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A Student Inventory Simulation Evaluating Changing Demand Variation and Customer Service

Craig G. Harms

The University of North Florida

ABSTRACT

This paper presents the pedagogy of an Excel student simulation that allows the user to change various costs and demand variation and experiment with the effects of those changes on a set of customer service levels. Unlike merely reading about inventory control and the importance of customer service, students can actually experience the results of experimenting with a variety of service levels and the effects on shortages. Track: Marketing Education

INTRODUCTION

Reading a college textbook is not an exciting use of a student's time, especially during the Fall football season. Can you imagine what the typical student thinks of reading chapters dealing with inventory control? Oh, yes, the topic is critical to a multi-echelon firm. However, couldn't we just leave it to the Just in Time system and go watch the football game?

The preceding paragraph is not meant to be flip. However, it presents an interesting problem that the normal college faculty member has when competing with the variety of interesting things that a college student can do with their time. Maybe it would be a more useful investment of class time to "play" a simulation rather than going over inventory formulas and terms.

This order point inventory simulation can stimulate student interest in a topic that is very important to a small business. While Just in Time may work for a large corporation that has both control and proximity, a small firm may have to meet its product/component obligations with on-hand inventory. Determining a sufficient, yet not too expensive customer service level is worth modeling through an Excel simulation.

This paper is a second paper using the simulation approach. The first paper looked at cost changes. This paper looks at demand variation. How the manager handles "small" versus "large" demand variation with respect to safety stock will be investigated.

BACKGROUND

This student case is part of a larger semester long project with forecasting, distribution, and production planning as other topics included in the term. In this simulation setting, the corporation is a multi-echelon, multi-facility entity that includes shipments of product from a number of factories

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to a total of 17 warehouses. Seventeen student teams are formed to make this case easier to complete.

Students as well as this faculty member have grave *reservations* about team cases where grades are involved. First, the logistics of team cases can create problems. The two common complaints are:

a) There is always a slacker in the group and one student has to do all the work; and

b) It was too difficult to coordinate class and work schedules to meet.

However, Herring & Khojasteh justify the greater benefits of working in teams. There paper utilizes the "cooperative learning technique" in assigning multiple tasks to the group which cannot be finished unless the group forms sub-groups to complete the case requirements. However, this paper does not incorporate their most important idea, that of making the team case the primary in-class activity during the term. These cases are merely an alternative to the professor repeating and repeating the learning expectations.

Fares & Faras, 2004, discuss the need to carefully select a team utilizing the variety and breadth of the students' backgrounds and skills. To follow that process will create the need for someone to carefully to select and assign people to teams. Throwing caution to the wind, and keeping in mind everybody's concerns, yet not using their imperative, several ground rules were put in place:

a) All team work must be started and finished and the case turned in at the end of the 75 minute class; and

b) Teams were randomly drawn upon entering the room by picking slips of paper with teams numbers on them.

A second *reservation* concerns quantitative topics. There is a wide diversity between student knowledge of the quantitative topics. This had to be addressed because of the slacker concern mentioned previously. A team is comprised of four students with enough computer work and calculations required that teams had to subdivide themselves to get the work finished by the end of class. All team members were required to do at least a little quantitative work. However, if anyone was totally oblivious to the quantitative tools, they could be the team captain and coordinate the computer work and record all of the needed answers to the various questions.

Finally, justification of using computerized simulations to aid student learning can be traced back to literally computer card input. A favorite computer case book, Berry & Whybark, is used throughout the semester for several simulations, modified to follow the given multi-echelon, multi-facility company.

RESEARCH SETTING

The simulation encompasses a time frame of 48 months of demand. The computer simulates a random demand based on a normal distribution around the monthly demand forecast. A time series

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model considering trend, seasonality, and 60 months of historic data is used to determine the monthly forecast using the following equation:

$$F(t) = [\, B(0) + B(1) * \text{Time} \,] * SI(\text{month}) \qquad (1)$$

where: F(t) = the forecast for month t.
B(0) = intercept of the Y-axis.
B(1) = slope of the trend line.
Time = month in the future, t = 61, 62, ...108 (60 + months in future).
SI = Seasonal Index -- 12 indices, one for each month.

The inventory cost equation is as follows:

$$TIC = \Sigma\, OC + \Sigma\, HC + \Sigma\, SC \qquad (2)$$

where: TIC = Total Inventory Cost in dollars for the year.
OC = Total Order Cost for the year.
HC = Total Holding Cost for the year.
SC = Total Shortage Cost for the year.

