Anatomy of a Newsvendor Decision: Observations from a Verbal Protocol Analysis

Srinagesh Gavirneni
Johnson Graduate School of Management
Cornell University
Ithaca, NY 14853
sg337@cornell.edu

Alice M. Isen
Johnson Graduate School of Management
Cornell University
Ithaca, NY 14853
ami4@cornell.edu

Abstract

We report on the information gathering and decision making efforts of subjects involved in newsvendor decision making. Previous research in this area identified significant biases (e.g. anchoring and insufficient adjustment) in inventory decisions, but was unable to identify specific thought processes that led to these biases. We overcome this by using a "think-aloud" approach and recording the thought processes underlying the subjects' eventual decisions. A protocol analysis of the transcripts revealed the following interesting insights. Most of the decision makers sought the very basic information, but failed to seek the additional, but non-trivial, information that could have significantly influenced their decision. A majority of the subjects struggled to deal with the abstractness of the business setting and were very keen to know information on the product type, industry setting, decisions taken in the past, competitor's situation, and vendor environment that they felt would have put them on a firmer footing. A large portion of the participants correctly identified the overage and underage costs that needed to be considered, but failed to convert that information into the optimal order quantity. This suggests that the mathematics involved is not as intuitive as perceived by the research community. Finally, the bias of the order quantity was significantly influenced by the specific type of risk (overage or underage) that was identified closer in time to the decision making point which indicates the presence of a recency effect. That is, if a subject first mentioned the risk of excess inventory followed by the risk of unsatisfied demand, then his/her order quantity was high. On the other hand, if a subject first mentioned the risk of unsatisfied demand followed by the risk of excess inventory, then his/her order quantity was low.

Introduction

After many years of focusing on rigorous mathematical analysis of various decisions made in operational settings, researchers in the operations management community have only recently started studying the behavioral aspects of the decision making process. While it should not have been a big surprise, it was observed that the decisions made by real people were substantially different from the optimal decisions predicted solely based on mathematics. These observations resulted in a significant change in the way people approached research in operations management. Since it is difficult to summarize all of the experimental and behavioral research in operations management, we describe a few studies that are most closely related to this research. Readers interested in detailed reviews of behavioral operations management research are directed to Boudreau, Hopp, McClain, and Thomas (2003) and Bendoly, Donohue, and Schultz (2006).

Schultz, Juran, Boudreau, McClain and Thomas (1998) and Schultz, Juran, and Boudreau (1999) conducted experiments and, based on time taken and number of tasks completed, showed that the speed at which a worker performs his/her task is dependent on the inventory levels. Subjects worked faster when they had more to do and more slowly when they had less to do. This observation clearly invalidated the independence assumption common in literature on production lines. Croson and Donohue (2005a, 2005b) studied the behavioral factors associated with information sharing in a serial supply chain setting and showed that sharing point-of-sale data can alleviate the bullwhip effect, the phenomenon in which the variance of the orders gets amplified as they move up the supply chain.

Schweitzer and Cachon (2000) and Bolton and Katok (2006) focused their attention on the newsvendor problem, which deals with stocking level decisions that require balancing the costs associated with overstocking and understocking. Experiments conducted by Schweitzer and Cachon, studying end-point decisions over thirty periods, reported that there was a significant anchoring around the mean of the demand distribution and that subjects always chose a stocking level that was between the mean demand and the optimal quantity. Bolton and Katok (2006) confirmed this phenomenon in experiments over a longer time horizon and further demonstrated that experience and feedback could lessen the anchoring effect of the mean demand. We investigate newsvendor decision making further, attempting to find out more about the thought processes in play as people are making these decisions. We use audio recordings and protocol analysis of the transcripts to capture differences in the subjects' information seeking efforts and also to obtain a better understanding of the thought process involved in a stocking level decision in the presence of uncertain demand.

A decision making process can be broadly divided into the following three stages: (i) the information gathering phase, (ii) the analysis phase; and (iii) the final decision phase. The existing research in experimental operations management has thus far only focused on the results from the final decision phase. These experiments were not designed to capture and analyze information from the information gathering and analysis phases. Our study seeks to capture the information seeking efforts and thought processes that subjects go through while making their decision. Using audio recordings of the interactions between the subjects and the experimenter, we gain new insights into the behavior of decision makers in the newsvendor setting. We are particularly interested in identifying reasons that most decision makers fail to reach the optimal decision. Building on the work of Schweitzer and Cachon (2000) and Bolton and Katok (2006), we focus on the newsvendor setting.

It is often assumed that the process involved in solving the newsvendor problem optimally may be understood by people intuitively (see page 522 of Collier and Evans (2007) and page 316 of Jacobs and Chase (2007)). However, the preponderance of errors discovered by Schweitzer and Cachon (2000) and Bolton and Katok (2006) indicates that, in fact, people may not intuitively apprehend the correct procedure for solving such problems at all. The present study attempts to uncover more about the actual processes that are used by people in solving this type of problem, by recording and analyzing the thoughts that people have while solving the task, when they are asked to reason aloud. This method has been used previously in studying decision-making procedures (e.g.

Estrada et al. (1997), Isen et al. (1991), Isen and Means (1983)). Ericsson and Simon (1993) provide more details on using such procedures in experiments.

Before presenting the details of the experiment, the method, and the results, we summarize some of our main findings. We observed that subjects tended to focus on the basic information relevant to the decision and did not identify and seek some of the advanced information that would have helped them make a better decision. The participants had difficulty dealing with the abstractness of the task at hand and were very keen to identify anchors for their decision-making process. For example, they asked for information related to product and industry settings, decisions from the past, competitors' actions, and the vendor situation. In the absence of that information, they anchored their decisions around the mean demand, the only significant piece of the information available to them. Most of the subjects correctly identified the precise overage and underage costs, but failed to convert that information effectively into the optimal order quantity. This suggests that the percentile calculation (as described in page 522 of Collier and Evans (2007)) is not as intuitive as the operations management community perceives it to be. The risk identified closer to the decision played a major role in the bias of the order quantity chosen by the subject. Close to the decision, if the subject was focused on the risk associated with excess inventories, then his/her order quantity was lower. On the other hand if the subject was focused on the risk associated with unsatisfied demand, then his/her order quantity was higher.

