APTARA | DSJI | dsji12089 | Dispatch: November 14, 2015 | CE: AFL
Journal | MSP No. | No. of pages: 15 | PE: XXXXX

Decision Sciences Journal of Innovative Education
Volume 00 Number 0
November 2015
Printed in the U.S.A.

TEACHING BRIEF

Using Spreadsheet Modeling to Teach Exchange Curves (Optimal Policy Curves) in Inventory Management

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ABSTRACT

Q3 Inventory management is widely researched and the topic is taught in business programs across the spectrum of operations and supply chain management. However, the concepts are notoriously difficult for students to practice once they finish school and become managers responsible for inventory control. This article explains the structure and details of an inventory management class module designed to bridge the gap between learning inventory management theory and applying the learning to practice. Through an active learning exercise, groups of logistics management graduate students in two sections of an introductory inventory management class (in-residence and online) are taught the exchange curve concept, introduced to its use in practice, and given a tool for implementing this learning in a variety of practical scenarios. The exercise is valuable as it is well suited for students with a limited math background because it allows the exchange curve concept to be taught and demonstrated without presenting complicated mathematics. A three-tiered assessment of the exercise reveals its effectiveness in meeting the goals of providing an engaging and interesting use of learning time and giving the students an in-depth practical understanding of the exchange curve concept. The exercise is designed to be equally useful for application in an undergraduate class.

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INTRODUCTION AND LITERATURE REVIEW

Teddy Roosevelt is credited with saying “Do what you can, with what you have, where you are.” The concept of exchange curves is a powerful yet practical analysis tool which implements Roosevelt’s advice in the context of inventory management. Logistics management students in an introductory graduate level inventory management course are taught this powerful concept using a straightforward spreadsheet modeling example, rather than elegant yet complicated mathematical modeling. The exercise is used simultaneously with in-residence and online courses. The assignment is completed by students in small groups, although it can also be completed by individual students. It works equally well for

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both modes of delivery (residence and online) and for groups as well as individuals because the graduated complexity with which the problem is presented allows the individuals to solve the problem in small steps, and the group interaction allows students to teach and learn from one another. This exercise is valuable because it allows students with limited math background to benefit from the practical application of the exchange curve concept and it is equally beneficial to graduate and undergraduate students because of its simplicity and its combination of practical relevance with important theoretical concepts. The objective of the exchange curves lesson, as stated by Silver, Pyke and Peterson (1998) is to teach the following key concept: "the inventory planning decision deals with design of an entire system consisting of an ordering function, a warehousing system, and the servicing of customer demand—all to top management specification." In other words, management decisions ultimately determine inventory levels and cost.

The use of spreadsheet modeling to teach management science and inventory management has been used and called for by operations management scholars and teachers for more than three decades (Cobb, 2013; Grossman, 1999; Silver, 1981; Umble & Umble, 2013; Winston, 1996). The exchange curve concept applied to inventory management has been proven effective in practice (Gardner, 1980, 1987; Gardner & Dannenberg, 1979). There is however, a noted gap in the application of inventory management theory to practice (Zanakis, Austin, Nowading, & Silver, 1980). The goal of the technique presented in this article is to both give students a thorough understanding of the exchange curve concept as well as to give them a tool to help complete this translation of theory to practice. Additionally, this type of hands-on practical instruction engages students in active learning (Fink, 2013) in order to create understanding and ability to apply the concepts.

BACKGROUND

After learning the economic order quantity (EOQ) model, students are familiar with the concept of an optimal order quantity for a single item given ordering cost, holding cost, demand rate, and item cost. However, the practical application of the EOQ concept is difficult for two reasons. First, the ordering and holding costs used to calculate the EOQ are seldom straightforward and are at best rough estimates including many variables such as overhead, labor, system costs, and other difficult to measure factors. In practice, management must decide which factors are related to the costs and what weight each factor contributes to the cost. Although the EOQ model is robust in that it is fairly insensitive to these flawed estimations of actual ordering and holding costs, the issue remains that management is rarely concerned with optimizing the inventory policy for a single item without consideration of the entire system.