Inventory control is a multiple objective problem trying to develop a “best” solution or service level that meets:

1) Minimize the Total Inventory Cost for the year (equation 2).
2) Maximize Customer Service, minimize the Shortage Cost.

The corporation has determined that every warehouse will be replenished every month. Therefore the Order Cost is not controllable by the warehouse manager. Order Cost is considered a sunk cost and drops out of the equation. This makes the first objective of the inventory control problem the following equation:

$$\text{Minimize } TIC = \Sigma\, HC + \Sigma\, SC \qquad (3)$$

The student simulator must determine a service level, or safety stock, that tries to meet both of the objectives of inventory control, equation (3) and maximizing customer service. Since there is an order to be placed at the end of every month, an equation is needed that addresses both the forecast and the service level:

$$MAXQ = F(t) + [\text{ Goodness of the Forecast } * \text{ Service Level }] \qquad (4)$$

or:

$$MAXQ = F(t) + [\, \sigma * \text{Z-score} \,] \qquad (5)$$

where: MAXQ = the maximum quantity on hand at the beginning of next month.
F(t) = the forecast for next month t.
σ = the standard deviation of the forecast equation.

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Z-score = the number of standard deviations of safety stock.

Finally, the order size is determined by the following equation:

$$Q^* = MAXQ - EI \quad (6)$$

where: Q^* = is the size of the order to be placed with the supplier.
EI = is the ending inventory level at the end of the current month.

The Excel simulation requires very little student input, namely the service level for the simulation trial, the Z-score. The costs for holding and shortage are inputs that the student must make before the simulation starts. The forecast information, the measure of accuracy of the forecast, the ending inventory, and the order pattern, i. e., order at the end of a month and assume overnight delivery are already stored in the template equations.

Once the student enters the Z-score and the respective service level, the template equations determine the inventory levels, the generated demand stream using a deterministic simulation protocol, and the various costs.

The important questions that the student teams will answer are:
1) How will the total cost be affected by "small" versus "large" demand variation?
2) How will the service level be affected by the "small" versus "large demand variation?
The team will perform the simulation first under "small" demand variation and then under "large" variation and then compare the results.

DETERMINING A SIMULATION STRATEGY

With the goal of finding the "best" service level for the firm, how should the student approach the problem? If we stock the forecast level (no safety stock) on a monthly basis, the service level would be 50%. Practically speaking this would create a product shortage about every other month, or 24 of the 48 month simulation. No manager would want to have unhappy customers running around every other month. Therefore it is a "no brainer" that the customer service level must be above 50% (and maybe a lot above 50%). However, we cannot afford an extremely high service level, say 98%. The cost of holding enough inventory to guarantee that out of every 100 months the company would run short only two times is prohibitive. The bottom line is that we know we need more than 50% and cannot afford 98%. We need to simulate a large number of alternatives between 50% and 98%. Students are guided toward a two step approach: First, let's get our hands around the shape of the TIC curve. We need to try service levels from 50% to 98%. Students simulate service levels from 55% to 95% by 5% and then end with 98%. The second step requires that we narrow the decision by playing "the clock game" from The Price is Right around the low cost service level currently in the solution. That will allow the student to find the **Low Cost Service Level**, which meets the first objective.

OUTPUT FROM PHASE ONE OF SIMULATION

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Table One presents the results of 10 trials with service levels from 55% through 98%. Figure One presents a graph of that information. The X-axis is the service level and the Y-axis is the Total Inventory Cost. The three curves on the plot are the TIC parabolic shaped curve, the Holding Cost curve that increases with larger and larger service levels, and the Shortage Cost that decreases with larger and larger service levels.

Table 1

Summary Report of Simulation Trials

Trial#	Service Level	$TIC	#Units Short	$Holding Cost	$Shortage Cost
1	55%	16,333	4,214	2,510	13,823
2	60%	14,518	3,518	2,976	11,541
3	65%	12,721	2,791	3,563	9,156
4	70%	11,507	2,237	4,169	7,338
5	75%	10,633	1,736	4,937	5,696
6	80%	10.098	1,289	5,867	4,230
7	85%	9,531	780	6,970	2,560
8	90%	9,257	277	8,348	909
9	95%	10,817	25	10,734	83
10	98%	13,437	0	13,437	0

“The Clock Game”

Looking at Table One or Figure One, it is easy to see that the 90% service level is currently the low cost service level. However, there is a possibility that 89% or 91% service level could have a lower cost. The same can be said for 87% or 93%. Therefore it is critical to go back to the Excel simulation and enter a few more Z-scores to determine the low cost service level to the nearest decimal number (the clock game). Table Two presents the cost information and Figure Two presents the graphical results.