The rest of this paper is organized as follows. The next section contains a brief description of the newsvendor model. Section 3 details the setup of the experiment. In section 4, we analyze the results from a protocol analysis of the transcripts. Section 5 contains the discussion and directions for future research.

The Newsvendor Model

The newsvendor problem deals with the decision of determining the stocking level when the demand is random. There is a profit (sales price minus the purchase price) with every unit that is sold, and when there is not enough inventory to satisfy the demand, the potential profit cannot be realized. When there is excess inventory that is not demanded, the money spent acquiring the product may not be fully recovered. The basic parameters of the problem are as follows:

c = purchasing price of a unit of product

p = sales price of a unit of product

$F(.)$ = cumulative distribution function of the random demand

Given this information, the optimal purchasing quantity can be computed as the $F^{-1}((p-c)/p)$. For example, if the demand is normally distributed with the mean m and standard deviation s, then the optimal stocking level would be $m+(z\times s)$ where z is the standard normal variable value associated with $(p-c)/p$. On the other hand if the demand is distributed uniformly between the lower and upper levels l and u respectively, then the optimal stocking level would be $l+(((p-c)/p)\times(u-l))$. Thus, once all these parameters are known, the optimal stocking level can be computed as described above.

This basic problem can of course be modified by other pieces of information, and as this information is incorporated, the optimal stocking level will be different. For example, there could be a penalty (in addition to the lost profit) associated with not having enough inventory when the product is demanded. This penalty is most commonly associated with loss of good will, as the customer may eventually purchase a competitor's product and that could result in loss of profits in the future. Alternatively, this cost could be interpreted as the incentive the business needs to give to the customer in order to compensate for the stock-out and retain him/her for the future. Another factor that may complicate the calculation is that there could be a salvage value associated with unsold inventory. This is the portion of the purchase price that can be recovered (on a secondary market) even if this product were not sold in the primary market. Suppose that the above mentioned penalty cost is b, and that the salvage value is s, then the optimal stocking level that balances the upside and the downside can be computed as $F^{-1}((p-c+b)/(p+b-s))$. In a real-world setting this type of purchasing decision can be further complicated by a number of other factors some of which are listed below.

Supplier Yield Rate: The product could have an inherent defect rate which may not be realized until the product has been received. In order to protect against these defects it would be necessary to amplify the newsvendor solution appropriately.

Supplier Volume Discounts: Many suppliers offer discounts for high volume orders. If that is the case, one needs to take note of the break points at which these discounts take effect. If these break points are close to the newsvendor solution, it might be better to increase the purchasing quantity in order to realize these discounts.

Customer Pre-commitments: It is also possible to communicate with the customers in order to draw more information about the probability of their purchasing a unit of the product. Such an inquiry would enable the decision maker to guarantee a minimum level of sales. Such strategies are most useful when the demands are highly uncertain and the downside (when compared to the upside) is quite large.

Demand Elasticity: While the newsvendor analysis assumes that the sales price has been exogenously determined, that is usually not the case in most business settings. The sales price can be altered if one were to realize that it could lead to more profits. In order to understand the impact of price changes on profits, one needs to know the elasticity of demand (i.e. the rate at which it changes with respect to changes in price). Once that information is available, it can be utilized in determining the appropriate sales price and the purchasing quantity.

Competitor Situation: In any business decision it is of course necessary to know what the competitor is doing. In this case, we may need to know whether our forecasts are in line with those made by the competitors. Also one could try to seek information about the pricing strategy that the competitors are pursuing. If they are planning to reduce their sales price in order to gain market share, we could take that into consideration and change our decision accordingly.

These extensions are by no means exhaustive, and decision makers placed in this setting may come up with other questions as they think about their decisions. In this experiment participants are encouraged to ask as many questions as desired, and their questions are answered by the experimenter, if the information is available.

Experimental Setting

In this section we describe in detail the experimental setup that we used to investigate the human thought process underlying the inventory control decision. Participants were first presented with a sheet that contained the details of the task, the business setting, and the method of the experiment:

Task Instructions

Task: Your task is to determine the purchasing quantity of a product for the upcoming selling season. The forecasting process placed the expected demand at a value of 10,000 but the actual demand is uncertain. You need to determine an order quantity that maximizes the profit for your company. If you order too much, you will incur costs associated with items left over and if you order too little, you will be foregoing profits that you could have otherwise collected. So you must choose the order quantity carefully.

Business Setting: You are the purchasing manager in a big company that sells many products to many market segments. Among other things, you are responsible for one specific product.

For the upcoming selling season you have to decide the stocking level of this product in order to appropriately meet the demand for that product. Your company is very successful in the market segments it participates in and has invested significant amounts of money in technology in order to remain one of the leaders in the business. As a result of these technological investments, a vast amount of information is available to every one in the company. You are allowed to ask the experimenter for information that you think could help you, but you need to be specific. Simply ask the experimenter for the information and if that information is available, it will be given to you. If it is not available, you will be informed of that as well.

Experimental Methodology: The methods behind this experiment use what is commonly known as a “think aloud” approach. As you perform your task, please express all the thoughts that enter your mind so that they can be recorded and analyzed. The experiment monitor is only present in the room in order to ensure that (i) the experiment runs smoothly, and (ii) to provide any information you request. This person is not an expert in issues related to this business context.

Time constraints: In order to ensure that the experiments are concluded in a timely manner, we have set a maximum time limit of 15 minutes for each participant. If this time limit is too restrictive, please express that and it will be noted in our analysis.

Once the subject has reviewed the instructions, he/she signals the experimenter that the study can be started. The experimenter makes sure that recording equipment is switched on, presents the subject with an answer recording sheet which looks as follows:

Please Record Your Answer Here

Subject No:

Order Quantity:

Notes and Calculations:

[additional space removed for compactness]

To enable the subject to start thinking aloud and also to refresh the subject's memory of the task details, the experimenter then reads aloud the following summary of the task instructions:

Task: Your task is to determine the purchasing quantity of a product for the upcoming selling season. The forecasting process placed the expected demand at a value of 10,000 but the actual demand is uncertain. You need to determine an order quantity that maximizes the profit for your company. If you order too much, you will incur costs associated with items left over and if you order too little, you will be foregoing profits that you could have otherwise collected. So you must choose the order quantity carefully.

