Extensions of the Newsvendor Model – Incorporating Real Life Scenarios Using Decision Analytics

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Decision Analysis is an important topic in the field of Operations Research. This article is a result of discussing the well-known newsvendor model in the classroom over many semesters. We present the newsvendor model in our MBA class but go beyond what textbooks provide. We extend this model by incorporating two specific real-life scenarios. We create the modified payoff table using spreadsheets. We then consider what-if scenarios and perform sensitivity analysis using the Data Table command in Excel. Important concepts like backordering/late shipment, cost of lost customer goodwill, and clearance pricing are discussed. The discussion of these concepts is extremely valuable even without spreadsheets.

Keywords: newsvendor model, decision analytics, inventory, spreadsheets, sensitivity analysis

INTRODUCTION

The paperboy was a common sight in several countries including the United States. Newspaper industry lore suggests that the first paperboy of New York, hired in 1833, was 10-year-old Barney Flaherty (https://www.irishcentral.com/roots/new-york-irish-paperboy.amp). The National Newspaper Carrier Day is celebrated each September in honor of Barney Flaherty, as well as every newspaper carrier today. Barney Flaherty was an entrepreneur (i.e., a newspaper hawker) where he bought newspapers to go on the streets and sell them but must incur the loss due to unsold copies. A newspaper hawker is not the same as the traditional paperboy. The paperboy has a regular route and earns a fixed amount of money each month. President Harry Truman, actors John Wayne and Bob Hope, TV journalist Tom Brokaw, cartoon great Walt Disney as well as investment wizard Warren Buffet all had paper routes when they were young (https://www.nbcnews.com/id/wbna12485231#.Xf0AA1VKiHs). Our article is about the *newspaper hawker* who incurs the loss of unsold newspapers. We will refer to this entrepreneur as the newsvendor or newsboy throughout this paper. According to a recent paper (Chen, Cheng, Choi and Wang, 2016), the term "newsboy" was first provided in an example in a book (Morse and Kimball, 1951). A newsvendor-type inventory model was examined and formulated in an influential paper (Arrow, Harris, and Marshak, 1951).

The basic newsvendor problem is found in textbooks related to operations research (Morse and Kimball, 1951) and management science (Gould, Eppen and Schmidt, 1993). However, for the benefit of the reader, we present it in the following section.

THE NEWSVENDOR PROBLEM

The newsvendor problem is a classic single period model where the newspaper has a fixed cost, has an uncertain demand and is perishable at the end of the day. In other words, it cannot be carried over to the next day as inventory. Similarly, since the newspaper is worthless at the end of the day, any unmet demand cannot be satisfied at a later date. Thus, the newsvendor problem is a special case of a single period model with a shelf life of one day. In the description below, we use the cost and revenue values given in a reputed textbook (Gould, Eppen and Schmidt, 1993).

A newsboy purchases a newspaper for 10 cents and goes on the street to sell it for 25 cents. If sold, it results in a profit of 15 cents. An unsold newspaper is worthless at the end of the day and results in a loss of 10 cents. Any unmet demand is essentially lost. The newsboy is *initially* assumed to sell in a new location with no history of past sales. Thus, he operates under uncertainty and needs to decide (on a daily basis) how many newspapers to purchase and then go on the street to sell them. If he buys too many, he must incur the loss of unsold newspapers. If he buys too few, he may not be able to satisfy potential higher demand. Only to make the problem small in size, we assume that the actual demand (A_t) for newspapers is either 0, 1, 2, or 3 on a given day. In other words, $A_t \in \{0, 1, 2, 3\}$ and the probability of each of these outcomes is unknown since the newsboy operates under uncertainty at first. However, since we assume only 4 outcomes, P(0) + P(1) + P(2) + P(3) = 1. Obviously, the newsboy has *four* possible decisions/forecasts he could make i.e., $F_t \in \{0, 1, 2, 3\}$. We now present the resulting payoff (profit/loss) table for this scenario of four forecasts (or decisions) and four actual demand (outcomes) values.

