I. GENERAL COURSE INFORMATION

VIRGINIA TECH
NORTHERN VIRGINIA CENTER
GRADO DEPARTMENT OF INDUSTRIAL & SYSTEMS ENGINEERING

ISE 5144 PERFORMANCE AND PRODUCTIVITY
MEASUREMENT AND EVALUATION:
ISE 6144: RESEARCH IN THE DESIGN OF PERFORMANCE MEASUREMENT SYSTEMS

Fall 2009
Dr. K. Triantis

Scope: The objective of this course is to present principles leading to the design of process-based yet integrated (i.e., that include multiple dimensions) performance measurement systems and within this context to introduce concepts leading to the advancement of measurement science in management systems engineering. In this course, the functions of benchmarking (assessing) current performance levels and planning (designing) for future performance improvement interventions will be stressed. Modeling approaches of performance measurement including index numbers, data envelopment analysis (DEA), statistical production frontiers, multi-attribute performance indices, system dynamics, and program evaluation will be introduced. Concepts will be demonstrated by completing a research/modeling project.

Justification: The effective management of performance (operational and strategic) impacts the long-term survivability of organizations and systems. Therefore, it is necessary to design (or plan for) the development of the organization's (system's) performance management capabilities. In this course, the organization's (system's) performance is being viewed as a multi-dimensional entity involving elements such as, profitability, quality, productivity (efficiency), effectiveness (outcome), innovation, quality of work life among others. Over the last six decades, within the scope of operational performance management, productivity and efficiency performance has received extensive attention by engineers, economists, operation research analysts, and managers. Engineers need to be aware of the productivity and performance management approaches proposed in the literature. These approaches offer a wide range of choices for the effective design of performance and process improvement interventions and address significant technological and societal issues.

Prerequisites: This course will use as part of its curriculum probabilistic/statistical, math programming concepts, and systems thinking modeling and simulation approaches. Students should be conversant with the basic principles of probability and statistics (STAT 5004, STAT 5614 or the equivalent) and math programming principles (ISE 5104 or ISE 5405).

Graduate Honor System: The Virginia Tech Graduate Honor System is in effect for this course and all assignments shall be subject to the stipulations of the Graduate Honor Code which is located online at http://ghs.grads.vt.edu/. Please take the time to read this document and make sure that you understand your responsibilities as a student. Be informed of the potential violations of the Graduate Honor Code: Cheating, Plagiarism, Falsification, and Academic Sabotage. Plagiarism or other forms of violations of the Graduate Honor System will not be tolerated. Take time to read how to avoid plagiarism which is located online at http://ghs.grads.vt.edu/student/avoiding.html. Please contact the instructor at any time if you have questions about the Graduate Honor System at Virginia Tech.
Major Course Concepts and Techniques

1. Process description
2. Organizational system analysis
3. Specification of inputs and outputs/expert opinion elicitation
4. Production axioms
5. Theory of the firm
6. Performance based decision making and improvement
7. Group modeling
8. Data envelopment analysis
9. Stochastic frontier analysis
10. Engineering applications of performance measurement
11. Distance and directional functions
12. Performance scores, targets and peers
13. Virtual versus real world
14. Model validation and verification
15. Uncertainty
16. Dynamic performance measurement
17. Outcome based measurement
18. Policy and best practice evaluation
19. Big-picture thinking
20. Measurement science

Educational Objectives

There are four broad educational objectives that relate to performance modeling that need to be developed for an organization. These include: qualitative skills (everyone), modeling skills (a few), facilitation skills (a few), and hard-to-measure life changing outcomes (hopefully many). The course will focus primarily on the first two set of educational objectives hoping to inspire continuous lifetime learning and research.