You are allowed to ask me for any information that you think could help you, but you need to be specific. Simply say what information you need and if that information is available, I will give it to you. If it is not available, you will be informed of that as well.

The subject is asked to perform the task of determining the order quantity while thinking aloud. As and when questions arise as to the information required to make the decision, the subject can ask the experimenter to provide the information. While it is difficult to a-priori think of all the information the subjects could ask for, we have identified the following ten (the subjects were not informed of this number) pieces of information that could be the most likely candidates. The key words and representative questions are pointers for the experimenter so that he/she can figure out which piece of information to provide to the subject.

1. INFORMATION ON DEMAND VALUES

Key Words: Range, Minimum, Maximum, Demand Quantity

Representative Questions:

1. Is the demand uncertain?

2. What is the maximum possible demand?

3. What is the minimum possible demand?

4. What is the range of demand?

INFORMATION:

The demand could be as low as 0 units and as large as 20,000 units.

2. INFORMATION ON DEMAND RANDOMNESS

Key Words: Demand Distribution, Probability, Statistical Distribution

Representative Questions:

1. What is the distribution of demand?

2. Do we have the probability distribution function for the demand?

3. Is the demand normally distributed?

4. Is the demand equally likely between the minimum and maximum?

INFORMATION:

The demand is uniformly distributed between the minimum and maximum. That is, the demand is equally likely to fall anywhere between the minimum and the maximum. There is a 50% chance that the demand is below the mean and there is a 50% chance that demand will be above the mean.

3. INFORMATION ON SELLING PRICE, PROFIT MARGIN

Key Words: Sales Price, Profit Margin, ROI.

Representative Questions:

1. What is the sales price for this product?
2. Do we know how much it sells for?
3. What is the profit margin for this product?

INFORMATION:

The product sells for $900 a unit.

4. INFORMATION ON PURCHASE PRICE, PROFIT MARGIN

Key Words: Purchase Price, Profit Margin, Cost.

Representative Questions:

1. What is the purchasing price for this product?
2. How much do we pay for this product?
3. What is the profit margin for the product?

INFORMATION:

We pay $300 per unit to purchase this product.

5. INFORMATION ON SALVAGE VALUE, OVERAGE COST, HOLDING COST, LEFTOVER INVENTORY

Key Words: Salvage Value, Holding Cost, Overage Cost, Leftover Cost

Representative Questions:

1. Is there any salvage value for leftover inventory?
2. What happens to leftover inventory?
3. Can leftover inventory be salvaged?

INFORMATION:

Leftover inventory can be salvaged for $100 per unit. That is, we can receive a benefit of one hundred dollars for every unsold unit of inventory.

6. INFORMATION ON PENALTY COST, UNDERAGE COST, LOSS OF GOODWILL, BACKLOGGING COST

Key Words: Penalty Cost, Loss of Goodwill, Cost of unsatisfied Demand.

Representative Questions:

1. Is there any penalty for not meeting demand?
2. Is there any loss of good will when we do not have enough inventories to meet demand?

INFORMATION:

There is no loss of good will when we are unable to meet a customer's demand. We will however not be able to collect the profit margin we would have collected if we had the necessary inventory.

7. INFORMATION ON QUALITY, YIELD LOSS, PRODUCT RETURNS

Key Words: Quality Problems, Yield Losses, Product Returns.

Representative Questions:

1. Are there any quality problems?
2. Is there any yield loss?
3. What is the defect rate?
4. What proportion of the product is returned to the supplier?

INFORMATION:

After inspection, 10% of the units are returned to the supplier. It is not clear whether the products are damaged during shipping or defectively manufactured. We must order more than what we need in order to ensure the quality of products sold to our customers. We obviously will only pay for the good products we keep.

8. INFORMATION ON QUANTITY DISCOUNTS, PRICE BREAKS, VOLUME DISCOUNT

Key Words: Quantity Discount, Economies of Scale, Price Breaks

Representative Questions:

1. Are there any price breaks?

2. Is there any discount for larger purchases?

3. Can we get a volume discount?

INFORMATION:

The supplier offers a discount of 50 dollars per unit if the order quantity is at least 20,000 units. This discount is based on the order quantity and will not be affected by the number of defective units we send back to the supplier.

9. INFORMATION ON MANAGING DEMAND, CUSTOMER RELATIONSHSIP MANAGEMENT

Key Words: Customer Relationship, Reducing Demand Variance

Representative Questions:

1. Are there ways to reduce the demand variability?

2. Can we reduce the uncertainty in demand?

3. Is there a way to make demand more predictable?

INFORMATION:

Yes. We can invest $250,000 in a CRM strategy and ensure that the demand falls between 5,000 and 20,000 units.

10. INFORMATION ON RAINCHECKS, CAPTURING LOST DEMAND, MAINTAINNG GOODWILL

Key Words: Rain Check Discount, Coupons for Unsatisfied Demand

Representative Questions:

1. Do we have the ability to re-capture unsatisfied demand?

2. If we run out of products, can we ask the customers to come back later?

INFORMATION:

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We can give a $100 off coupon or rain check and be confident that
the customer will come back later for the product.
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Once the participant has acquired all the information he or she requests and has reached a decision, the order quantity is recorded on the answer sheet and the following concluding remarks are presented to him/her.

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CONCLUDING INSTRUCTIONS

Thanks once again for your participation. Once all the
participants have completed the experiment, we will send you an
email explaining the purpose of the study and instructions for
receiving your compensation. Until you receive this email, please
do not talk to any one about any aspects of this study. Thank
you.
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Participants: Twenty-one second-year MBA students who had expressed specific interest in operations participated in this study. They had been previously exposed to the newsvendor model in the classroom setting, but it is conceivable that they might have forgotten the mathematical details. In addition, having been involved in a course that had a number of factory visits and guest speakers from the industry, these students should have been in a position to ask the right questions. It is worth noting that the number of subjects used in this study is similar to or slightly larger than the number of subjects used in earlier decision making studies using verbal protocol analysis. Isenberg (1986) used fifteen subjects and Ball et al. (1998) used twenty. The incentive for participation was a flat (i.e. not impacted by the subject's performance) fifteen dollar payment.