TABLE 1
PAYOFF TABLE

		Demand (A_t)		
Decisions (F_t)	**0**	**1**	**2**	**3**
0	0	0	0	0
1	-10	15	15	15
2	-20	5	30	30
3	-30	-5	20	45

Textbooks first discuss solution approaches for decision making under uncertainty. Some well-known approaches being (i) Maximax (optimistic); (ii) Maximin (conservative); (iii) Laplace (equal likelihood); and (iv) Minimax Regret. The discussion then focuses on the fact that the newsboy has been selling newspapers at that location for several weeks (or more) and also been collecting data of the actual demand for newspapers during this period of time. Based on this data collection effort, he is no longer operating under uncertainty but operating under *risk* (risk is another word for probability). Based on the data collected by the newsboy, let us assume the following demand distribution:

$$P(Demand=0)=0.1;\ P(Demand=1)=0.3;\ P(Demand=2)=0.4;\ P(Demand=3)=0.2$$

where P is probability.

Using the Expected Value (EV) Approach, we obtain the following EVs for the four possible decisions/forecasts.

$EV_0 = 0*0.1 + 0*0.3 + 0*0.4 + 0*0.2 = 0$;
$EV_1 = -10*0.1 + 15*0.3 + 15*0.4 + 15*0.2 = 12.5$;
$EV_2 = -20*0.1 + 5*0.3 + 30*0.4 + 30*0.2 = \mathit{17.5}$; and
$EV_3 = -30*0.1 + -5*0.3 + 20*0.4 + 45*0.2 = 12.5$

Thus, the recommended decision for the newsboy is to purchase two newspapers as it maximizes his payoff (17.5 cents a day on an average) in the long run.

Textbooks do not extend the newsvendor problem discussion to other single-period models with a shelf life of more than one day. In the real world, there are several products that are perishable in nature but have a shelf life of more than one day (fresh fruits, vegetables, bread, milk, eggs, magazines, etc.). Such products lend themselves to discussion of important concepts like *backordering (or late shipments*), *cost of lost goodwill* in the case of unmet demand, and *clearance pricing* in the case of leftover inventory. We discuss this in the following section in greater detail.

EXTENSION OF THE NEWSVENDOR PROBLEM

Newsvendor problems have been extensively studied by researchers and there is sufficient literature to support our rationale of extending the discussion of the newsboy model in the classroom. For example, a recent study extends the newsvendor problem with access to additional ordering opportunity during the selling season (Vipin and Amit, 2017). The study provides an example of a university bookstore ordering textbooks ahead of an academic term and later placing emergency orders on the excess demand. This is an example of a newsvendor problem under recourse option. Another recent study (Mitra, 2018) deals with clearance pricing of leftover inventory. Clearance sale is routine practice in the retail/apparel industry dealing with fashion or seasonal products (Hammond and Raman, 1994). Furthermore, the newsvendor model has been adopted to analyze issues in supply chain systems involving perishable and seasonal products. Other studies include the newsvendor problem with risk considerations (Eeckhoudt, Gollier, and Schlesinger, 1995; Chung, 1990). Thus, a classroom discussion of the newsvendor problem and its extensions to mimic real-life scenarios is necessary and enhances the learning experience of the students.

We wish to clarify that textbooks are not inaccurate in their discussion of the newsvendor problem. However, there are limitations since a newspaper is a special case of a single-period inventory model with a shelf life of only one day. Hence, we extended our classroom discussion to other perishables or seasonal products with a longer shelf life. This gave us sufficient leverage in the classroom to discuss concepts such as backordering/late shipment, loss of goodwill, inventory, and clearance pricing. This made the discussion very valuable and enhanced student participation. *Note that throughout this paper, we will continue to use the newspaper as the product but we will now assume that it has a shelf life of more than one day*. With this assumption, we state two limitations of the original newsboy model with a shelf life of one day.

Limitation 1. The basic newsboy model assumes that any unmet demand is essentially lost.

This indicates shortage i.e., $F_t < A_t$. With our assumption of a longer shelf life, we consider the possibility of some customers accepting late shipments when the vendor offers a discount (which is equivalent to a penalty for late shipments). Of course, there is also the possibility of some customers not willing to accept late shipments and this results in lost sales and thus, there is the cost of lost goodwill.

Limitation 2. The basic newsboy model assumes that leftover newspapers are worthless which results in a loss of 10 cents for each unsold newspaper (the cost at which the newsboy initially purchased it).