In its most basic form, the exchange curve presents a practical tool used to find an optimal frontier between the amount of total system inventory investment and workload, or number of orders placed in a given time period. When students are first introduced to the EOQ, it is derived as the minimum of the total ordering and holding costs for an item. The familiar equation is presented as

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$$EOQ = \sqrt{\frac{2AD}{vr}}. \quad (1)$$

where *EOQ* is the economic order quantity in items; *D* is the annual item demand in items/year; *A* is the fixed cost to place an order in \$; *r* is the inventory carrying cost in \$/\$/year; *v* is the item cost per unit in \$.

Lead in for Students

Students are familiarized with the trade-off represented in that the EOQ equalizes the item holding cost and ordering cost, so that just enough is ordered each cycle that holding costs for the year are equal to ordering costs for the year. As stated, this is dependent upon knowing exact values of *A* and *r*, and is computed at the single item level.

After a mastery of the EOQ and some of its extensions, students are presented with the idea of the system view, where now the subject of concern is the ordering policy for a group of items, and the measures of interest are aggregate inventory investment and total orders per year across the group. Additionally, students are reminded that in practice the ordering cost, the holding cost, or both are not known with certainty.

The EOQ exchange curve concept is introduced by characterizing the ordering and holding costs as management decision variables as opposed to calculated costs. The EOQ formula is broken down and used to illustrate precisely how the values or *A* and *r* are related to the order quantity in the following manner.

$$EOQ = \sqrt{\frac{2AD}{vr}} = \sqrt{\frac{2D}{v}}\sqrt{\frac{A}{r}}. \tag{2}$$

Such that all else held constant, the EOQ changes by exactly the ratio $\sqrt{\frac{A}{r}}$.

This value of the ratio *A*/*r* is then shown to be the determining factor for an optimal frontier between total average cycle stock (TACS) and total number of orders per year (*N*).

METHOD

Overview

The technique presented in this article was used in a graduate inventory management class with students in a logistics management program. The exercise was completed by groups in order to encourage peer learning, however, the highly structured nature of the exercise allows for individual learning as well. The lesson is designed to be completed with approximately four hours of in-class time spent on the exercise and four to eight additional hours outside the classroom completing the exercise and readings. The readings should be assigned so that they can be completed before class. Although the underlying theory is useful to the knowledge creation goal of graduate students, the straightforward practical application is useful at the undergraduate and graduate levels.

The method of teaching the practical application and implementation of exchange curves using Excel is presented by gradually taking the students from a simple explanation of the concept through an exercise where they are expected to apply and extend the concept with increasing complexity—a technique similar to that used by Gentry and Reutzel (1976). This “explain, crawl, walk, run, evaluate” process starts with a brief primer lecture and readings on the topic, then the students are assigned a "crawl" exercise where they are given specific instructions and answers to check their work, next they complete a "walk" exercise where they are given a new exercise with a familiar structure, and last, they are assigned a "run" exercise in which they are expected to extend the concepts learned.

Student understanding of the concept is then evaluated on three levels. First, a score is assigned to the initial three exercises based on quantitative and mechanical correctness in order to assess students' technical understanding of the concept, next a qualitative assessment is made of how they answer conceptual questions about the topic in order to assess their conceptual understanding of the concept, and finally a postexercise survey is conducted to assess students' perceptions of their own learning.

Exercise Phases

In the explain phase, the topic is presented in the latter portion of the class when students have been familiarized with and gained a mastery of basic inventory management principles, systems, and techniques. When the topic is introduced, the students are given an explanation of why exchange curves are important and how they can be applied. A brief primer lecture is used to give students an overview of the concept. Text readings from chapters 3, 5, and 7 of Silver et al. (1998) are assigned to familiarize students with the technical aspects and mathematical underpinnings of the material. These chapters of the text present the exchange curve concept with varying levels of complexity and application. Finally, academic research papers are assigned. Gardner (1987) uses a case to illustrate how the use of tradeoff curves has resulted in substantial financial savings in real world inventory systems. Gardner and Dannenbring (1979) shows the power of the simple exchange curve in communicating and influencing inventory management decisions at executive level (only sections one and two of this article are mandatory reading for the students in this lesson, although they are encouraged to read the entire article). Finally, Gardner (1990) shows how the concept can be easily extended as an illustrative tool.

