USING SIMULATION TO ENHANCE INDUSTRIAL ENGINEERING TECHNOLOGY EDUCATION

David F. Caudill [1]

Abstract – Currently, at Southern Polytechnic State University new methods to improve learning outcomes are being explored in both the graduate and undergraduate programs. One such method that shows great promise is the use of interactive games to supplement classroom lectures. In these games, real-world industrial scenarios are simulated, students are allowed to make process improvement decisions and the impacts of their decisions are provided as feedback. Students are allowed to work in groups or alone to compete for the best process improvements. Games have the potential to not only let students get a hands-on feel for decision making but also have the potential to interject new enthusiasm and interest into the classroom experience. Two simulation models currently being used in Design of Experiments and Black Belt courses will be explained. The Black Belt model utilizes ARENA software to model a simplified production environment. Students can make machine adjustments, change input levels and prioritize routing in the process. The model is then executed for one week of production and the student gets a detailed analysis of the impact of their decisions on scrap, production and profit.

Keywords: Simulation, Education, Industrial Engineering Technology

BACKGROUND

Objectives

Engineering educators strive to provide an education that is useful in solving real-world problems. To meet this objective, it is important to seek out new methods and new technology that will expose the students to real-world uses of engineering principles and methods. One new methodology that is presenting itself as a valuable classroom aid is simulation and gaming. In much the same way that pilots and astronauts train for real-world situations using flight simulators, students can use process simulators to experience real-world situations and enhance their engineering technology education. Based on their responses during the simulation, actions can be analyzed and suggestions made to improve student responses. Additionally, the instructor can use the results to determine if the subject matter is adequately mastered or if additional work is needed.

Adult learning is most effective when the adult learners are involved in the learning experience, and are not merely passive recipients of information [1]. Simulations modeled from actual processes provide the opportunity for this type of involvement without leaving the classroom.

What is Computer Simulation?

Computer simulation refers to methods for studying a wide variety of models of real-world systems by numerical evaluation using software designed to imitate the system's operations or characteristics, often over time [2]. Simulation began in the 1960's and 1970's but has only in recent years come into its own as a practical industrial

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engineering tool. The advent of faster computers and more usable software, such as ARENA, has allowed problem solvers to model processes in much less time and to run iterative scenarios much faster.

In general, the approach for applying simulation to real-world problems is as follows:

DEFINE PROCESS ⟶ MODEL SYSTEM ⟶ ITERATE SOLUTION

Its application in education is similar but not necessarily in the same sequence. The instructional model must be built first and then used to establish the process definition. The model can be patterned after any industrial process or generated from known system characteristics but must be done in advance by the instructor. Problems can then be introduced into the simulated process. The student subsequently exercises the model to define the process and identify the problem. Corrective actions are implemented by the student by means of model changes. If the actions are appropriate, the results should show improvement. If not, additional iterations may be needed. For the student it becomes an iterative search for the best results. In this search, the student not only becomes involved in the learning experience but also gains greater understanding of the underlying technical principles.

Additionally, since random variation can be introduced to the simulated model, the student becomes familiar with the fact that most real-world processes are not deterministic but are probabilistic in nature.

One concern should be noted on the use of simulation. Since the simulation model is a simplification of the real-world process by necessity, using its results to infer about the real-world process must be done cautiously [3].

The whole learning process that occurs while using simulation can be summed up in the saying attributed to Confucius,

> "I hear and I forget. I see and I remember. I do and I understand."

In education, the ultimate goal should be to gain "understanding". Simulation allows the student to "do" and to "understand".

Benefits and Problems

The benefits of simulation are summarized by Dumblekar [4]. "Simulations would therefore be useful to learn about complex situations (where data is incomplete, unreliable or unavailable), where the problems are unfamiliar, and where the cost of errors in making decisions is likely to be high. Therefore, simulations offer many benefits. They accelerate and compress time to offer foresight of a hazy future. They are experimental, experiential, and rigorous. They promote creativity amongst the participants, who develop a shared view of their learning and behaviors."