Discussion of our Experimental Setting: Our experimental setting differs from the previously reported newsvendor experiments in many ways. Ours was a one time decision making situation whereas the earlier experiments studied these decisions in a repeated environment. In spite of this difference, we were pleased to observe the pattern of anchoring and insufficient adjustment reported in earlier literature. Based on the analysis of the order quantities chosen by our subjects, we are very confident in concluding that they behaved similar to the subjects in earlier studies. We, however, now have information on how these subjects reached these decisions.

Our experiment also differs in the manner in which information was presented. In the previous experiments, all the relevant information (such as costs, demand distribution) was given en-masse to the subjects. In our setting, only the most basic information (i.e. demand forecast) was initially told to the subjects. They had to obtain the rest of the information by specifically asking for it. This enabled us to determine which pieces of information they were able to recognize as being pertinent to this decision. As a result of the different subsets of information obtained by the subjects, each one would have a different decision that would be optimal for them. We evaluated the effectiveness of a subject's decision by comparing it to the optimal solution dictated by the set of information he/she possessed.

The previous experiments, with their emphasis on the end decision, were conducted in a computer laboratory setting. Our experiment, due to its emphasis on interaction and audio recording, was conducted individually in a small room with a one-on-one interface between the subject and an experimenter. The experimenter was not an expert on inventory control, but was trained (supported by the use of key words and representative questions) to understand what the subject could be asking for. As a result, there was always a chance that the experimenter misunderstood the information requests made by the subjects. We are glad to report that our protocol analysis of the transcripts did not identify any such errors.

The interaction between the subject and the experimenter was not designed to be a conversation and the subjects were made aware of this. For any information requested by the subject, the experimenter either: (i) acknowledged the availability of information and provided it; (ii) informed the subject that the information requested was not available; or (iii) reminded the subject that the request has to be specific. The idea behind designing the study in this manner was to simulate the availability of an information database (and not a domain expert) that the subjects could use to obtain any information that they felt could help them in their decision.

Many real world decision makers are intricately involved in the business environment in which they are making their decisions. This familiarity with the environment probably enables them to figure out the pieces of information that would be useful in their decision making. On the other hand, it is also possible that the real-world decision makers, due to their long term familiarity with the environment, get pigeonholed and fail to think about issues that are not in their immediate attention. Whatever the case may be, our subjects participated in the experiment in a clean, laboratory setting (not quite unlike earlier research) and we were not able to create the environment associated with a real business. It would indeed be interesting (in a future study) to see if the environment plays a big role in determining how the subjects approach this inventory decision.

Results from the Protocol Analysis

We transcribed each audio recording onto paper and performed a detailed protocol analysis of these transcripts. The analysis is divided into four segments. First we focus on the information gathering efforts of the subjects. Initially we focus on the information that was available in the experiment and later we describe the information that was extraneous to the experiment. After that, we focus on the mechanics of the inventory control decision and how the subjects approached it. Then we focus on the specific risks to which the subjects paid attention and how that impacted their order quantity decision.

Seeking Information that was Available

Ten pieces of information were available to the participants. Table 1 shows which information was sought by each subject. An '×' in a cell indicates that the subject sought and acquired that piece of information. Notice that most subjects asked for and obtained pieces 1 to 5 only. The other 5 pieces of information were requested by 2.4 subjects on average (ranging from 1 to 4). Only two pieces of information, namely purchase cost and selling price were acquired by all the subjects. The demand distribution (including the minimum and maximum) and the salvage value information were sought by two-thirds of the subjects.

This leads us to conclude that most of the subjects were able to recognize the major factors (costs and demand uncertainty) that play a role in the newsvendor inventory decision, but failed to recognize the importance of more advanced (or non-trivial) information that would have significantly influenced their decision.

Subject Number	Information Available									
	Demand Range	Demand Distribution	Selling Price	Purchasing Cost	Salvage Value	Loss of Goodwill	Quality Problems	Quantity Discount	Demand Management	Rain Checks
1	×	×	×	×	×					×
2	×		×	×	×					
3	×	×	×	×	×					
4	×	×	×	×		×				
5	×	×	×	×						
6			×	×						
7			×	×						
8	×	×	×	×	×					×
9		×	×	×	×					
10	×		×	×	×	×				
11	×	×	×	×	×	×				
12	×	×	×	×	×					
13	×	×	×	×	×		×	×		
14	×	×	×	×	×					
15			×	×		×				
16	×		×	×			×	×		
17	×	×	×	×	×					
18	×	×	×	×	×					
19		×	×	×	×					
20			×	×	×					×
21			×	×					×	
Total	14	13	21	21	14	4	2	2	1	3
Percentage	67	62	100	100	67	19	10	10	5	14

Table 1: Details on which subjects sought which pieces of the available information.

However, it is also interesting to see that 5 subjects (almost 25%) did not ask for demand distribution information. In the absence of that information, they have no choice but to anchor their decision to the mean demand.

Seeking Information that was not Available

Next, we focus on the efforts of our subjects in gathering information that was not available in the experiment. It should not be a surprise that, during the study, the subjects asked a large number of questions for which the experimental design did not have the information. While it is not clear whether having the information to those questions would have changed the way the subjects made their decisions, it is important to analyze those questions as well, since that could provide additional insights into the subjects' thought processes.

Information Sought	No. of Questions
What did we do in the past? Has there been a change this year?	17
Are there any storage and distribution costs or restrictions?	9
What is the Product? What Industry?	8
What are the competitors doing?	8
What is the customer base? Affordability? Market Size?	8
How was the forecast arrived at?	4
Is there any production capacity restriction?	4
Is the product perishable?	4
Can we place multiple orders in the season?	3
What is the length of a season?	3
Do you have the formula or equation?	3
Is the technology good? Is there new technology?	3
Who is the vendor? Where are they located?	2
What is the cost of capital?	1
What is the elasticity of demand?	1
What is number of stores selling this product	1
Are there any batch sizes in production?	1
What is the correlation between demand and order quantity?	1
Is it sold in the US or abroad?	1

Table 2: A summary of the additional pieces of information sought by the subjects

Table 2 contains the list of questions asked by the subjects and the frequency with which they were asked. Questions seemed to focus on different aspects of the business setting such as the product characteristics, where its utility came from, what other products the company manufactured, whether it was perishable, etc. Clearly, the subjects seem interested in creating a business environment for their decision making situation. It is striking is that more than two-thirds of the participants asked about the decisions made in the past, decisions made by the competitors, decisions made by the vendors, etc. Perhaps they were apprehensive about making a decision with sole responsibility and were looking for other sources to justify their decision. That is, they may have thought that if someone else such as the previous decision maker or a competitor made a decision similar to the one they were considering, they would be on firmer ground.