Qualitative Educational Objectives

1. Develop an appreciation for the design of performance measurement systems;
2. Define a problem, a system where the problem is manifested and hypothesize the structure of the system that is responsible for the problem;
3. Use process flow diagrams (transformation or production function);
4. Use organizational system analysis;
5. Define inputs (resources) and outputs (products and services) that represent production systems;
6. Identify the physical, organizational, decision-making structures within systems;
7. Identify structural (infrastructure) and environmental (socio-economic) variables that impact production (operational) performance;
8. Identify critical variables in a system and their relationships (statistical and causal) to other variables;
9. Define the production behavior of systems;
10. Understand how to elicit tacit knowledge;
11. Identify peers and performance targets;
12. Identify best practices;
13. Define a performance improvement policy;
14. Work within a group-modeling paradigm;
15. Complete model verification and validation;
16. Test models using software (SAS, EXCEL SOLVER, MATHEMATICA, other).

**Modeling Educational Objectives**

1. Develop very specialized modeling skills that will enable the modeler to build and code data envelopment analysis models;
2. Build user interfaces to the DEA models for easy input of production data and interpretation of DEA model results;
3. Use and integrate the DEA models with additional quantitative frameworks grounded in fuzzy set theory (fuzzy DEA, fuzzy clustering), statistical theory (bootstrapping and robust methods (high breakdown procedures)), economic theory (directional and distance functions), system dynamic theory, math programming theory (validation and verification), systems theory, and organizational theory;
4. Interpret the results of data envelopment models and build the resulting decision support systems;
5. Become in-house trainers for the design of integrated performance measurement systems.

**Facilitation Educational Objectives**

1. Develop facilitation skills that can enable individuals within the organization to lead in-house group modeling initiatives.

**Hard-to-measure Life Changing Objectives**

1. Experience the power of learning when designing integrated measurement systems.

**Professor**

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**GA**

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Office Phone: 703-538-3765  
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**Visiting Lecturers**

Professor Chris Parmeter  
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Ms. Yueqin Zhao, Ph. D. candidate  
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e-mail: yueqinz@vt.edu
Student Services

Ms. Hannah Swiger
Grado Department of ISE
250 Durham Hall
Office Phone: 540-231-5586
e-mail: hsswiger@vt.edu

Class Meeting Time

Wednesday: 4:00 p.m. - 6:45 p.m.

Required Notes

Triantis, K., ISE 5144: Performance Productivity Measurement and Evaluation, Class Notes, Fall 2009

Discussion Case Studies


Required Course Reading Materials


9) Sink and Tuttle, Planning and Measurement in Your Organization of the Future, Industrial Engineering and Management Press, chapter 4 (pp. 75-116), 1989.


Reference Textbook


Other Reference Textbooks


**Supplemental Course Reading Materials and Advanced Topics**


Notes:

1. The required course reading materials will be posted on Blackboard.
2. The in-class presentation materials will be posted on Blackboard.
3. Some of the supplementary readings will be posted on Blackboard.
4. Go to amazon.com and order the discussion case studies.
5. The detailed procedure to order the book is:
   1. Go to http://www.nvc.vt.edu/
   2. Go to the link for Book store on left hand side menu http://www.bkstr.com/webapp/wcs/stores/servlet/StoreCatalogDisplay?langId=-1&storeId=101404&demoKey=d&catalogId=10001
   3. Go to FIND YOUR TEXTBOOKS AND COURSE MATERIALS http://www.bkstr.com/CategoryDisplay/10001-9604-101404-1?demoKey=d
   4. Enter information about the term, department, course and section (for the DEA textbook the section number is 96161)
   5. Submit
   6. Add to cart and go to cart
### II. OUTLINE OF TOPICS AND READINGS