This indicates surplus (or inventory) i.e., $F_t > A_t$. With our assumption of a longer shelf life, we now consider the possibility of carrying leftover items as inventory. This means the items are sold later at a salvage/clearance price. Of course, it is also possible not being able to sell the leftover items at all. Note that the idea of inventory is not discussed in any textbook for the newspaper model (since it was assumed to have a shelf life of one day).

The following section provides the mathematics of payoff values in the case of shortage and surplus.

THE MATHEMATICS OF SHORTAGE AND SURPLUS

As stated earlier, a shortage occurs when $F_t < A_t$ and surplus occurs when $F_t > A_t$. We refer to these possibilities as Cases 1 and 2 and provide a detailed discussion and computation using numerical examples.

Obviously, $F_t = A_t$ implies that the product was delivered to the customer(s) on time resulting in maximum profit per unit (= 15 cents using the newsboy model related information presented earlier).

Case 1 (Shortage i.e., $F_t < A_t$)

There are two possible scenarios for this case.

Scenario 1: The customer accepts late shipment (equivalent to *backordering*) and the vendor may offer a discount (equivalent to penalty for late shipment). Although the discount offered depends on the vendor, we use a discount of 20% for this article. Since the original sale price is 25 cents, a 20% discount on this indicates a discounted sale price of 20 cents which results in a reduced profit of 10 cents (Note that the profit with no discounts is 15 cents).

Scenario 2: The customer does not accept late shipment. This implies lost sales and loss of goodwill. Typically, there is a cost associated with "loss of goodwill". We will use 12 cents per newspaper as the cost of lost goodwill in this discussion.

We assume that the above scenarios are equally likely to occur. Thus, there is a 50% probability that a customer accepts late shipment (resulting in a profit of 10 cents to the newsvendor) and a 50% probability of lost sales which results in a loss of 12 cents (i.e., cost for lost goodwill). The following example explains this shortage computation.

<u>*A Numerical Example*</u>: Consider $F_t = 1$ and $A_t = 2$. This indicates that 1 newspaper is sold for a profit of 15 cents. As for the shortage of 1 newspaper, there is a 50% chance of being backordered and eventually sold for a profit of 10 cents each and a 50% probability of lost sales. The computation of this shortage is:

$$0.5*10*(A_t - F_t) + 0.5*(-12)*(A_t - F_t) \Rightarrow 0.5*10*1 + 0.5*(-12)*1 \Rightarrow 5 - 6 = -1 \text{ cent.}$$

To make our Excel formula less cumbersome when creating a spreadsheet, we will refer to this value as Alpha i.e., $\alpha = -1$. This is the expected loss incurred each time there is a shortage of one unit. Note that this loss is only for that one unit in shortage. The overall payoff for this example is 15 – 1 = 14 cents though (since one unit was sold at a profit of 15 cents). Using the α notation, the overall payoff can be represented as $15 + \alpha$.

Case 2 (Surplus i.e., $F_t > A_t$)

There are two possible scenarios for this case too.

Scenario 1: The leftover product is carried over and we assume that it is eventually sold at a clearance price of 14 cents. This results in a profit of 4 cents.

Scenario 2: The surplus cannot be sold at all. This means a loss of 10 cents (cost at which it was purchased).

We assume these scenarios are also equally likely to occur. Thus, there is a 50% chance of selling an item at a clearance price (obtaining a profit of 4 cents) and a 50% probability of not being able to sell an item at all (resulting in a loss of 10 cents). The following example explains this leftover computation.

<u>*Numerical Example*</u>: Consider $F_t = 2$ and $A_t = 1$. This means, 1 newspaper is sold for a profit of 15 cents. As for the surplus/leftover newspaper, there is a 50% probability of being sold at a clearance price (with a profit of 4 cents) and a 50% probability of not being sold at all (a loss of 10 cents). The computation of this surplus is shown below:

$$0.5*4*(F_t - A_t) + 0.5*(-10)*(F_t - A_t) \Rightarrow 0.5*4*1 + 0.5*(-10)*1 \Rightarrow 2 - 5 = -3 \text{ cents.}$$

To make our Excel formula less cumbersome when creating a spreadsheet, we will refer to this value as Beta i.e., $\beta = -3$. This is the expected loss borne by the newsboy each time there is a leftover unit. Note that this loss is only for that one leftover unit. The overall payoff for this example is 15 – 3 = 12 cents though (since one unit was sold at a profit of 15 cents). Using the β notation, the overall payoff can be represented as $15 + \beta$.