Next, the students are presented with problem 5.23 from Silver et al. (1998) and given step-by-step instructions to complete the exercise in Excel. This is the crawl phase. Appendix A is used as a handout to provide answers and screenshots to ensure the students are completing the exercise as planned.

Then in the walk phase, the students are asked to complete problem 5.12 from Silver et al. (1998), a similar problem in which the same solution process as in the crawl phase must be followed. This time, however, the students are not given the answers to the problem.

Finally, in the run phase, students are given an extension problem to solve that involves much more complexity and critical thinking/problem solving than the first two. Appendix B includes the assignment instructions handout with the details of this problem. The specific exercise is for students to recreate tables 7.8 and 7.9 in Silver et al. (1998), which include reorder point, safety stock level, item cost, lead time, and demand data on three items. Students are asked to develop an exchange curve of total safety stock value to expected total value short per year (ETVSPY), a service measure. They must answer questions concerning tradeoffs between the value of safety stock held and the service level indicated by ETVSPY. In particular, the characteristics of this more complex problem include the incorporation of stochastic demand (the first two were deterministic), safety stock, lead time, a direct service measure, the use of safety factor as a policy parameter, and questions on how to interpret the results. For example, the students must explain how they would use this analysis to advocate a change in inventory policy to top management given a budget constraint. The problem parameters could include any scenario that requires more critical and technical thought while applying the exchange curve concept. The successful completion of this problem ensures the students have grasped both the technical and conceptual aspects of exchange curves and are able to illustrate tradeoffs between two opposing parameters. Evaluation of the problem by the instructor also indicates where further instruction may be needed. This extension allows students to see that the simple yet powerful exchange curve concept can be applied to various scenarios in inventory management. Additionally, it requires a deeper level of critical thinking in order to complete correctly.

Exercise Evaluation

Success of the exercise in teaching students the concept is evaluated by the instructor by assessing students' level of technical understanding (correct completion of the increasingly difficult exercises) and conceptual understanding (essay questions). Additionally, a self-rated assessment of the exercise is performed where students are asked to evaluate the effectiveness of the exercise after they have completed all portions.

THE STRUCTURE OF THE PROBLEM

As an example, a group of items is presented with known demand rate, unit cost, and current ordering policy for each item, where ordering policy has been determined without consideration of the associated cost factors (a fixed time supply ordering policy for each item). This example problem and notation is taken directly from Silver et al. (1998), problem 5.23. This problem is recreated in Appendix A, which is given as a handout to the students. When combined, the aggregate ordering policy is suboptimal in that it does not lie on the optimal frontier represented by an exchange curve where an equal value of A/r is assigned to each item across the group. Students are then asked to find the following:

As-is State of the System (Group of Items), Found in Appendix A, Step 1

(1) The implied value of A/r for each item in the group. From the EOQ, this is simply:

$$\frac{A}{r} = \frac{Q^2 v}{2D}. \tag{3}$$

where Q is order quantity.

This exercise demonstrates that the order quantities are set based on non-calculated policies which then imply different ordering and holding costs for each item. It is assumed that this group of items is similar in that they will all have the same (or similar) ordering and holding costs.

(1) The current aggregate operating position in terms of total average cycle stock (TACS) and number of orders (N) per year.

$$TACS = \sum_{i=1}^{n} \frac{Q_i}{2} v_i, \tag{4}$$

$$N = \sum_{i=1}^{n} \frac{D_i}{Q_i}, \tag{5}$$

where n is the number of items in the group.