#### Program of Study

<table>
<thead>
<tr>
<th>Session</th>
<th>Topic</th>
<th>Assignment</th>
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<tbody>
<tr>
<td>8/26</td>
<td>Review of Course Outline; High Performance Systems; Performance Management; System Performance Lab (SPL); Formation of Project Teams</td>
<td>Units #1, #2, #3 Formation of project teams</td>
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<tr>
<td>9/2</td>
<td>Why Productivity Matters; The Productivity Management Process; Organizational Systems Analysis; Productivity Measurement Process; Productivity Basics; No-Nonsense Guide to Measuring Productivity; Data Envelopment Analysis Tutorial; Project Issues and Approach.</td>
<td>Units # 4, #5, #6 Required Material Readings: #1 (Chapter 2) #9 (Chapter 4) #10 Case Study #1 Final Formation of project teams</td>
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<tr>
<td>9/9, 16</td>
<td>Theory of the Firm.</td>
<td>Unit #7, Systems Modeling: Part 1 Systems Modeling: Part One Required Material Readings: #7 (Chapter 4); Problem Definition and Process/ System Description Presentation (9/9)</td>
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<tr>
<td>9/23, 30</td>
<td>Efficiency Measures; Data Envelopment Analysis; Issues in DEA; Software for DEA Analysis</td>
<td>Units #8, #9, JORS Reading Required Material Readings: Chapters 1-3 from Cooper, Seiford and Tone; #2, # 3 (Chapters 1, 2) Project proposals and Literature Review Presentations are due on 9/23); Constrained Optimization Assignment Due on Session 6 (9/30) Ms. Bhatkoti’s Presentation (9/30)</td>
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<tr>
<td>Date</td>
<td>Topic</td>
<td>Reading</td>
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<tr>
<td>10/7</td>
<td>Statistical Production Frontiers; Systems Modeling: Part 1</td>
<td>The New Productivity Challenge</td>
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<td>Systems Modeling: Part 1</td>
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<tr>
<td>10/14</td>
<td>Statistical Production Frontiers</td>
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<td>10/21</td>
<td>Midterm Exam</td>
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<td>10/28</td>
<td>Index Number Approach. The Graig &amp; Harris Model; The Bela Gold Approach; The Multifactor Productivity Measurement Model; Multi-criteria Performance/ Productivity Technique</td>
<td>Unit #12, #13</td>
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<td></td>
<td>Required Material Readings: #4, #5, #6, #8 (chapter 5)</td>
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<td>DEA Results and Interpretation Presentation</td>
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<td>11/4</td>
<td>Engineering Applications of DEA</td>
<td>Unit #14, Satellite Scheduling, Road Maintenance, Project Selection</td>
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<td>Satellite Scheduling, Road Maintenance, Project Selection; Meta Frontiers; Bootstrapping</td>
<td>Required Material Readings: #13</td>
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<td>Required Material Readings: #13</td>
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<tr>
<td>11/11</td>
<td>The Assessment of Technical Efficiency Using Fuzzy Set Theory</td>
<td>Unit #15</td>
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<td>11/18</td>
<td>Dynamic Efficiency</td>
<td>Units #16, #17, Dynamic Service Performance</td>
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<td></td>
<td>Why Some Factories are More Productive than Others;</td>
<td>Required Material Readings: Case Study #3, Research Projects Due on 11/18</td>
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<tr>
<td>12/2</td>
<td>Outcome Performance; Network Model and its Applications</td>
<td>Unit #18c</td>
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<tr>
<td>12/9</td>
<td>Final Project Presentations</td>
<td>Ms. Zhao’s Presentation</td>
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III. PROJECT DESCRIPTION, HOMEWORK AND CASE STUDIES

RESEARCH PROJECT DESCRIPTION

The objective of the project is to implement and integrate the concepts and techniques presented in this course and to research in-depth a topic and modeling issue in performance measurement.

The first and most critical task is to select an organizational process that will be analyzed in terms of its productivity (efficiency) performance. This process should be one that produces a clearly defined output(s) and one that has clearly definable boundaries. It should be one that has performance/efficiency goals, uses inputs (resources), produces outputs (products/services), achieves outcomes, uses a technology that can be represented by its value-adding activities, and has feedback mechanisms. It should also be one for which input (resource) and output (product/service) data can be accumulated.\(^1\) It is recommended that this process be work-related but it doesn't have to be.

A generic outline for the project is presented subsequently. This outline delineates the tasks that need to be accomplished for the project. It is expected that the final project document will follow this outline format. Weights indicate the importance of each section for the final grade of the project.

1.0 Introduction (5%)


1.2 The Research Hypothesis or hypotheses; Critical research and project questions.

1.3 Project Objectives and Purpose of Model

1.4 An overview of the Methodologies to be Used (DEA (necessary), Multi-Factor Productivity Method (optional), Statistical Production Frontier (optional), Fuzzy DEA (optional), Dynamic Modeling (necessary).