Figure 1

Cost Curves for Initial Simulation

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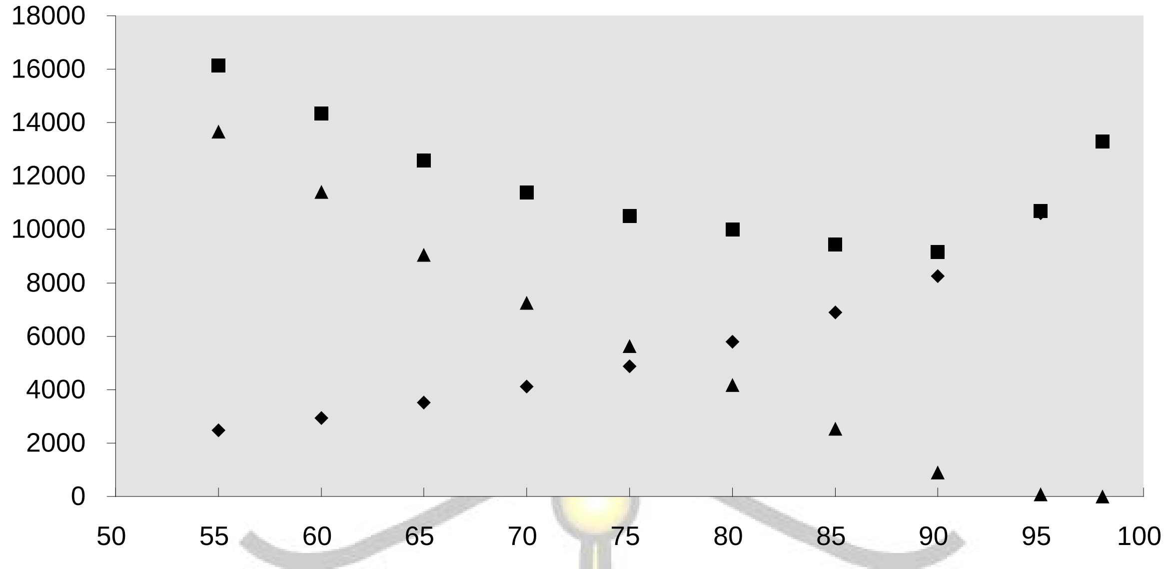

Analysis of Results -- The Low Cost Service Level

Looking at Table Two, the 89% service level is the low cost service level minimizing the TIC at a value of $9,217. Over the four year simulation there were 356 shortages or unhappy customers. Is the low cost service level the best service level for the corporation to operate? From a short term cost basis probably 89% is the best. However it is important to think about longer term customer service. If a customer goes away unhappy, will they come back to the business next time they need the product? Will they ever come back? What would it cost to raise the service level? What would it cost to make the next customer happy? How much are you willing to spend to make the next customer happy?

Table 2

Summary Report of Simulation Trials

Trial#	Service Level	$TIC	#Units Short	$Holding Cost	$Shortage Cost
1	55%	16,333	4,214	2,510	13,823
2	60%	14,518	3,518	2,976	11,541