Some problems also are inherent:

1) Typically, although simulations can be good learning tools, they may not be very useful as grading tools. Since the simulation is typically a search technique, the understanding results as a by product of the search and is not necessarily reflected in the absolute final improvement in the objective. For example, the simulation that will be described later in this paper uses profit as the objective. Students that achieved the maximum profits may have been helped by initial decisions made without complete understanding of the process. A student who generated less total profit improvement may have learned just as much as those who obtained higher profit improvements.

2) Some students do not adapt well to the simulation way of learning. They prefer the typical lecture style of classroom experience. Since this method typically requires more group interaction, some students seem intimidated by the whole experience.

3) The professor is responsible for producing a simulation model that teaches the subject. Clear cause and effect must be apparent to the student. Robustness must be inherent in the model. Other causal factors should be minimized. Unexpected, unexplainable results may make the experience counter-productive.

BLACKBELT QUALITY IMPROVEMENT SIMULATION

Simulation Overview

This simulation was created using ARENA [5] software for Extended University classes leading to the Black Belt certification. The overall objective is to allow students an opportunity to apply basic sampling techniques to define and improve an existing electronic process. The students' changes to the system will be reflected in varying profits for the electronic line of business for a simulated week of production. The students are divided into teams. Each team runs its own company independent of other teams' company/decisions. Progress is measured by improved profits. The first weeks' results will be identical for each team. Each team will be allowed to make various production and quality decisions that hopefully will improve profit for the product line. Seven to nine decision opportunities will be provided in which changes can be made to interdependent process characteristics. Changes will then be applied and the results determined by the simulated production model. Since this is a process with inherent variability, identical output cannot be guaranteed beyond the first week.

Assumptions

-Teams are to work independently.
-Teams may use any Black Belt analysis techniques and are encouraged to use the computer for that analysis.
-Since inventory space in the clean environment is at a premium, weekly overproduction is strongly discouraged. It will be assumed that any weekly overproduction incurs the cost of raw materials but is disposed of at the end of the week with no credit for its sale.
-Any weekly demand not supplied is lost.

Company Description

The company is the maker of two electronic components; the 917AT which is used in missile guidance systems and the 602A which is used in automotive GPS positioning systems. Even though the company makes various other electronic components, only the two products above are considered to be under the control of the Black Belt quality management team. As a participant in this game, each team will be asked to examine weekly results and suggest changes for the upcoming week. The company will judge its success purely on estimated profit of its process. Although these do not comprise the total manufacture process, there are five main areas of concern in this process:

1) 917AT components are placed on the printed circuit board by three automated placement machines. The time to complete the placement and soldering of each 917AT board is approximately 3 minutes. Each of these machines depends on a unique process whereby individual components are fed to it by support processes that are unique to that machine. It can be assumed that the characteristics of the loading machines do not change significantly over the week of production.

2) 602A components are placed on the printed circuit board by two automated placement machines. The time to complete the placement and soldering of each 602A board is approximately 3 minutes.

3) Both 917At's and 602A's are then routed to an initial test area where they are tested for resistance of the xm sub-path and circuit signal gain. Both of these have upper and lower specifications which determine whether each unit is to be scrapped or is to proceed in the process. The specifications are as follow:

Component	Resistance		Gain	
	Low	High	Low	High
917AT	8	11	2.2	2.8
602A	8	11	5.5	6.7