1.5 Organization of the Report

2.0 Literature Review (15%)

2.1 Measurement Issue (for example, the measurement of pollution prevention) (what?)

2.2 Modeling Issue (for example, the use of directional distance functions) (how?)

2.3 Contribution to Performance Measurement (for example, the inclusion of undesirable outputs in DEA)

\(^1\)Sensitive organizational data should be protected and in the context of this course, data will be treated as confidential.
3.0 Process Definition (15%)

3.1 An overview of the process (with a clear definition of the process boundaries)

3.2 Productivity mission/goals

3.3 Inputs (resources used)

3.4 Transformation (value-adding) activities that define the technology of the process

3.5 Outputs (products and/or services produced)

3.6 Outcomes

3.7 Process feedback mechanisms

3.8 Customers (Internal/External)

3.9 Vendors (Internal/External)

3.10 Other Important environmental and managerial factors

4.0 Input and Output Variables (15%)

4.0 Definition of the input variables (including units of measurement; classification (controllable or not, environmental or not, infrastructure or not); uncertainty in measurement)

4.1 Definition of the output variables (including units of measurement classification (controllable or not, environmental or not, infrastructure or not); uncertainty in measurement)

4.3 Input/Output variables for which no data are available; Implications for performance measurement.

4.4 The Input/Output data

5.0 DEA Efficiency Measurement (25%)

5.1 DEA Formulation

5.2 The DEA efficiency scores, performance targets, and peers

\(^2\)A flow-process diagram that clearly delineates the inputs, transformation activities and outputs is required for the final document.

\(^3\)The input/output variable definitions should accurately represent the underlying production technology.

\(^4\)For each input/output one can accumulate and use quantity or value data. If you have the capability of gathering both the quantity of each input/output and its unit cost or price, this will prove useful when implementing the DEA and the dynamic efficiency approaches.

\(^5\)It would be good to accumulate at a minimum thirty data points for your productivity/efficiency analysis.
5.3 The evaluation of the DEA efficiency scores (validation and verification)\(^6\)

6.0 Systems Modeling: Qualitative Model (10%)

6.1 Problem Definition Revisited (performance issues; policies; model purpose; system-subsystem definition; time horizon; endogenous/exogenous excluded variables; reference modes)

6.2 Key Dynamic Hypotheses

6.3 Qualitative Model\(^6\)

7.0 Policy Analysis (Efficiency/Productivity Improvement) (10%)

7.1 DEA based Policy Analysis (operational improvement goals and strategies)

7.2 Qualitative Model Policy Analysis

8.0 Conclusions (5%)

8.1 How do the results relate (support) the research hypothesis and research questions?

8.2 Future performance/efficiency issues

8.3 Assessment of the project

Appendices

Developed Software Code

Iterations of the Qualitative System Dynamics Model

Project Deliverables and Due Dates

9/9 Problem Definition and Process Description Presentation
9/23 Project Proposal: it is expected that each team will submit sections 1, 2, and 3 of this outline so as to obtain feedback; Literature review presentation.
10/7 Input/Output Data Presentation
11/4 Qualitative Model Presentation
11/18 Final Project due.

The grading of the whole project will take place at the end of the semester. It is mandatory that the final project document be typed and double-spaced. The final document for the project is due on November 18.

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\(^6\) Determine the root causes of inefficient and efficient behavior. Describe the main production characteristics.
Constrained Optimization Problem Set

Please answer the following questions. Show all of your work and write as clearly as you can.

(10%) 1) Prove that the MP curve intersects the AP curve at its maximum point.

2) Consider the following production function

\[ q = A x_1^2 x_2^2 \quad - \quad B x_1^3 x_2^3 \]

(5%) a) Find \( AP_{x_1}, MP_{x_1} \)

(5%) b) Find the maximum value of \( AP_{x_1} \).

(10%) c) Find the output elasticity with respect to \( x_1 \)

3) Consider the following production function

\[ q = AK^\alpha L^\beta \quad where \quad A > 0, 0 < \alpha < 1, 0 < \beta < 1 \]

(5 %) a) Find \( MP_K, MP_L \). Show that they are both positive.