Optimal Trade-off Values of TACS and *N* (Common Value of *A*/*r* is Applied across the Group), Found in Appendix A, Step 2

(1) The EOQ aggregate exchange curve given by assigning a common value of A/r to all items in the group. This is done in several steps.
   (1) Find TACS for the group at a set A/r:

$$TACS = \sqrt{\frac{A}{r}} \frac{1}{\sqrt{2}} \sum_{i=1}^{n} \sqrt{D_i v_i}. \tag{6}$$

   (2) Find N for the group at a set A/r:

$$N = \sqrt{\frac{r}{A}} \frac{1}{\sqrt{2}} \sum_{i=1}^{n} \sqrt{D_i v_i}. \tag{7}$$

Note that the term $\frac{1}{\sqrt{2}} \sum_{i=1}^{n} \sqrt{D_i v_i}$ is common to finding both *TACS* and N, so that it can easily be calculated for the group of items and referenced as a cell throughout the spreadsheet.

Construct a graph of *TACS* versus N by varying values of A/r, found in Appendix A, Step 4.where

$$(TACS)(N) = \frac{1}{2} \left(\sum_{i=1}^{n} \sqrt{D_i v_i} \right)^2, \tag{8}$$

which is a hyperbola, and

$$\frac{TACS}{N} = \frac{A}{r}. \tag{9}$$

The solution is straightforward thus far, with the intuition concerning the use of exchange curves being built step by step. Next, we present the problem of finding savings in the system costs and/or workload by adopting a common value of A/r across all items.

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However, the method to obtain values of A/r to achieve a given *TACS* or N (given the other) is not readily apparent. This involves minimization of N subject to a specified value of *TACS* (or minimization of *TACS* subject to a specified value of *N*) and then an easy calculation of *A*/*r* from these two values. An analytic solution involving the use of a Lagrange multiplier can be used to find the values of *TACS* and *N* in this case as in Silver et al. (1998), however, for students in an introductory inventory management course with limited math background this may prove a difficult concept to grasp. Therefore, a trial and error approach is presented which is easily implemented in a spreadsheet using goal seek. This method is better suited for students with limited math background because it allows the concept to be taught and demonstrated without presenting complicated mathematics. The method of having students construct spreadsheets that build on the steps presented ensures that they are actively engaged in the learning process as opposed to passively being presented information that they may not understand. This method is accessible in that it uses the basic built-in goal seek function of Excel. Additionally, this method gives students the intuition needed to understand the general concept of exchange curves, which can be extended to other tradeoff decisions.

The Remainder of the Exercise is Presented in the Following Steps, Found in Appendix A, Step 3

(1) Find the improvement in *N* if management wants to hold the current level of TACS. Objectively, we want to minimize *N* subject to a given *TACS*. The utility of this simple yet powerful tool is demonstrated by Gardner (1987).
   (1) Using goal seek in Excel, find *N* by varying the value of *A*/*r*, given current TACS.
   (2) Calculate the difference (savings) in this optimal tradeoff value of *N* versus the as-is *N*.

(2) Find the improvement in *TACS* for the current level of *N* (where number of orders per year is characterized as workload). Objectively, we want to minimize *TACS* subject to a given *N*.
   (1) Using goal seek in Excel, find *TACS* by varying the value of *A*/*r*, given as-is *N*.
   (2) Calculate the difference (savings) in this optimal trade-off value of *TACS* versus the as-is TACS.

By answering these questions, students will build the intuition that cost efficiencies or workload reductions are easily attainable within the system by choosing a common *A*/*r* value and assigning a *Q* for each item based on this common cost factor.

The concept is extended to the case of probabilistic demand with a problem asking students to construct an exchange curve of expected total value of stockouts per year (ETVSPY) versus safety stock. This problem allows students to see how easily the concept can be extended to analyze tradeoffs between system costs, and various cost, service, or shortage measures.

