting point for the Brownian motion process.


  Findings: This paper gives an efficient sequential method for computing confidence intervals for the mean of a steady-state simulation process. The technique is based on the method of batch means, and we find that it outperforms other sequential procedures on a variety of stochastic processes.

**From the 2nd Year**


  Findings: The paper examines properties of linear combinations of overlapping standardized time series area estimators for the variance parameter of a stationary stochastic process. The paper shows that the linear combination estimators have lower bias and variance than their overlapping constituents and nonoverlapping counterparts.


  Findings: The paper studies estimators for the variance parameter of a stationary stochastic process that are calculated from a set of overlapping batches. In particular, we present general theory for overlapping variance estimators based on standardized time series area and Cramér–von Mises estimators. The new estimators have the same bias as, but substantially lower variance than, their nonoverlapping counterparts.


  Findings: The paper presents algorithms that require order-of-sample-size work to calculate overlapping versions of standardized time series estimators. Also, the paper shows that the asymptotic distribution of each overlapping variance estimator is closely approximated by
that of a rescaled chi-squared random variable whose scaling factor and degrees of freedom are set to match the mean and variance of the target asymptotic distribution.


Findings: The paper provides a solution to the problem of finding the best among a finite number of simulated systems in the presence of a stochastic constraint on a secondary performance measure. We first find a set that contains feasible or near-feasible systems (Phase I) and then choose the best among those systems in the set (Phase II). The paper contains a procedure for Phase I and another procedure that performs Phases I and II sequentially to find the best feasible system.


Findings: The paper solves the problem of finding a set of feasible or near-feasible systems among a finite number of simulated systems in the presence of a number of stochastic constraints. The paper extends a procedure for Phase I presented by Andradóttir, Goldsman, and Kim (2005) to the case of multiple constraints by the use of the Bonferroni inequality. Moreover, to accelerate the efficiency of the resulting procedure, a procedure is presented that applies screening to linear combinations of the collected observations across stochastic constraints as well as raw observations from each stochastic constraint.


Findings: The paper considers a procedure called $K_N^{++}$ that updates a variance estimate as more observations become available. The procedure is specially designed for a steady-state simulation and proven to be asymptotically valid when common random numbers (CRN) are not employed. The paper presents a modification of $K_N^{++}$ that is asymptotically valid with the use of CRN. The modified $K_N^{++}$ is tested when data are obtained from a terminating simulation (not a steady-state simulation), possibly with the use of CRN. Specific applications include the finding-the-best problem when (i) the data are normal, and (ii) the data are Bernoulli. Experimental results show that the modified $K_N^{++}$ is significantly more efficient than a statistically valid fully sequential procedure without variance update for independent and identically normally distributed data with only slight degradation in the probability of correct selection. For Bernoulli data, it works better than other competitors under some configurations.

**From the 3rd Year**

Findings: We formulate exact expressions for the expected values of selected estimators of the variance of the sample mean arising from a steady-state simulation output process. Given in terms of the autocovariance function of the process, these expressions are derived for variance estimators based on the methods of nonoverlapping batch means, overlapping batch means, and standardized time series. Comparing estimator performance in a first-order autoregressive process and the M/M/1 queue-waiting-time process, we find that certain standardized time series estimators outperform their competitors as the sample size becomes large.


Findings: The paper examines properties of linear combinations of overlapping standardized time series area estimators for the variance parameter of a stationary stochastic process. In addition to materials covered in our paper in the *Proceedings of the 2005 Winter Simulation Conference*, this paper provides more details of the results including theorems, proofs, and experimental results.


Findings: The simulation output analysis method of replicated batch means (RBM) combines good characteristics of the methods of independent replications and batch means. This article gives analytical results for the mean and variance of the RBM estimator for the variance of the sample mean for a class of processes having initial transients with an additive form. We provide succinct complementary extensions of some of the results in the literature. Our expressions explicitly show how the transient function affects estimator performance and suggest that in some cases, the RBM estimator is a good compromise choice with respect to bias and variance. However, care must be taken to avoid an excessive number of replications when the transient function is pervasive.


Findings: It is known that Cramér–von Mises estimators for the variance of the sample mean can sometimes produce negative values. We found that this problem can be overcome by taking batches of observations, forming a variance estimator from each batch, and then averaging. In fact, for all practical purposes, the negativity problem goes away completely after just a few batches.

**From the 4th Year**


Findings: This proceedings paper expands on the earlier results from our Aktaran-Kalaycı et al. (2007) *Operations Research Letters* article (listed in the Findings from the 3rd Year).