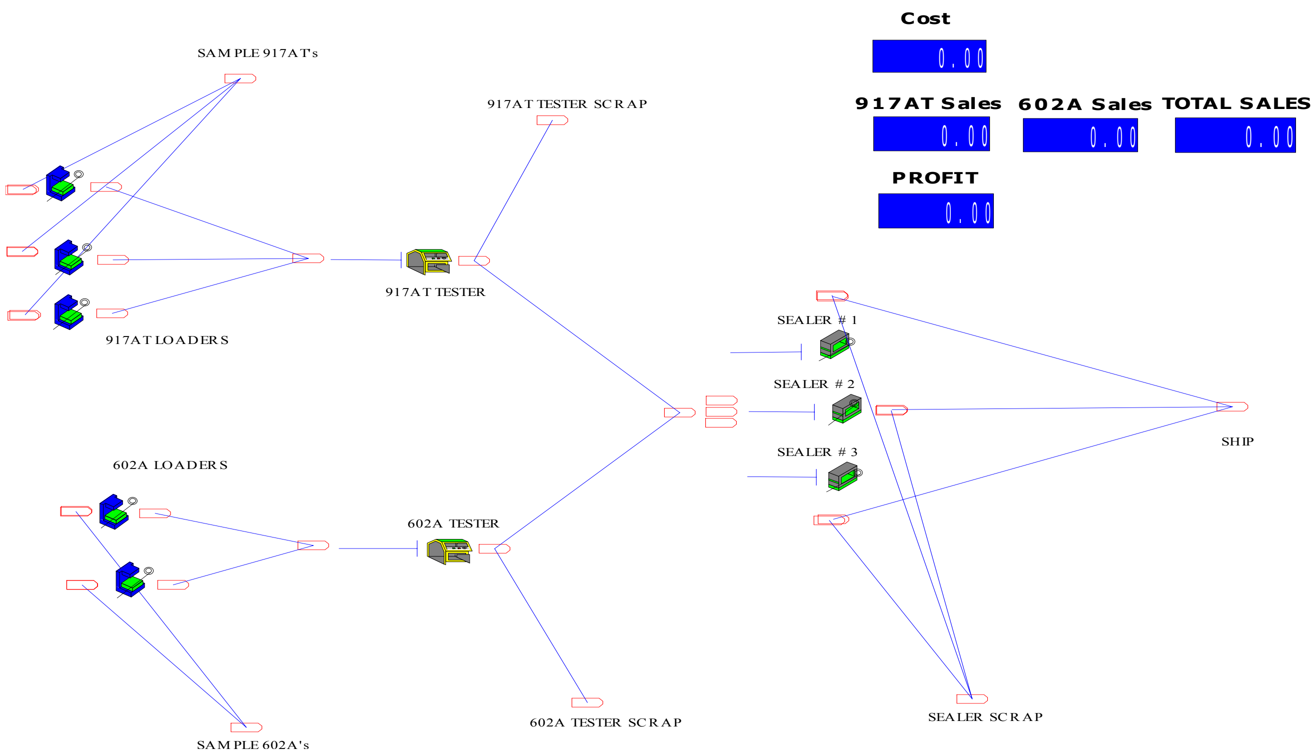
The 917AT test series requires approximately 1.2 minutes. The 602A test series requires approximately 2.1 minutes.

4) Passing units of either type are then sent to a sealing machine for encapsulation. There are three encapsulating machines that have their own characteristics and cycle times. The seal cycle (cycle time) is an automated process but can vary depending on the characteristics of the unit being sealed. On the average the encapsulation cycle requires about 1.50 minutes per unit.

5) Sealed units are then manually checked and any with poorly encapsulated units being scrapped.

6) Good units are shipped (up to the amount demanded).

ARENA PROCESS OVERVIEW



Quality Management Team's Responsibility

In a nutshell, the teams' objective is to make as much money as possible. Currently, the LOB cost and sales values are assumed to be as follows:

Component	LOB Cost	LOB Sale Credit
917AT	30	50
602A	20	40

The weekly demand is a constant 1500 units of 917AT and 1000 units of 602A.

The quality team can decide/request the following:

1) Number of units to be produced by each loading machine. Each loading machine running at full capacity can produce about 800 units regardless of type (917AT or 602A). Some variability in capacity does exist due to some variability in the loading cycle time.