At the conclusion of the exchange curves instruction module, the students have an easily implementable tool for finding optimal policy curves as well as an understanding of the interaction and relationship between key cost factors in

Table 1: Postexercise survey results. Please rate the validity of each of the following statements on a scale of 1–5, where 1 is strongly disagree, 2 is disagree, 3 is neutral, 4 is agree, and 5 is strongly agree

Questions: The Exchange Curve Exercise	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	Average Rating
(1) was an interesting, hands-on learning experience	0	3	4	17	4	3.79
(2) was a good use of learning time	0	1	5	15	7	4.00
(3) reinforced my understanding of the tradeoffs involved in inventory management	0	1	4	14	9	4.11
(4) enhanced my understanding of management's role in setting inventory policy	0	1	7	13	7	3.93

inventory management. The tool and knowledge itself can be generalized to other areas.

ASSESSMENT OF THE EXERCISE AND METHOD

Seven groups of four students each completed the assignment. Students' technical understanding of the concept was assessed by assigning a score of one to three based on their completion of the three assigned problems in the crawl, walk, run portion of the assignment. A score of one means they correctly accomplished the first part of the exercise (step-by-step duplication with answers). A score of two means they accomplished the second part of the exercise correctly (familiar problem without given answers). A score of three means students accomplished the third part of the exercise correctly (extension). Six of seven groups scored a three and one group scored a two. Upon further examination of the "two" group's conceptual answers, they seem to have grasped the concept well, but were confused as to the mechanics of the more detailed portions of the extension exercise. This confusion could have been based on many external factors (time constraints, communication difficulties, or geographic separation—this was an online group). Overall, the students achieved a very high level of technical understanding of the concept and are able to practically apply the learned techniques to problems.

To assess the students' level of comprehension of the concept, they answered conceptual questions relating to the topic which dealt with the application, advantages, and managerial implications of using exchange curves in the practice of inventory management. Did students answer follow up conceptual questions correctly? All seven groups answered follow up conceptual questions correctly with a level of depth that indicates a thorough understanding of the topic.

Finally, to assess the students' perception of the usefulness of the exercise, a follow up survey was administered the day after all students had turned in the exercise to ensure the information was fresh in their minds. A total of 28 student responses were collected. The following questions as adapted from a similar study (Umble & Umble, 2013) were asked and the results of the survey are presented in Table 1 below.

DISCUSSION AND CONCLUSIONS

Based on the three-tiered assessment of the student's performance and perception, the exercise was an overwhelming success in teaching the technical and conceptual aspects of exchange curves in inventory management. Their technical understanding and conceptual comprehension of the topic was confirmed by the instructor's assessment of the exercise and conceptual question answers. Their perceived value of the exercise was confirmed by the survey ratings collected after the exercise's completion. Although student perceptions of the exercise were overwhelmingly positive, the ratings included several student's responding with either a "neutral" or "disagree" rating. This could be due to the fact that students worked in groups. Although the groups' answers to all questions were correct and accurate, the individual students may have had various levels of understanding and contribution to the exercise as evidenced by observation of group dynamics.

Overall, this exercise and teaching method was a huge success. Both in teaching the students a valuable and practical concept, applying an innovative and called for technique, and creating an interesting, hands on learning experience for students. This exercise forced the students to apply critical thinking skills and develop an intuition for the topic over and above what could possibly be gained through traditional lecture and homework style modules. Additionally, this exercise was well suited for the flipped classrooms as well as the virtual distance learning classroom in that it made maximum use of active learning techniques (hands on) to enhance understanding of the topic. This exercise also gives the students a tool for use in their future careers as logisticians and analysts which will help them to be influential in management positions and successful in the technical aspects of inventory management.

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APPENDIX A

SPREADSHEET MODELING OF EXCHANGE CURVES USING AN EXAMPLE PROBLEM

Q10 Given Information
A group of items with Demand
Unit cost
Current ordering policy (Q)
The example problem: (Silver, Pyke, and Peterson exercise 5.23, p.192)
A company stocks three items with the following characteristics:

Item, i	$D(i)$ units/year	$v(i)$ \$/unit	Current $Q(i)$
1	1,000	$5.00	250
2	4,000	$.80	1,000
3	200	$4.00	50

a. Develop an exchange curve of total average stock (in $) versus total number of replenishments per year under an EOQ strategy treating *A/r* as the policy parameter.

b. Plot the current operating position on the graph.