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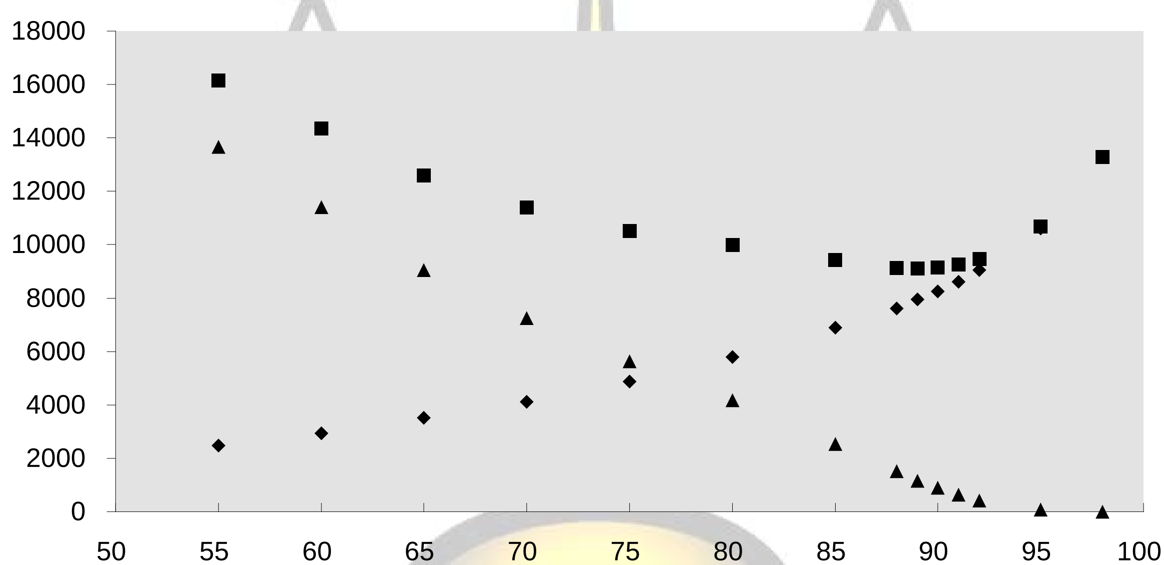
3	65%	12,721	2,791	3,563	9,156
4	70%	11,507	2,237	4,169	7,338
5	75%	10,633	1,736	4,937	5,696
6	80%	10.098	1,289	5,867	4,230
7	85%	9,531	780	6,970	2,560
8	90%	9,257	277	8,348	909
9	95%	10,817	25	10,734	83
10	98%	13,437	0	13,437	0
11	88%	9,226	466	7,696	1530
12	92%	9,573	127	9,155	417
13	89%	9,217	356	8,048	1,168
14	91%	9,365	197	8,715	649

Figure Two

Cost Curves for Simulation with Clock Game Trials



The shortage cost (SC) is set by using the after tax corporate profit for the item, $3.28. Therefore, as a "loss-leader" the manager may spend up to about $3.28 to make the next customer happy. Once the customer is satisfied, they may very well return and after making the second purchase the company will make money. For purposes of the student simulation, the cut off is set at $1.00, rather than $3.28, plus or minus a few cents. This shortens the time required to find a solution and may be more reasonable. For comparison purposes, the 89% service level will be compared with the costs of increasing the service level one percentage point to 90%. The calculation of this **cost trade-off** is as follows using the values in Table Two:

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Cost-Trade-Off = Δ [TIC(90%) - TIC(89%)] / Δ [#US(89%) - #US(90%)] (7)

where: #US = the number of units short.

Cost-Trade-Off = [9,257.30 - 9,217.30] / [356 - 277] = $0.51 (8)

As you can see, the cost trade off is well below our cutoff of $1.00. Therefore, moving from an 89% to a 90% service level satisfies 79 more customers at a cost of 51 cents per customer. Are you willing to spend 51 cents to make the next customer happy? Yes, and therefore we compare the low cost service level, 89%, against an increase of two percentage points, or 91%.

Cost-Trade-Off = [9,365.2 - 9,217.3] / [356 - 197] = $0.93 (9)

This solution is very close to our $1.00 limit. However, just to be confident that the "best" decision is 91%, let's compare 89% versus 92%.

Cost-Trade-Off = [9,573.1 - 9,217.3] / [356 - 127] = $1.55 (10)

Using a service level of 92% is deemed too expensive. Thus the conclusion can be reached that the "best" service level is 91%. This decision includes the effects of out-of-pocket costs and being willing to spend a little extra money to make the customer happy in hopes that they will come back and buy again.

Students may wonder why we just don't use a 98% service level? The cost to increase each one percentage in service level becomes more and more expensive--the law of diminishing returns comes into play. Thus too much customer service may be nice for customers, but bankrupt the company who is trying to make every single customer happy.

Changing the Factor Levels

With a class of 44 students, it is wonderful to be able to have students use different warehouses to create different solutions. However, it is most interesting that after discussing the solutions among all of the groups, although the costs are different for each warehouse, the "best" service level is the same for all of the warehouses, 91%. This occurs because the simulation is a deterministic simulation--each trial draws the same demand stream, thus fixing the demand variation for each warehouse the same. Students do not realize this until we discuss the case.