2) The mean resistance and/or gain of any loading machine's output can be adjusted. The standard deviation is not adjustable. To request a change identify the machine(s) to be adjusted and the increase or decrease desired in the mean for that machine. Example: Increase the mean resistance for 917AT Loader # 1 by .20.

3) Sample size as a percentage of one or more loading machine(s)'s output. It should be noted that sampled units are destroyed in the testing and are lost from production. A sampled unit will have both its resistance and gain recorded for your analysis.

4) Each week the quality management team will be given information on each unit that failed the testing operation for analysis.

5) Percentage of units within normal variability that are routed to each of the sealing machines. Each week an analysis of all scrap units from the sealer operation will be available to the quality management team for analysis.

Simulation Game Output

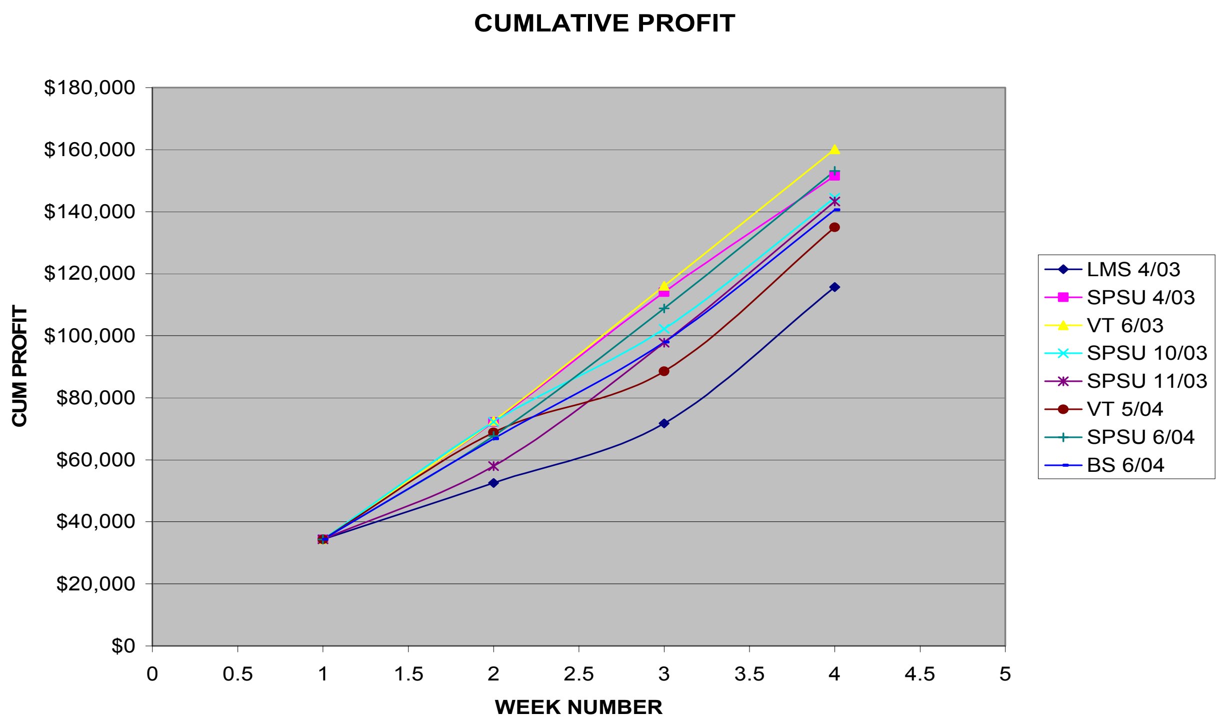
FINANCIAL DATA	SALES	COST	PROFIT
917AT 1	23300.00	15000.00	8300.00
917AT 2	21200.00	15000.00	6200.00
917AT 3	21850.00	15000.00	6850.00
917 Over Demand	0.00		
602A 1	15800.00	10000.00	5800.00
602A 2	17200.00	10000.00	7200.00
602 Over Demand	0.00		
TOTAL	**$ 99350.00**	**$ 65000.00**	**$ 34350.00**