Order Quantities Chosen

Table 3 contains a summary of the order quantities selected and the time taken by each of the twenty-one participants in the study. A cumulative distribution of the order quantities is given in Figure 1. They covered the whole range of the demand. That is, the lowest chosen value was zero and the highest chosen value was 20000. Because of the availability of the transcripts, we can explore more about how the participants made their decisions. Order quantities may be classified into four different categories: (i) mean demand used; (ii) extreme value selected; (iii) optimal value chosen; and (iv) miscellaneous values.

Mean Demand Used

Six (#s 4, 9, 10, 11, 15, 20) out of the twenty-one subjects identified the mean demand (10000) as their order quantity. Two (#s 19 and 20) of these subjects did not ask for the minimum and maximum values of demand or its distribution. As a result, they were not able to figure out the variation in demand and decided to stick with the mean. Two other participants (#s 4 and 9) were not able to estimate (or even identify) the risks associated with overage and underage and as a result were not able to use the distribution information even though they had it available. Subject # 9 stated that he/she wanted to “be risk averse” and decided to go with the mean demand value. Subject #4 stated that he/she wanted to “order close to what I think will sell” and decided to order 10000 units. The remaining two subjects (#s 10 and 11) correctly identified the overage and underage costs as 200 and 600 dollars respectively. Subject #10 stated that “some operations model can be used” but could not figure out how to do it and decided to “sit at 10000”. Subject

#11 stated that he/she wanted to “go on the higher side of demand” but could not figure out what the extra quantity would be. So he/she decided to stay with the mean demand.

Selecting an Extreme Value

Four of the subjects (#s 8, 13, 17, and 21) chose an extreme value (0 or 20,000) as their order quantity. Subject # 8 chose an order quantity of zero because he/she asked for and received the information about the rain checks. Recognizing that $100 per unit is a small sacrifice to battle against the uncertainty in demand, he/she decided to order zero units. Subject #17 compared the profits realized from 0 and 20,000 units and decided that ordering 20,000 units was more profitable and decided to go ahead with that.

Participants 13 and 21 were able to obtain information that helped them to lean towards ordering 20,000. Subject # 13 asked for and received information on the price discount for ordering 20,000 units and the presence of a defect rate. He/she put those two pieces of information together and decided to order 20000 units. Subject # 21 asked for and obtained the information on the CRM strategy that guarantees that sales will be at least 5000 units. That encouraged him/her to order the full 20,000 units.

Ordering the Basic Optimal Value

Five subjects (#s 2, 5, 12, 16, and 18) figured out that the underage cost was three times the overage cost and used that ratio to determine that they should order three-fourths of 20000. This resulted in an order quantity of 15000 which would be the optimal order quantity if only the first five pieces of information were available. Three (#s 5, 12, and 18) of them knew all the information necessary for them to make this determination. Subject # 2, however, did not know the demand distribution but knew that the demand ranged from 0 to 20000. He/she must have guessed that the demand was uniformly distributed between the minimum and maximum. Subject # 16 knew the information on the defect rate and the quantity discounts, but ignored them while determining the order quantity.

Selecting Miscellaneous Values

The remaining six (#s 1, 3, 6, 7, 14, and 19) subjects chose order quantities ranging from 8900 to 12000. Three (#s 3, 14, and 19) of these subjects correctly computed the overage cost ($200) and the underage cost ($600) and had the demand distribution information available to them, but they were not able to put this information together to come up with a good order quantity. Rather, they recognized that they should be above the mean and not knowing how far above, they chose 11000 (subject # 3) and 12000 (subject #s 14 and 19) as their order quantities. Subject # 6 chose 12000 as his/her order quantity and upon closer examination, we realized that he/she did not have the demand distribution information. He/she was only aware of the selling price ($900) and the purchasing cost ($300). He/she however recognized that it "it is more costly to be under-stocked than over-stocked," and ordered 2000 (randomly chosen, we believe) above the mean demand.

The other two subjects (#s 1 and 7) chose 8900 and 9000 as their order quantities. A closer examination of their analysis showed that they made major mistakes in their analysis. For example, subject #1 somehow figured that the cost of stocking out is $700 per unit and the cost of overstocking is $800 per unit. Based on these costs, he/she estimated that the order quantity should be below the mean and decided to order 8900 units. Subject #7 only gathered the information on selling price and purchasing cost, and using that, he/she correctly calculated that he/she would need to sell 3,333 units to break even if he/she purchased 10,000 units. Not knowing where to go from there, he/she said that "to be conservative", he/she decided to order 9000 units.

<u>Relationship between order quantity and the number of questions</u>

Figure 2 contains a graph of the number of questions asked by the participants seeking information that was not available in the experiment versus the order quantity selected by them. Notice that those people who ordered close to the mean asked significantly more questions than the rest. A linear regression showed that this relation is marginally significant with a *p*-value of 0.11. As discussed above, the subjects who chose values ranging from 8900 to 12000 were the ones who seemed to have the most trouble with this task. They demonstrated a lack of confidence in solving this problem and this lack of confidence appears to have manifested itself in the number of questions they posed to the experimenter.

Subject Number	No. of Experiment Questions	Order Quantity	Time (seconds)	No. of Other Questions	Optimal Order Quantity	Order Quantity Differential
1	6	8900	593	3	13333	-4433
2	4	15000	621	5	15000	0
3	5	11000	538	0	15000	-4000
4	5	10000	727	1	13333	-3333
5	4	15000	860	2	13333	1667
6	2	12000	685	5	10000	2000
7	2	9000	529	7	10000	-1000
8	6	0	1219	5	6667	-6667
9	4	10000	290	1	13333	-3333
10	5	10000	676	8	15000	-5000
11	6	10000	998	10	15000	-5000
12	5	15000	593	1	15000	0
13	7	20000	713	2	20000	0
14	5	12000	791	3	15000	-3000
15	3	10000	897	9	10000	0
16	5	15000	676	5	20000	-5000
17	5	20000	603	1	15000	5000
18	5	15000	948	0	15000	0
19	4	12000	676	3	15000	-3000
20	4	10000	676	6	10000	0
21	3	20000	819	5	15000	5000

Table 3: A summary of the order quantities chosen by the twenty one subjects. The optimal order quantity reported here is specific to the subset of information that the subject acquired.