Although we have used random values for the cost of "lost goodwill", discount for late shipments, and clearance price for inventory, the final values (–1 cent and –3 cents) for the above numerical examples seem to make sense intuitively as it implies that a shortage is better than surplus for perishable products.

We use the following table of values (Table 2) to create a modified Payoff Table (using α and β notation).

TABLE 2
VALUES

Cost of a newspaper = 10 cents/unit
Revenue (when sold on time) = 25 cents/unit
Profit (when sold on time) = 15 cents/unit

The α and β notation was used in the numerical examples presented earlier in this section. α = –1 indicates loss per unit due to shortage, and β = –3 indicates loss per unit due to surplus (or leftover unit).

TABLE 3
MODIFIED PAYOFF TABLE (USING α AND β NOTATION)

	Demand (A_t)			
Decisions (F_t)	**0**	**1**	**2**	**3**
0	0	α	2α	3α
1	β	15	15+α	15+2α
2	2β	15+β	30	30+α
3	3β	15+2β	30+β	45

We now use the following comprehensive Table of values (Table 4) to create a payoff table using Excel formulas. Additionally, let us assume the same demand distribution used in an earlier section (Gould, Eppen and Schmidt, 1993) i.e., *P(Demand = 0) = 0.1; P(Demand = 1) = 0.3; P(Demand = 2) = 0.4; P(Demand = 3) = 0.2* where P is the probability.

TABLE 4
COMPREHENSIVE TABLE OF VALUES

Cost of a newspaper = 10 cents/unit
Revenue (when sold on time) = 25 cents/unit
Profit (when sold on time) = 15 cents/unit
Discounted/reduced revenue for late shipment = 20 cents (since discount is 20% of revenue)
Discounted profit for late shipment = 10 cents
Cost associated with loss of goodwill = (12) cents where the parenthesis indicates that this is a negative number
Clearance price for surplus inventory: 14 cents
Profit for surplus inventory: 4 cents
Profit for unsold inventory: –10 cents (thus, a loss)

TABLE 5
MODIFIED PAYOFF TABLE (USING EXCEL FORMULAS)

	Demand (A_t)				
Decisions (F_t)	**0**	**1**	**2**	**3**	**EV** Expected Value
0	0	–1	–2	–3	*–1.7*
1	–3	15	14	13	*12.4*
2	–6	12	30	29	*20.8*
3	–9	9	27	45	*21.6*

Based on the EVs in the above table, it can be concluded that the optimal decision for the newsboy is to purchase 3 newspapers (although purchasing 2 newspapers results in an expected value that is fairly close). The above table can be easily created manually. However, we emphasize spreadsheets in the classroom for two reasons. One is that students must enhance their Excel skills. The other important reason is for students to look at some what-if scenarios by changing the following variables: probabilities, goodwill cost, and clearance pricing. A detailed set of instructions to create a spreadsheet for the above payoff table is provided in Appendix 1. We also provided two screenshots of how the spreadsheet looks before entering Excel formulas and after entering Excel formulas.

In Appendix 2, we look at some what-if scenarios by performing sensitivity analysis with the help of the Data Table command in Excel. We also provide a rationale for this analysis and interpret the results.

CONCLUSIONS

Since the newspaper has a shelf life of only one day, we extend the newsvendor model by now assuming a longer shelf life. Although still a perishable product, we assume that it can be sold for the next few days. We also assume that demand not satisfied on a given day can be replenished the following day. A longer shelf life is a realistic assumption as there are several products that belong to this class of single period inventory models (fruits, vegetables, etc.). The classroom discussion which earlier used to be limited, is now significantly enhanced by incorporating concepts like penalty for late shipments, clearance pricing, and cost of customer goodwill due to lost sales. The classroom experience is richer when these concepts are collectively factored into the discussion. Furthermore, it is an enriching experience for students as they are involved in creating the Excel spreadsheet. In addition to using the important IF function, they also gain an understanding on relative and absolute cell references. In addition, they are introduced to the Data Table command to understand and interpret sensitivity analysis and what-if scenarios.