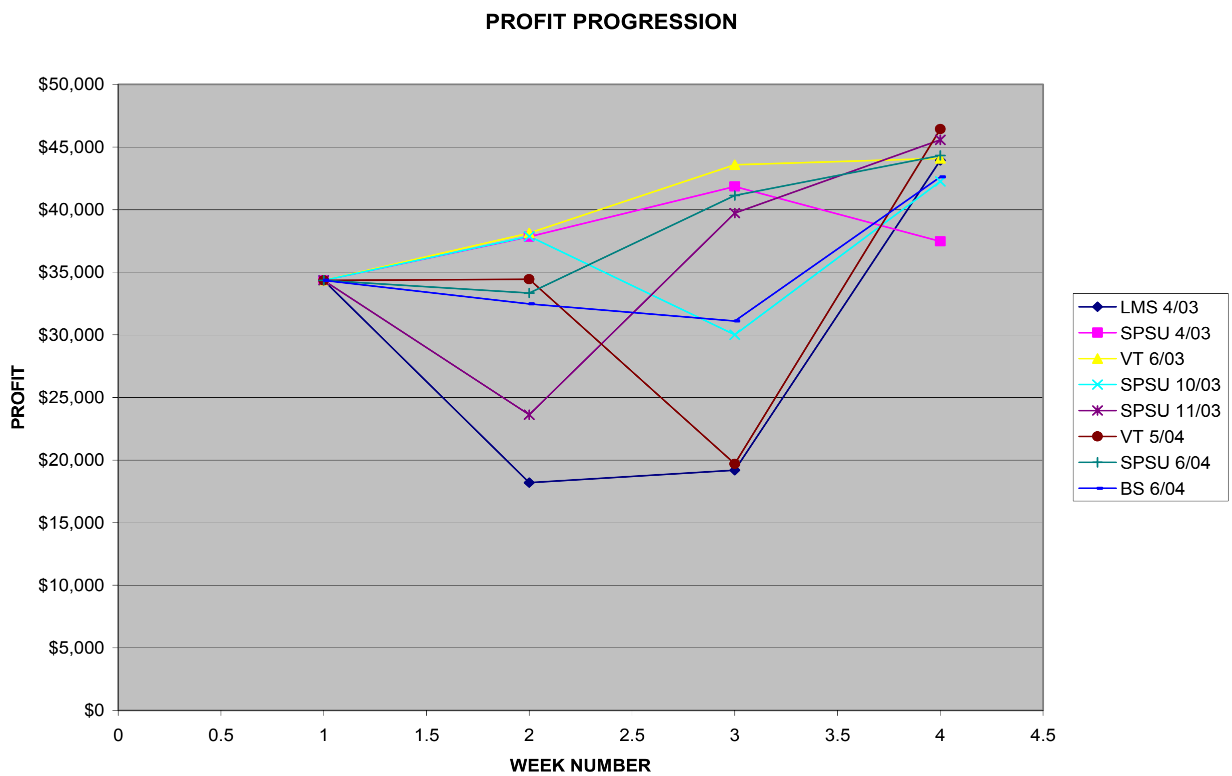
PRODUCTION DATA	QUANTITY	SAMPLE	LOADER Q	AVAILABLE
917AT 1	500	0	0	500
917AT 2	500	0	0	500
917AT 3	500	0	0	500
602A 1	500	0	0	500
602A 2	500	0	0	500

TEST SCRAP DATA	QUANTITY	SHIP DATA	QUANTITY
917AT 1	11	917AT 1	466
917AT 2	58	917AT 2	424
917AT 3	45	917AT 3	437
602A 1	80	602A 1	395
602A 2	33	602A 2	430