What would happen if the predictability of the demand stream was not so precise, maybe a newer product or a product with a lot of competition from other businesses? Would that change the safety stock requirements? How could I portray this in the student simulation?

Simulated Demand(t) = Forecast(t) * R(noise) (11)

where: Forecast(t) = the monthly forecast for next month for a given warehouse

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R(noise) = a list of 48 numbers with mean 1.0 and demand variability = to σ

For purposes of this paper, the holding cost and shortage cost remain the same. The demand variation [R(noise)] is raised 50%. Several percentage increases are tried (100% and 200%), but increasing the variability by 50% garners the desired effect for the student case.

How will this change in demand variability affect the solution of 89% as the low cost service level and 91% as the “best” service level? The students can simulation the new situation and graph both Total Inventory Cost curves on the same graph. The same simulation procedure is used as presented before. Table Three presents a list of the trials. The new trials for the larger demand variation are #15 through #27. Figure Three presents the graph with all six cost curves.

You can see the new cost curve shifts up and to the right. The curve shifts up because the larger demand variability adds to the inability to predict the desired stocking level. To compensate for this lack of certainty or knowledge about demand, the system adds inventory (adds service) to the system, thus increasing the total system holding cost. Secondly, because of the larger chances of a very large demand and thus an increase of possible shortages, the total shortage cost is slightly increased. The new low cost TIC is at 97% at a cost of $17,620 as shown in Table Three. There are 579 shortages or unhappy customers.

Table 3

Summary Report with Additional Trials

Trial#	Service Level	$TIC	#Units Short	$Holding Cost	$Shortage Cost
1	55%	16,333	4,214	2,510	13,823
2	60%	14,518	3,518	2,976	11,541
3	65%	12,721	2,791	3,563	9,156
4	70%	11,507	2,237	4,169	7,338
5	75%	10,633	1,736	4,937	5,696

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6	80%	10.098	1,289	5,867	4,230
7	85%	9,531	780	6,970	2,560
8	90%	9,257	277	8,348	909
9	95%	10,817	25	10,734	83
10	98%	13,437	0	13,437	0
11	88%	9,226	466	7,696	1530
12	92%	9,573	127	9,155	417
13	89%	9,217	356	8,048	1,168
14	91%	9,365	197	8,715	649
15	55%	31,192	7,312	7,206	23,986
16	60%	29,130	6,552	7,640	21,491
17	65%	26,948	5,723	8,176	18,773
18	70%	25,078	4,995	8,694	16,384
19	75%	23,279	4,249	9,340	13,939
20	80%	21,728	3,534	10,136	11,592
21	85%	20,493	2,848	11,150	9,342
22	90%	19,513	2,158	12,435	7,079
23	95%	18.069	1,111	14,423	3,646
24	98%	17,748	308	16,727	1,011
25	99%	18,783	79	18.523	260
26	97%	17,620	579	15,718	1,902
27	96%	17,769	852	14,972	2,797