ENDNOTE

1. The spreadsheet used in this exercise is available and the reader can obtain it from the author.

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APPENDIX 1: CREATING THE SPREADSHEET

Step-by-step instructions and related discussion for the modified Payoff table and expected values.

Our specific *cell address based instructions* are based on the instructor prepared spreadsheet. So, when a student has a question about a particular cell, it becomes easy to respond and guide the student.

Step 1: Open an Excel spreadsheet and INPUT the following data/text in various cells of the worksheet.

- D3, E3, F3, G3: Enter 0.1, 0.3, 0.4, and 0.2 respectively
- C4: Decisions
- D4, E4, F4, G4: Enter 0, 1, 2, and 3 respectively
- H4: EV
- C5, C6, C7, C8: Enter 0, 1, 2, and 3 respectively
- J3, J4, J5: Type *Cost*, *Revenue*, and *Profit* respectively
- K3: 10
- K4: 25
- J7, J8, J9, J10: Type *Shortage*, *Profit (LS)*, *Goodwill*, and *Alpha (α)* respectively
- K8: 10
- L8: 0.5
- K9: –12
- J12, J13, J14, J15: Type *Surplus*, *Profit (Cl)*, *Unsold*, and *Beta (β)* respectively
- K13: 4
- L13: 0.5
- K14: –10

Note: Since the above is merely data entry/typing, the instructor may eliminate the above Step. Instead, an Excel file similar to Figure 2 (see below) can be emailed to students.

FIGURE 1
A SCREENSHOT OF THE SPREADSHEET BEFORE ENTERING EXCEL FORMULAS

	0.1	0.3	0.4	0.2	
Decisions	**0**	**1**	**2**	**3**	**EV**
0	**D5**	**E5**	**F5**	**G5**	**H5**
1	**D6**	**E6**	**F6**	**G6**	**H6**
2	**D7**	**E7**	**F7**	**G7**	**H7**
3	**D8**	**E8**	**F8**	**G8**	**H8**

Cost	**10**
Revenue	**25**
Profit	**K5**

Shortage		
Profit (LS)	**10**	**0.5**
Goodwill	**-12**	**L9**
Alpha (α)	**K10**	

Surplus		
Profit (Cl)	**4**	**0.5**
Unsold	**-10**	**L14**
Beta (β)	**K15**	

Step 2: The students will now work with the instructor by entering Excel formulas in various other cells of this spreadsheet. We write the Excel formulas in a logical sequence and explain the formulas as we create this spreadsheet. Our first set of formulas will be for cells K5, L9, K10, L14, and K15.

K5: =K4 – K3 (i.e., Revenue – Cost)

L9: =1 – L8 (since we discussed only two possibilities for Case 1 i.e., shortage)

K10: =L8*K8 + L9*K9 (this computation was already discussed in a Numerical example)

L14: =1 – L13

K15: =L13*K13 + L14*K14 (since we discussed only two possibilities for Case 2 i.e., surplus)

We now enter the most important formula in cell D5 which essentially creates the modified payoff table.

D5: =IF($C5<D$4,$C5*$K$5+ABS($C5-D$4)*$K$10, D$4*K5+ABS($C5-D$4)*K15)

This formula would have been longer if we had not created Alpha and Beta values in cells K10 and K15 of the spreadsheet. Once this formula is entered in cell D5, the cells E5, F5, and G5 are easily populated by copying this formula and pasting it into these cells. This gives Row 1 of the payoff table. The remaining three rows of the payoff table are then populated by copying Row 1 and pasting it in Rows 2, 3, and 4.

Finally, we write an Excel formula for cell H5.

H5: =D5*D3+E5*E3+F5*F3+G5*G3

Cells H6, H7, and H8 are populated by copying this formula and pasting it into these cells. Thus, the modified payoff table with EV values is now complete and will look similar to Figure 3 below.