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c. For what values of *A/r* would the EOQ strategy produce an improvement on both aggregate dimensions?

Steps to solving the problem with spreadsheet modeling.

Step 1

For the as-is operating policy (given order quantities based on equal time supplies):

1. Find (using EOQ):
   a. Inventory investment per item
   b. Aggregate Inventory Investment of the system (sum of item investments)
   c. Number of orders per year, *N*, for each item
   d. *N* for the system (sum of *N* for all items)
   e. Implied *A*/*r* for each item

Such that the spreadsheet is set up as in Figure 1 below:

Figure 1: As-is calculations.

Note that a cell (H8) has been set up with the expression $\frac{1}{\sqrt{2}}\sum_{i=1}^{n}\sqrt{D_i v_i}$ to use in calculations throughout the exercise.

	A	B	C	D	E	F	G	H	I
1	**As-is System**								
2		**Demand**	**Item Cost**	**Order Qty.**	**Investment**	**Orders/Yr.**	**Implied A/r**		
3	Item, i	D(i) units/yr	v(i) $/unit	Current Q(i)	(Q/2)*v	N	A/r	$\sqrt{D_i v_i}$	
4	1	1000	$5.00	250	$625.00	4	156	$70.71	
5	2	4000	$0.80	1000	$400.00	4	100	$56.57	
6	3	200	$4.00	50	$100.00	4	25	$28.28	
7									
8			**As-is**	**System Values**	**$1,125.00**	**12**		$110.00	$\frac{1}{\sqrt{2}}\sum_{i=1}^{n}\sqrt{D_i v_i}$
9									

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Step 2
For the system in general:

2. Find (for any value of *A*/*r*):
   a. Total average cycle stock (TACS)
   b. Number of orders per year, *N*, for the system
   c. *Q* (EOQ) for each item based on the common *A*/*r*
   d. *N* for each item (given new *Q* calculated in step c)

Q11 **Figure 2:** Savings calculations.