Summary of Observations on Order Quantities

1. Most of the subjects (19 out of 21) had reasonable logic in determining the order quantity. Only the remaining two (about 10%) subjects made analytical or logical mistakes that prevented them from reaching a reasonable decision. However for most of the subjects, the reasoning was not rigorous enough to lead them to the optimal decision.

2. Ten out of the 21 subjects used a parameter (minimum, mean, or maximum) of the demand distribution as their order quantity.

3. Five of the 21 subjects chose 15000, which would be the optimal order quantity if using only the basic (pieces 1 to 5) information that was available to them. These

are the subset of people who fully understood the newsvendor model, remembered it, and were able to use it.

4. Four participants chose values of 11000 or 12000, recognizing that they should choose a quantity above the mean, but could not figure out how far above the mean they should be.
5. In all there were six people who correctly computed the overage and underage costs and were aware of the demand distribution. They were unable to convert that information correctly into the optimal order quantity, however. This indicates that this computation may be the hardest part in the newsvendor calculation.
6. The people who seemed to be unsure (and chose a value close to the mean demand) of their solution tended to ask more questions for which the information was not available in the experiment.

Time Taken for the Decision

The time taken by the subjects to complete this study varied from 529 seconds to 1219 seconds. Figure 3 below contains a graph of the time taken versus the number of questions (those in the experiment and those that were not) asked by the participant. Notice that those who spent more time asked more questions that were included in the experiment. In addition those who took longer asked more questions that were not included in the experiment as well. The interesting issue is whether this increase in number of questions enabled them to make better decisions. Figure 4 contains a graph of the time taken by the subjects versus the error in their order quantity. There is no clear trend in the graph. We repeated this analysis using the percentage error as the measure of performance and there was no trend in that data as well. Thus, we conclude that while the people who took longer asked more questions, their decisions were no better.

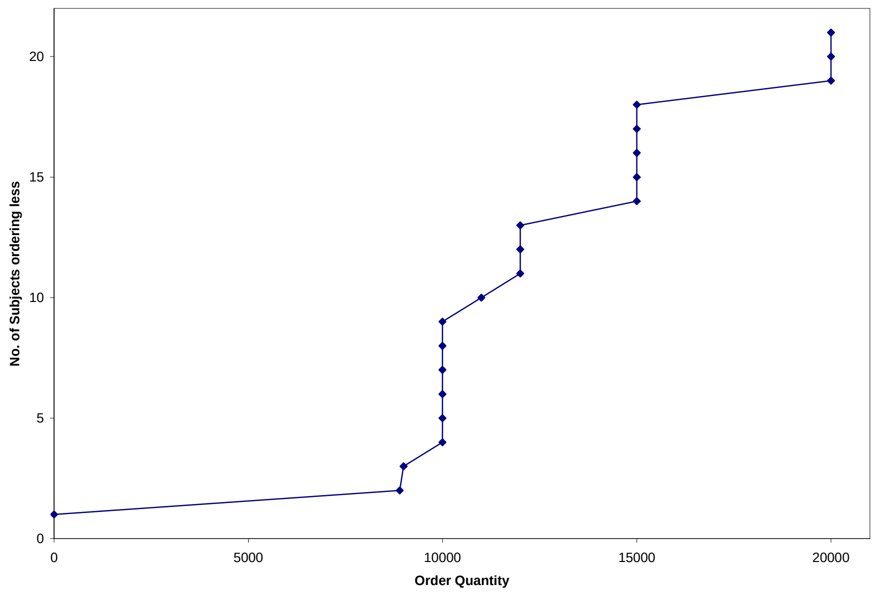

Figure 1: Cumulative distribution of the order quantities chosen by the subjects

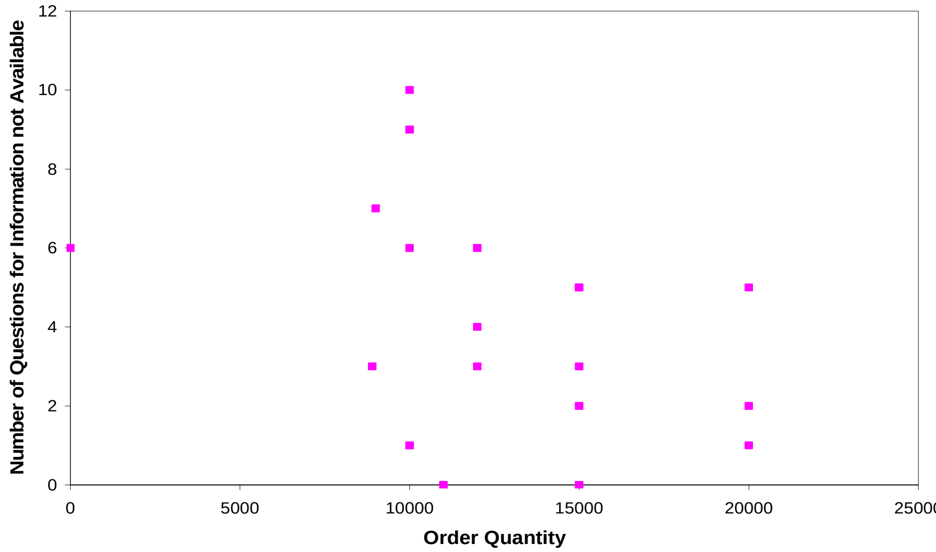

Figure 2: A plot of the order quantity versus the number of questions seeking information that was not available in the experiment