Figure Three

Cost Curves for Two Levels of Demand Variation

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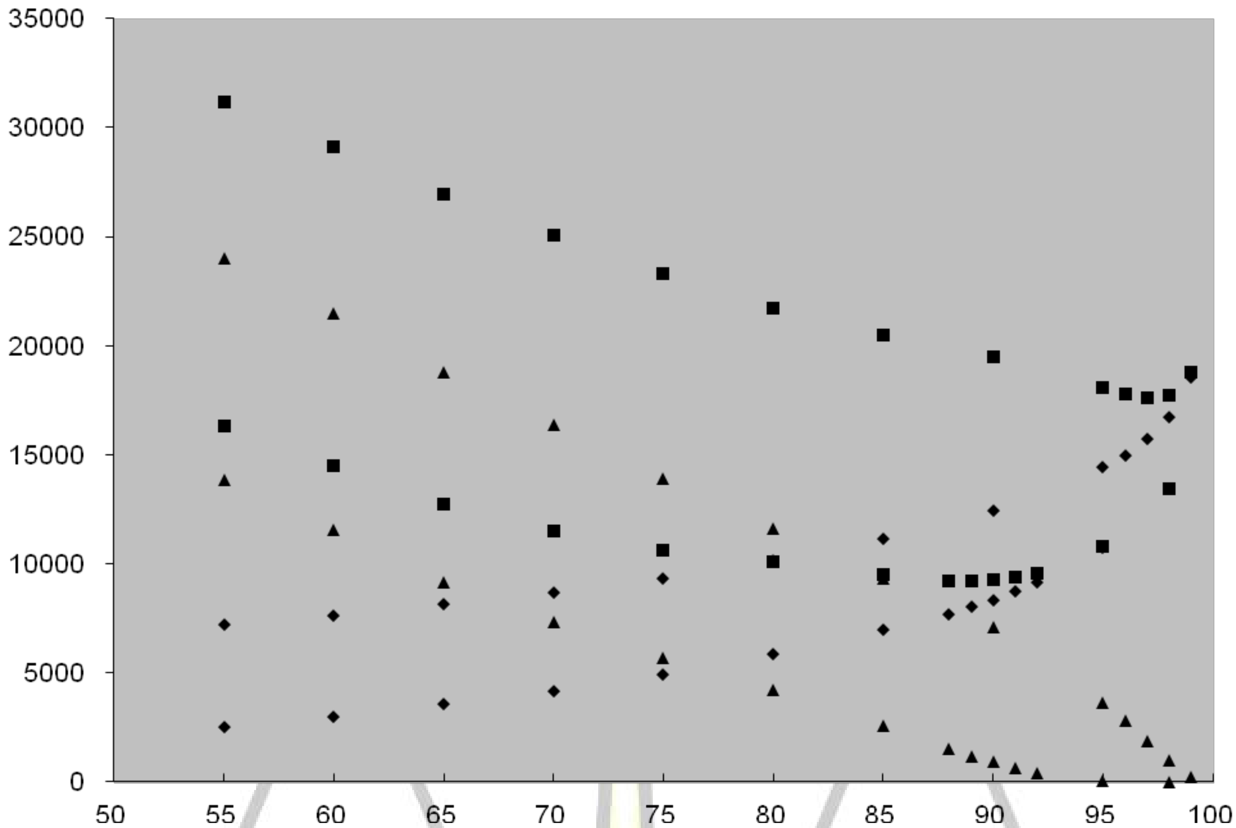

Finally the same cost trade off analysis is followed to see if it is possible to increase the service level without costing the company "an arm and a leg."

Cost-Trade-Off = Δ [TIC(98%) - TIC(97%)] / Δ [#US(97%) - #US(98%)] (11)

where: #US = the number of units short.

Cost-Trade-Off = [17,748 - 17,620] / [579 - 308] (12)

= 128 / 271 = $0.47 (13)

It seems as if a service level of 98% is beneficial, saying that to make the next customer happy (really, 271 of them), the cost per customer is only 47 cents. How about a 99% service level?

Cost-Trade-Off = Δ [TIC(99%) - TIC(97%)] / Δ [#US(97%) - #US(99%)] (14)

Cost-Trade-Off = [18,783 - 17,620] / [579 - 79] (15)

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$$= 1{,}163 \;/\; 500 = \$2.32 \qquad (16)$$

Therefore, with the cost trade-off well above the $1.00 cut off, the 98% service level is the "best" service level for the larger demand variation.

Finally, students are asked which demand variation they would like to "live with." To a student, they all say, "The low demand variation!" That leads to a short discussion about the fact that demand variation is uncontrollable (sorry).

CONCLUSION

As previously stated, this inventory simulation is one topic in a semester long project. This is the first and only team case of the semester where cooperative effort of the students is required. Although some of the teams struggled, scoring on the quiz given the class after the case is completed revealed that students learned the material very well. Almost all students received an "A" or a "B" for the case. This is quite remarkable given the quantitative nature of the topic.

Students enjoy using the computer to "play games." It is much easier than doing calculus or other difficult math or memorizing terms. The students gain valuable real world insight to the problems of inventory and customer service. The program is very small and the case can be executed in roughly 75 minutes.

With the addition of the ability to change holding and/or shortage costs presented in the first paper, a complete experimental design can be set up to involve more factor levels and thus another piece of the education puzzle.

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Craig Harms received has Ph.D. from The Ohio State University in 1984. He has taught at Miami (Ohio) University from 1976-1980 and is currently at The University of North Florida in Jacksonville, Florida (1980-present). Currently using the 6th edition of his major book, *The Swift Shoe Company*, Dr. Harms is working on his 7th and last edition. The book has over 100 adoptions around the world including Notre Dame University and The University of Capetown, South Africa. His latest book, *Technical Analysis in the Stock Market*, 2011, is used in the quantitative methods course and is sold in the open market as a self help to conservative stock trading.

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