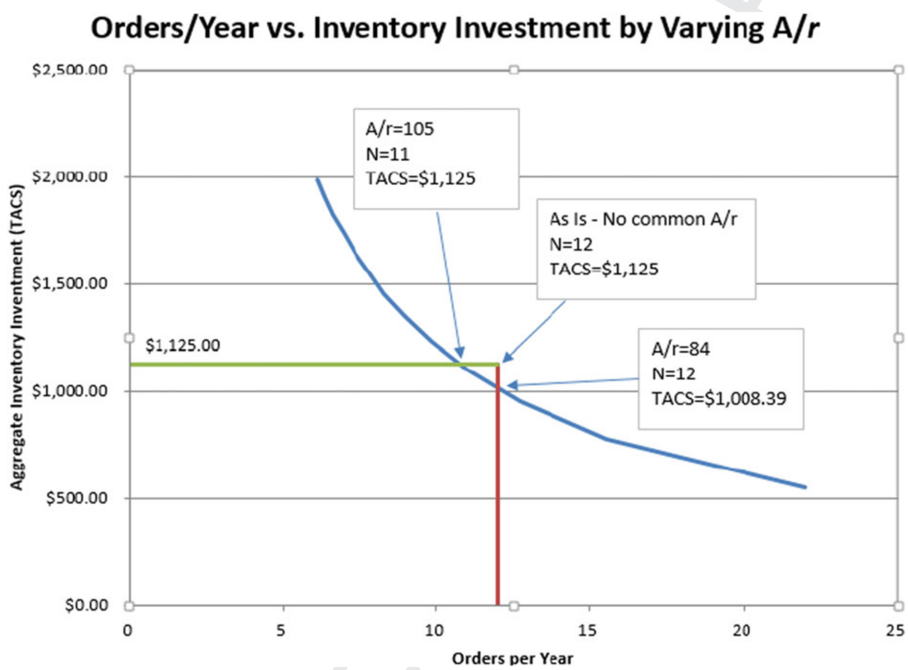
	A	B	C	D	E	F	G	H	I	J
1	**As-is System**									
2		**Demand**	**Item Cost**	**Order Qty.**	**Investment**	**Orders/Yr.**	**Implied A/r**			
3	Item, i	D(i) units/yr	v(i) $/unit	Current Q(i)	(Q/2)*v	N	A/r	$\sqrt{D_i v_i}$		
4	1	1000	$5.00	250	$625.00	4	156	$70.71		
5	2	4000	$0.80	1000	$400.00	4	100	$56.57		
6	3	200	$4.00	50	$100.00	4	25	$28.28		
7										
8			**As-is**	**System Values**	**$1,125.00**	**12**		$110.00	$\frac{1}{\sqrt{2}}\sum_{i=1}^{n}\sqrt{D_i v_i}$	
9										
10				Steps 2-3 in columns B through I						
11	**Common A/r Applied to System**									
12	**A/r**	**N**	**TACS**	**Item 1 New EOQ**	**Item 2 New EOQ**	**Item 3 New EOQ**	**Item 1 New N**	**Item 2 New N**	**Item 3 New N**	
13	25	22	$550.00	100	500	50	10	8	4	
14	50	16	$777.82	141	707	71	7	6	3	
15	75	13	$952.63	173	866	87	6	5	2	
16	100	11	$1,100.00	200	1,000	100	5	4	2	
17	125	10	$1,229.84	224	1,118	112	4	4	2	
18	150	9	$1,347.22	245	1,225	122	4	3	2	
19	175	8	$1,455.16	265	1,323	132	4	3	2	
20	200	8	$1,555.63	283	1,414	141	4	3	1	
21	225	7	$1,650.00	300	1,500	150	3	3	1	
22	250	7	$1,739.25	316	1,581	158	3	3	1	
23	275	7	$1,824.14	332	1,658	166	3	2	1	
24	300	6	$1,905.26	346	1,732	173	3	2	1	
25	325	6	$1,983.05	361	1,803	180	3	2	1	
26	User chosen range of A/r in cells A13:A25									
27	**Solution Rows**									
28	**A/r**	**N**	**TACS**	**Item 1 New EOQ**	**Item 2 New EOQ**	**Item 3 New EOQ**	**Item 1 New N**	**Item 2 New N**	**Item 3 New N**	
29	105	11	$1,125.00	205	1,023	102	5	4	2	
30	84	12	$1,008.39	183	917	92	5	4	2	
31				Step 5 solutions in cells B33 (=F8-B29) and C32 (=F9-C30).			Step 4 in rows 29-30 4a. target cell is B29 4b. target cell is C30			
32	**TACS Savings**		$116.61							
33	**N Savings**	1								
34										

Step 3

3. Copy the cells down to find these values (2a–2d) for a range of *A/r* values (this range of *A/r* values should include the minimum and maximum implied *A/r* values of the items found in Step 1e above).
4. Copy down formulas into two additional rows (we will label these solution rows).
   a. Use goal seek to find *N* given current TACS by varying *A/r* (one solution row).
   b. Use goal seek to find *TACS* given current *N* by varying *A/r* (second solution row).

(The result is an optimal *TACS* or *N* given the other, and the associated exact value of *A/r*. Alternately, the two *A/r* values represent the range of *A/r* over which the

Figure 3: Graph construction.



EOQ strategy with a common *A/r* value applied to the system would produce an improvement on both aggregate dimensions.)

5. Calculate the resulting savings in *N* or *TACS* at these two points on the curve over the current operating point.

Step 4

6. Produce and label the exchange curve in the spreadsheet.

a. Graph orders per year, *N*, versus *TACS* for these values.
b. Graph the point representing current operating policy.
c. Label the graph.

Excel hints to construct a graph as above:

1. Arrange data so that the *X* and *Y* columns are adjacent. This may mean creating duplicate columns for the sake of inserting a clean chart.
2. Select the two data columns including the header (title) rows.