(5%) b) Find the output elasticity with respect to \( L \) and \( K \).

(5%) c) Find the value of technical substitution and show that its value depends on the \( K/L \) ratio and is independent of the output level.

(5%) d) What do the conditions of concavity suggest?

(5%) e) Derive the equation of an isoquant.

(5%) f) Find the elasticity of substitution.

4) A theorem exists in production economics (Shephard (1953)) that states that the technology of an organization can be represented by its production or cost function under cost minimizing conditions. For each production function there exists a unique cost function and vice versa.

Assume that your production function is of the form:

\[ q = \prod_{i=1}^{n} A x_i^{\alpha_i} \quad (1) \quad where \quad \alpha_i > 0 \quad and \quad \sum_{i=1}^{n} \alpha_i = r. \]

You are also given a set of input factor prices \( r_i, i = 1, 2, 3 \) for each of the factor inputs \( x_i, i = 1, 2, 3. \)

(20%) a) Using the constrained cost minimization hypothesis derive the factor demand equations; \( x_i = f (q, r_1, r_2, r_3) \)
For example,

\[ x_2 = q^\alpha A^\frac{1}{\alpha_3} \left( \frac{\alpha_1}{r_1} \right)^{\frac{a_1}{r}} \left( \frac{\alpha_2}{r_2} \right)^{\frac{a_2+a_3}{r}} \left( \frac{\alpha_3}{r_3} \right)^{\frac{-a_3}{r}} \]

(20%) b) Then derive the equivalent cost function to the production function (1), i.e.,

\[ C = b + q^\alpha A^\frac{1}{\alpha_3} r^\frac{1}{\alpha_3} \prod_{i=1}^{3} \frac{r_i^\alpha}{\alpha_i} \prod_{i=1}^{3} \alpha_i^\frac{\alpha_i}{r} \]

where b is a constant.
IV. COURSE GRADING

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<table>
<thead>
<tr>
<th>Grade Distribution</th>
<th>% of Final Grade</th>
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<tbody>
<tr>
<td>Midterm Exam</td>
<td>30</td>
</tr>
<tr>
<td>Research Modeling Project (Team Effort)</td>
<td>50</td>
</tr>
<tr>
<td>Constrained Optimization Assignment</td>
<td>10</td>
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<tr>
<td>Class Participation</td>
<td>10</td>
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</table>

Since 50% of the course grade is a function of a team effort, it is imperative that the team members collaborate in a spirit of trust and should equally share in the burden of each of the assignments. In the case that a team member is not working well within the team, each remaining member can evaluate the contribution of the "troublesome" team member. This evaluation should be submitted to me in writing prior to November 18. These evaluations will be confidential.

Evaluation of a "Non-Cooperating" Team Member
(Maximum Discretionary Points: 20)

<table>
<thead>
<tr>
<th>Contribution to Class Project and Case Studies</th>
<th>Penalty</th>
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<tbody>
<tr>
<td>Two-Thirds of the Required Effort</td>
<td>5 points</td>
</tr>
<tr>
<td>Half of the Required Effort</td>
<td>10 points</td>
</tr>
<tr>
<td>A Third of the Required Effort</td>
<td>15 points</td>
</tr>
<tr>
<td>No Effort at All</td>
<td>20 points</td>
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Grading Policies:

Class participation: Throughout the semester you will be called upon to contribute to the class discussion. If you are called upon and do not respond because you are not in class more than three times during the semester you will receive one letter grade less than you would otherwise receive. If you are called upon and do not respond because you are not in class more than four times during the semester you will receive two letter grades less than you would otherwise receive.
**Project:** The final document for the project is due on November 18. Projects handed in late will forfeit 20% of the project grade. Projects will not be accepted after November 18.

**Re-evaluation Requests:** All re-evaluation requests of any graded assignments, midterms, and projects should be communicated no later than one week after the graded assignment has been initially returned otherwise they will not be considered.

All of these grading policies will be strictly enforced.