FIGURE 2
A SCREENSHOT OF THE SPREADSHEET AFTER ENTERING THE EXCEL FORMULAS

	0.1	0.3	0.4	0.2	
Decisions	**0**	**1**	**2**	**3**	**EV**
0	**0**	**-1**	**-2**	**-3**	**-1.7**
1	**-3**	**15**	**14**	**13**	**12.4**
2	**-6**	**12**	**30**	**29**	**20.8**
3	**-9**	**9**	**27**	**45**	**21.6**

Cost	**10**
Revenue	**25**
Profit	**15**

Shortage		
Profit (LS)	**10**	**0.5**
Goodwill	**-12**	**0.5**
Alpha (α)	**-1**	
Surplus		
Profit (Cl)	**4**	**0.5**
Unsold	**-10**	**0.5**
Beta (β)	**-3**	

APPENDIX 2: SENSITIVITY ANALYSIS

We perform sensitivity analysis to understand how the newsboy's decisions may be impacted due to changes in a certain variable. We use the Data Table command in Excel to perform sensitivity analysis.

Question 1: What would happen to the optimal decision if the probability of a customer accepting late shipment increases?

Rationale: The newsboy initially operates under uncertainty and no customer relationships have been formed yet. So, a shortage will most likely result in lost sales i.e., the probability of a customer accepting late shipment is very low. As the newsboy continues to sell in this location, he increases his customer base and increase the likelihood of customers accepting late shipments.

To address Question 1, we use the Data Table command to vary the probability of customer accepting a late shipment from 0 to 1 in increments of 0.1 (thus, a total of 11 values). This results in the following table.

Decisions	**0**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
0	**-20.4**	**-16.7**	**-12.9**	**-9.2**	**-5.4**	**-1.7**	**2.0**	**5.8**	**9.5**	**13.3**	**17.0**
1	**3.6**	**5.4**	**7.1**	**8.9**	**10.6**	**12.4**	**14.2**	**15.9**	**17.7**	**19.4**	**21.2**
2	**18.6**	**19.0**	**19.5**	**19.9**	**20.4**	**20.8**	**21.2**	**21.7**	**22.1**	**22.6**	**23.0**
3	**21.6**	**21.6**	**21.6**	**21.6**	**21.6**	**21.6**	**21.6**	**21.6**	**21.6**	**21.6**	**21.6**

Interpretation: The above table of EVs clearly indicates that as the newsboy builds his customer base and they accept late shipments, a shortage leading to lost sales is minimized. He can replenish the product the following day and minimize the cost of lost goodwill. Such analytics improves the newsboy's decisions.

Question 2: What would happen to the optimal decision if the probability of selling leftover items at clearance pricing increases?
Rationale: The newsboy initially operates under uncertainty and no customer relationships are formed at this stage. So, he is less likely to sell his leftover items at clearance prices. As the newsboy continues selling in this location, he increases his customer base and increase the likelihood of selling leftover items at clearance price.

To address Question 2, we use the Data Table command to vary the probability of customers accepting leftover items from 0 to 1 in increments of 0.1 (thus a total of 11 values). This results in the following table.

Decisions	**0**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
0	**-1.7**	**-1.7**	**-1.7**	**-1.7**	**-1.7**	**-1.7**	**-1.7**	**-1.7**	**-1.7**	**-1.7**	**-1.7**
1	**11.7**	**11.8**	**11.9**	**12.12**	**12.3**	**12.4**	**12.5**	**12.7**	**12.8**	**12.9**	**13.1**
2	**17.3**	**18**	**18.7**	**19.4**	**20.1**	**20.8**	**21.5**	**22.2**	**22.9**	**23.6**	**24.3**
3	**12.5**	**14.3**	**16.1**	**17.9**	**19.8**	**21.6**	**23.4**	**25.2**	**27.1**	**28.9**	**30.7**

Interpretation: The above table of EVs clearly indicates that as the newsboy improves his chances of selling leftover items, surplus or inventory would hurt his profits to a lesser extent. This is because he can now find customers willing to purchase his leftover items at a clearance price. Such data analytics enhances the newsboy's decision making. The newsboy will be less concerned about inventory.

There are many such "what-if" scenarios that could be considered. For example, the instructor could ask the student to create data tables to address the following questions and then try and interpret those tables.

Question 3: What would happen to the optimal decision if the cost of lost goodwill changes?
Question 4: What would happen to the optimal decision if the clearance sale price were different?