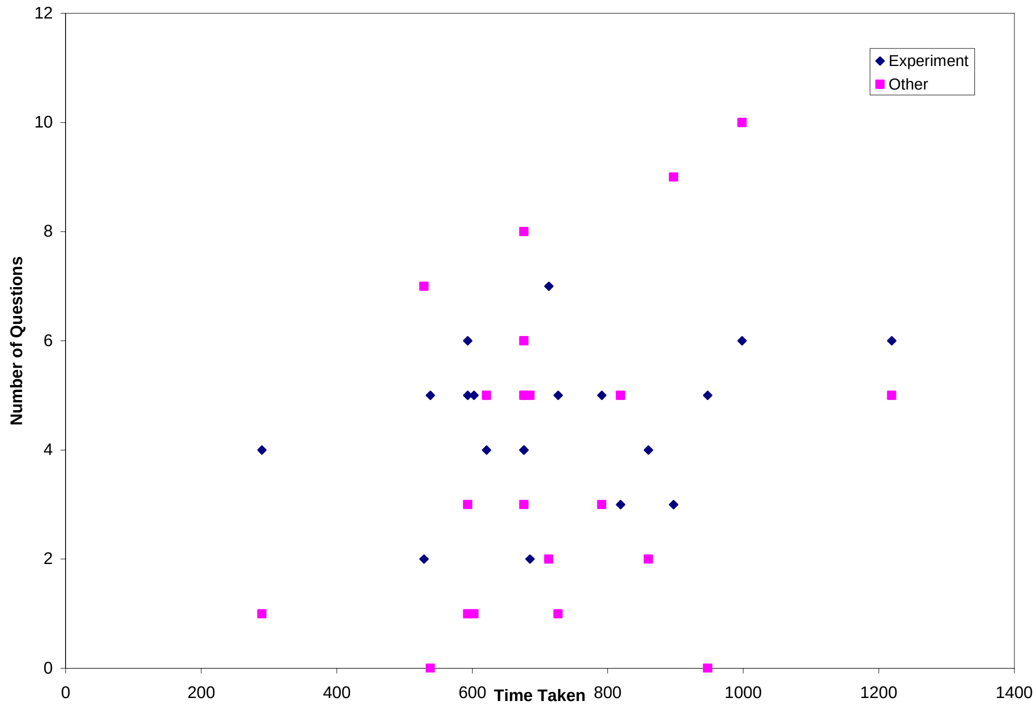

Figure 3: Plot of the time taken versus the number of questions (experiment and the other) asked by the subjects

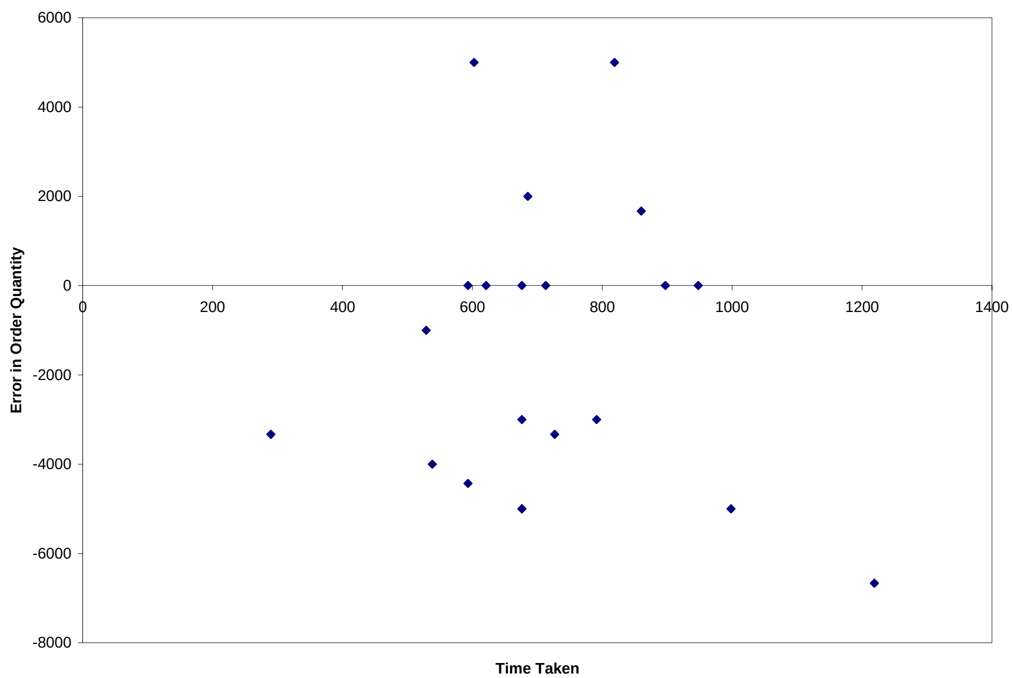

Figure 4: A plot of the time takes versus the error in the order quantity decisions of the subjects.

Subject Number	First identified risk	Order quantity	Bias in the order quantity
1	Underage	8900	-4433
2	Overage	15000	0
3	Overage	11000	-4000
4	Underage	10000	-3333
5	Underage	15000	1667
6	Overage	12000	2000
7	Overage	9000	-1000
8	Underage	0	-6666
9	Underage	10000	-3333
10	Overage	10000	-5000
11	Underage	10000	-5000
12	Underage	15000	0
13	Overage	20000	0
14	Underage	12000	-3000
15	Overage	10000	0
16	Overage	15000	-5000
17	Underage	20000	5000
18	Overage	15000	0
19	Underage	12000	-3000
20	Underage	10000	0
21	Overage	20000	5000

Table 4: First identified risk and the bias in the order quantity

Risk Identification Sequence and its Impact on Order Quantity

Here we focus on the sequence in which the risks were identified by each subject and how that impacted their order quantity decision. For each subject, from the protocol analysis we were able to determine whether he/she was first focused on the risk of excess inventory or the risk of unsatisfied demand. We were also able to determine the time at which they identified that risk. We attempt to relate that information to their eventual order quantity decision. Table 4 contains the details of that analysis.

Ten subjects first identified the overage risk (the risk associated with excess inventory), while the other 11 subjects first identified the underage risk (the risk associated with unsatisfied demand). For the participants who identified the overage risk first and the underage risk later, the average order quantity was 13,700 units. On the other hand, for those who identified the underage risk first and overage risk later, the average order quantity was 11,173. This trend was also present in the bias (distance between the subject's decision and his/her optimal solution) of the order quantity. For the subjects who identified overage risk closer to the decision, the order quantity was on the average 800 units below the optimal value. On the other hand, for those who identified the overage risk closer to the decision, the order quantity was on the average 2,000 units below the optimal value. While this difference, illustrated in figure 5, was only marginally significant (the one-tailed *p*-value was 0.203), the trend indicated the presence of a recency effect which is known to exist (see table 1 in Hogarth and Einhorn (1992)) in complex tasks with end-of-sequence processing of information.