*Note: to add a single point for the current operating position, just add the values of *N* and *TACS* in a row below your data table and include that row in the selection in Step 2. After you insert the chart, you will then have to select that single point and format it to remove the line connecting it to the rest of the points (or else you will have an odd line cutting across your graph).

3. Go to insert > charts > scatter > and select chart type—scatter with straight lines.
4. Now, for this example, you should have a chart with *N* values on the *X* axis and *TACS* values on the *Y* axis.
5. To add vertical and horizontal lines from the axes to the point at the current operating location, create a 3 × 5 block of data somewhere in the sheet that will not interfere with the other data. I used cells AB4:AD8 in the example. For the data in the cells you should link the values for AC4 and AD4 back to your calculation of the current operating *N* (cell F8 in this example). Enter 0 in AC5. Link AD5 back to the calculation of the current operating TACS (E8 in this example). Enter 0 in cell AC7. Link AD7 back to AD4. Link AC8 and AD8 back to AD5.

With values as in Figure 4 below.

Figure 4: Values and formulas for graph construction. With formulas.

With values

	AA	AB	AC	AD
3				
4		Vline	12	12
5		Range	0	$1,125.00
6				
7		Hline	0	12
8		Range	$1,125.00	$1,125.00
9				

With formulas

	AA	AB	AC	AD
3				
4		Vline	=F8	=F8
5		Range	0	=E8
6				
7		Hline	0	=AD4
8		Range	=AD5	=AD5
9				

6. Now that the data for these two lines is in place, we need to add them to the chart. Right click on the chart, in the pop up menu click on select data. You should get a dialogue box. Under legend entries (series) click on TACS to highlight then click the Add button to add a series. The edit

series box should pop up. In series name enter Hline. For *X* values, click the select data icon and then select AC4:AD4. Under the *Y* values, click the select data icon and choose AC5:AD5. Click Ok. You should now have a horizontal line from the current operating location to the *Y* axis.

7. Repeat the steps in (7) to add another series for Vline. You should now have a chart with a horizontal and vertical line from the current operating location to the *Y* and *X* axes, respectively.
8. Note, when selecting data make sure you click the button for hidden and empty cells and check the box next to show data in hidden rows and columns.
9. Size your graph, label the chart, arrange or remove your legend, and label the axes. You should now have something that looks like the example above.

APPENDIX B

EXCHANGE CURVE EXERCISE HANDOUT

Using "Appendix A: The spreadsheet modeling of exchange curves method applied using an example problem," complete Silver et al. (1998), problem 5.23.

Complete problem 5.12 in the same manner as you completed problem 5.23.

Extend the exchange curve concept and tools to the case of probabilistic demand.

1. Recreate the values in table 7.8 (entire table) and 7.9 (columns 1–4 only) in Silver et al. (1998, pp. 287–288), with the addition of any columns needed to complete your exchange curve analysis.

2. Develop an exchange curve of total safety stock (SS) in dollars versus expected total value short per year (ETVSPY) treating k as the policy parameter (in the same manner that you treated A/r as the policy parameter in problem 5.12). Hint: you will need to use Excel functions to find $P_{(u)\geq\ k}$ and the approximation technique in Silver et al. (1998), appendix C, to find values of $G_{(u)k}$.

The rest of the spreadsheet will be developed using the same general technique and structure as in problems 5.23 and 5.12, but with different variables.

Note: You should calculate expected total stockouts per year (ETSOPY) in your analysis, but it will not be needed for the graph.

Answer the following questions:

- What are the values of SS and ETVSPY for $k = 1.6$?
- What k value gives the same SS as the current rule?
- What k value gives the same ETVSPY as the current rule?
- Include a graph in your spreadsheet (similar to the graphs in problems 5.23 and 5.12).
- Explain how you would use this analysis to advocate a change in inventory policy to your top management team if your organization was operating under the constraint of holding exactly $7,450 in Safety Stock. What would your recommended reorder point be for each item?
- Explain the application, advantages, and managerial implications of using exchange curves in the practice of inventory management.

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