Findings: This proceedings paper gives some additional results above and beyond those in the Alexopoulos, et al. (2006) ACM TOMACS paper. Specifically, we look at the performance of replicated batch means under more general assumptions than heretofore considered.


Findings: The paper investigates how to correctly select the best feasible system when there is one constraint on a secondary performance measure. Solving this problem requires the identification and removal from consideration of infeasible systems (Phase I) and of systems whose primary performance measure is dominated by that of other feasible systems (Phase II). The authors consider two approaches, namely, carrying out Phases I and II sequentially and carrying out Phases I and II simultaneously, and provides specific example procedures of each type.


Findings: We estimate the variance parameter of a stationary simulation process using “folded” versions of standardized time series area estimators. Asymptotically as the sample size increases, different folding levels yield unbiased estimators that are independent scaled chi-squared variates, each with one degree of freedom. We exploit this result to formulate improved variance estimators based on the combination of multiple levels as well as the use of batching. The improved estimators preserve the asymptotic bias properties of their predecessors, but have substantially lower asymptotic variances.


Findings: This paper is the proceedings version of the Antonini et al. (2008) *IIE Transactions* paper on the same subject.


Findings: In this paper, we attempt to minimize the variance of an estimator subject to a bias constraint — a goal that differs from that of minimizing mean squared error, in which case there would be no explicit bias constraint. We propose a *bias-aware* mechanism to achieve our goal. Specifically, we use linear combinations of estimators based on different batch sizes to approximately satisfy the bias constraint; and then we minimize the variance by choosing appropriate linear combination weights.

Findings: The experimental study of the paper shows that the performance of ranking and selection procedures can be improved over other procedures in the literature by the use of better variance estimators with good statistical properties.


Findings: This tutorial provides an overview on recent advances made in ranking and selection for selecting the best simulated system and discusses challenges that still exist in the field.

From the 5th Year


Findings: The paper presents an improved jackknifed version of Durbin-Watson type estimators for the asymptotic variance parameter from a steady-state simulation. These new estimators are based on combinations of standardized time series area and Cramér-von Mises estimators. Analytical and empirical examples demonstrate their efficacy in terms of bias and variance.


Findings: The paper studies how to find a set of feasible systems in the presence of multiple constraints. It shows that the Bonferroni inequality can be used to extend procedures for a single constraint to multiple constraints; furthermore, it shows that aggregation and variance updates can help improve the efficiency of the procedures.


Findings: The paper studies the effects of variance estimators with good statistical properties on the performance of ranking and selection procedures for steady-state simulations. The paper also gives a recommendation for the best variance estimator.


Findings: We extend and analyze the class of folded estimators for the variance parameter of a steady-state simulation output process (originally discussed in Antonini et al. 2009 from the 4th year findings). In particular, we derive the asymptotic distributional properties
of the various estimators as the run length increases, as well as their bias, variance, and mean squared error. We also study linear combinations of these estimators, and we show that such combinations yield estimators with lower variance than their constituents. Finally, we consider the consequences of batching, and we see that the batched versions of the new estimators compare favorably to benchmark estimators such as the nonoverlapping batch means estimator.


Findings: We formulate an optimal linear combination of overlapping variance estimators (OLCOVE) to estimate the variance parameter of a steady-state simulation output process. Each variance estimator is computed from the same data set using one of the following methods: (i) overlapping batch means (OBM); or (ii) standardized time series (STS) applied to overlapping batches separately and then averaged over all such batches. Each estimator's batch size is a fixed real multiple (at least unity) of a base batch size, appropriately rounded. The overall sample size is a fixed integral multiple of the base batch size. Exploiting the control-variates method, we assign OLCOVE coefficients so as to yield a minimum-variance estimator. We establish asymptotic properties of the bias and variance of OLCOVEs computed from OBM or STS variance estimators as the base batch size increases. Finally, we use OLCOVEs to construct confidence intervals for both the mean and the variance parameter of the target process. An experimental performance evaluation reveals the potential benefits of using OLCOVEs for steady-state simulation analysis.
As a Business Analyst, requirement analysis is the most important part of your job. It will help you determining the actual needs of stakeholders. At the same time, enable you to communicate with the stakeholders in a language they understand (like charts, models, flow-charts,) instead of complex text. A requirement analysis has a specific goal. Specific input. Specific output. Uses resources. Has a number of activities to be performed in some order. May affect more than one organization unit. Creates value of some kind for the customer. Requirement Analysis Techniques. Requirement analysis t...