SEALER DATA	IN	QUEUE	SCRAP	OUT	BUSY
SEALER X	747	0	67	680	0.4636
SEALER Y	796	0	26	770	0.4969
SEALER Z	730	0	28	702	0.4540

Student Results For Eight Black Belt Classes 2003 Through 2004





Analysis of Student Progress

In the “Profit Progression” results above it can be seen that the ARENA model is very robust. If slightly less than optimal decisions are made the resulting profits show significant drops. In some instances other than those above, negative profits have been achieved. As a result of this robustness in the model, students are able to readily see the impact of their decisions. Often students tend to make the following inappropriate decisions, all of which present teaching opportunities in the classroom:

1) Make fairly significant production and/or machine adjustment changes in the first stages prior to defining the process through sampling.

2) Fail to realize that there is a law of diminishing returns at work as the “low hanging fruit” is harvested.

3) Fail to realize that fine tuning changes make be lost in the random noise of the system.

4) Fail to recognize that over-sampling reduces profit with little improvement in sampling confidence.

5) Have a reluctance to take error prone machines out of service.

Looking at the cumulative profit, there is an unusual factor evident. Regardless of the large variation in individual week’s profits, the cumulative profit at the end of the four weeks of simulation and decision making is remarkably constant. It is the author’s hypothesis that using the model really does force student understanding as the weeks progress and produces better decisions along the way. If this is true, learning/understanding can be attributed to the students’ simulation experience.

DESIGN OF EXPERIMENT MACHINE

Simulation Overview

Although much less complex than the model above, a model to aid the teaching of basic Design of Experiment (DOE) theory and application is shown below. This model represents a molding machine outputting a product which must have controllable plasticity. The students are given the results of a ”brain-storming” session that suggests mold temperature, mold pressure, raw material additive and mold type may be factors influencing plasticity of the final molded product. Normal operating ranges of these input variables are made available. The student is then told rather abruptly: “It is your responsibility to analyze this machine and determine which of the input factors are important as well as develop a strategy for controlling the final product plasticity by adjusting the input factors.” This represents a classical application for DOE which most recognize immediately. However, the actual initiation of the study, randomizing test runs, considering “outlier” results, performing the analysis, drawing conclusions, applying results to achieve plasticity objectives are not well understood. This model allows the student to plan the experiments, exercise the machine under various input settings and record the results for DOE analysis. The machine can be programmed for more/less randomness as well as linear and non-linear output.

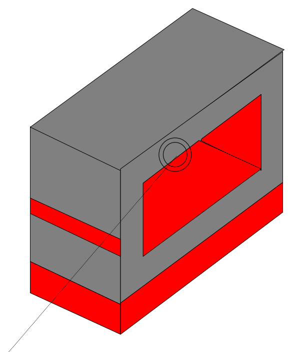
Analysis of Student Progress

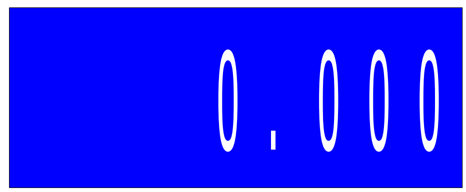
Once the shock of “what do we do” wears off , the students find this simulation very informative and enjoyable. They consistently have been able to run the complete DOE analysis and have been very adept at applying the results to control plasticity. The experience gives them a complete end-to-end look at DOE application and its usefulness, a better understanding of how non-causal random variation affects the results and how to recognize potential “outlier” results. Since this can be done in teams or as individuals, further team interaction skills can also be taught. To date, no comparative analyses of the game have been done. However, this game has the potential to help assess teaching effectiveness and teaching methodology.