Discussion

Based on the results observed from the protocol analysis of the subjects' thought processes while making the newsvendor decision, we can draw a number of insights into how inventory decisions can be improved. The most striking observation was that more than eighty percent of the subjects failed to identify non-trivial information that would have made significantly impacted their decision. Such information included quantity discounts, possibility of rain checks, yields, etc. It seems necessary to provide training that enables the decision makers to seek and obtain "out-of-the-box" information that could have a significant impact on their decision. It is such creative thinking (more than any mathematical analysis) that provides the business with a competitive edge and thus it must be fostered.

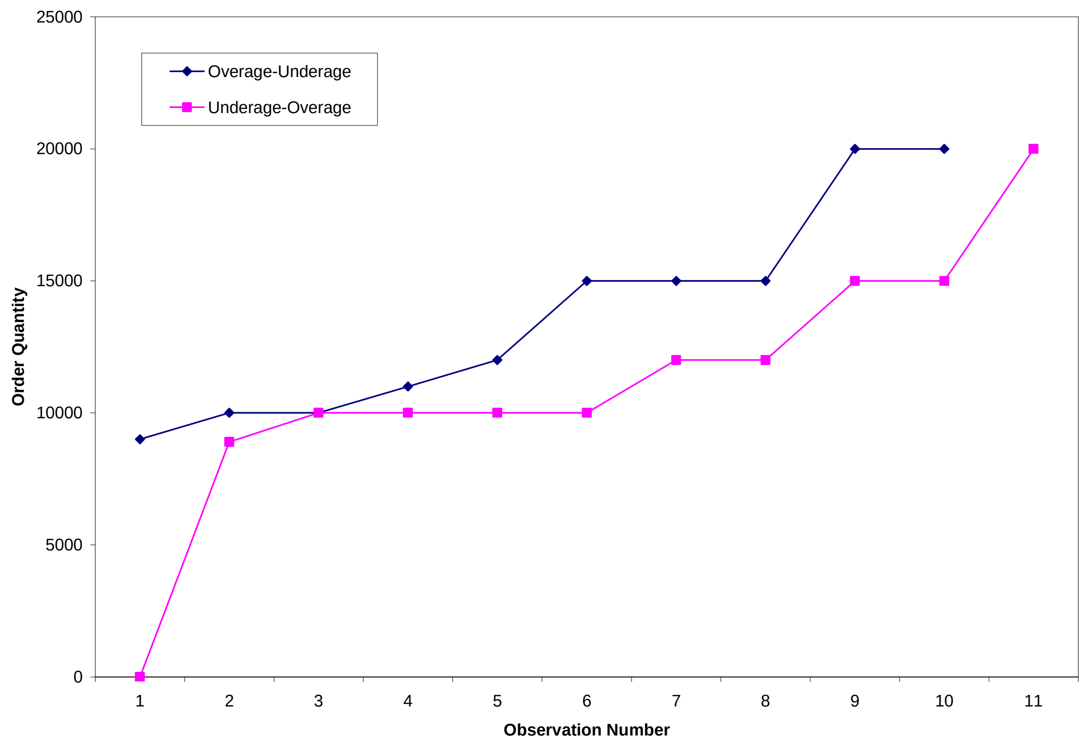

Figure 5: A plot of the order quantities chosen by the subjects as a function of the sequence in which they identified the risks associated overage and underage.

Almost half of the subjects were able to compute the overage and underage costs correctly, but failed to convert them into the optimal order quantity. This clearly indicates that (i) computation of the critical fractile; and (ii) taking the inverse of the cumulative distribution are not easy for the decision makers to remember and replicate. One way to overcome this problem is to encourage the decision makers to use computer based decision support systems. These decision support tools can be utilized via user friendly spreadsheets, but the decision makers must be encouraged to use them. It is important for everyone to realize the solution cannot be determined by intuitive reasoning alone.

It is interesting to note that the decision makers are looking for additional information (decisions in the past, competitor's decision, etc.) that would give them clues about how much to order. In the absence of that information, it is quite clear that many anchor their decision to the mean demand. It makes us wonder how the subjects would have reacted if they were provided with this additional information. Would they still have anchored to the mean demand or would they have anchored their decision to a quantity closer to the optimal solution. We plan to study this issue more rigorously in future research.

The sequence in which the subjects identified the two risks in the problem appears to play a key role in the amount they ordered. However their decisions would have been much better if they had focused on the magnitudes of the risks and not emphasized the one that was identified closer to the decision. It is imperative to think about strategies that would enable the decision makers to focus more on the quantitative aspects of the risks and less on their sequence of identification. Certainly, the use of computer based decision support systems would help in this regard as well. But we also wonder if effective managerial oversight could help the decision makers avoid or mitigate these behavior patterns.

Conclusions

In this paper, we reported our observations on the decision makers' thought processes while making a newsvendor decision. We were able to achieve this via protocol analyses of audio recording of participants' verbalization of their thoughts while solving the problem. These transcripts allowed us to understand the information-gathering efforts of our subjects and also further decipher how they used that information to make their inventory decision. Thus, this study illustrates how this technique may be used to investigate the processes of operational decision making.

We first observed that most of the subjects only sought the most basic information and failed to recognize the possibility of additional, non-trivial information that could have helped them in their decision making process. Further, we observed that subjects had significant trouble with the abstractness of the problem setting and asked a number of questions aimed at removing this abstractness. Once the information was available, most participants were able to compute the overage and underage costs accurately, but failed to couple that with the demand information to determine the optimal inventory level. This led us to believe that computation of the critical ratio (and the subsequent conversion of that to the inventory level) is not as intuitive as commonly perceived by the academic community.

Finally we noted the sequence in which the two risks (overage and underage) were identified by the decision makers and observed that this sequence had a significant impact on the order quantity chosen. Those who first identified overage risk ordered a larger amount of inventory, while those with the other sequence (underage risk followed by overage risk) order a smaller amount of inventory.

In addition to providing several insights into the decision makers' thought processes, this research raised a number of issues that could be addressed in future research. One example of such future research is a deeper investigation into the recency effect and identifying strategies to effectively mitigate it. Another idea for future research would be to investigate the impact of managerial oversight (which was completely absent in the previous experiments) on the effectiveness of the decisions.

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