ARENA MOLDING MACHINE (PLASTICITY) OVERVIEW

Ranges:

Temperature 300-700 F
Pressure 100-300 psi
Additive 2 to 10 grams
Mold Type 1 or 2





PLASTICITY

Design of Experiment Output Example Results from DOE KISS [6]

Factor	A	B	C	D				
Row #	**Temp.**	**Press.**	**Add.**	**Mold**	**Y1**	**Y2**	**Y bar**	**S**
1	-1	-1	-1	-1	17.06	17.58	17.32	0.367695526
2	-1	-1	-1	1	17.64	16.91	17.275	0.51618795
3	-1	-1	1	-1	22.41	21.7	22.055	0.502045815
4	-1	-1	1	1	22.21	22.35	22.28	0.098994949
5	-1	1	-1	-1	10.04	10.05	10.045	0.007071068
6	-1	1	-1	1	9.99	10.41	10.2	0.296984848
7	-1	1	1	-1	12.74	13.43	13.085	0.487903679
8	-1	1	1	1	13.54	12.87	13.205	0.473761543
9	1	-1	-1	-1	26.06	26.5	26.28	0.311126984
10	1	-1	-1	1	26.96	25.54	26.25	1.004091629
11	1	-1	1	-1	32.08	32.71	32.395	0.445477272
12	1	-1	1	1	31.26	32.5	31.88	0.876812409
13	1	1	-1	-1	14.85	15.3	15.075	0.318198052
14	1	1	-1	1	15.27	15.76	15.515	0.346482323
15	1	1	1	-1	19.05	18.66	18.855	0.275771645
16	1	1	1	1	20.18	18.99	19.585	0.84145707

Y-hat Model

Factor	Name	Coeff	P(2 Tail)	Tol	Active
Const		19.456	**0.0000**		
A	Temperature	3.77313	**0.0000**	1	X
B	Pressure	-5.01063	**0.0000**	1	X
C	Additive	2.21125	**0.0000**	1	X
D	Mold Type	0.06750	0.4716	1	X
AB		-0.96125	**0.0000**	1	X
AC		0.23813	**0.0193**	1	X
AD		0.01062	0.9091	1	X
BC		-0.47438	**0.0001**	1	X
BD		0.11312	0.2345	1	X
CD		0.00250	0.9786	1	X
ABC		-0.01250	0.8931	1	X
ABD		0.10125	0.2851	1	X
ACD		-0.02687	0.7729	1	X
BCD		0.02937	0.7525	1	X
ABCD		0.06750	0.4716	1	X

Rsq	0.9971
Adj Rsq	0.9943
Std Error	0.5179
F	361.6390
Sig F	0.0000

Source	SS	df	MS
Regression	1455.1	15	97.0
Error	4.3	16	0.3
Total	1459.4	31	

Conclusion/Areas of Future Study

Based on the results that have been seen to date in increased understanding provided by simulated applications, additional emphasis will be placed on their use. They promote the link between classroom lecture and real-world application in a very positive way for the students. They were accepted by the students and provided a break in the standard lecture format. By exception, however, when part of the student's final grade was based on the simulation results, it seem to impede the free flow of learning and caused the students to be much less excited about its use in the classroom. Further study on simulation's use as an assessment tool needs to be done to see if a verifiable link can be made between simulation results and changes in teaching methodologies. All in all, the use of simulation has been a very positive addition for this author and will continue to be used extensively.

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David is a graduate of North Carolina State University with a B. S. in Mechanical Engineering and has received a Master of Science from Lehigh University in Industrial Engineering. He has over 15 years experience in corporate planning, project management and information systems with AT&T. He directed Southern Polytechnic State University's CIM Center for two years. He is currently teaching simulation, project management and statistically oriented subjects in Industrial Engineering Technology and is the interim Chair of the Industrial Engineering Technology, Quality Assurance and Systems Engineering Department at Southern Polytechnic State University in Marietta, Georgia. He teaches Green Belt and Black Belt certification courses on campus as well as for various companies nationwide.