12-21-2010

A Simulation to Illustrate Periodic-Review Inventory Control Policies

Matthew J. Drake
Duquesne University, drake987@duq.edu

Kathryn Marley
Duquesne University, marleyk@duq.edu

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Abstract

Within an undergraduate or graduate operations management course, inventory management is a critical area of learning and understanding for all students. This teaching module usually includes a discussion of the differences between continuous (Q) and periodic (P) review inventory systems. In our teaching, we have found that the most difficult concept for students to grasp is the concept of the review interval for the periodic review system. Therefore, in this paper, we develop a simulation using Crystal Ball to demonstrate for students the importance of using the review period of P+L in a periodic review system and how using this interval protects a firm more adequately against stockouts. This tool also provides an opportunity to introduce simulation concepts into operations management courses that do not normally have time to present these concepts.

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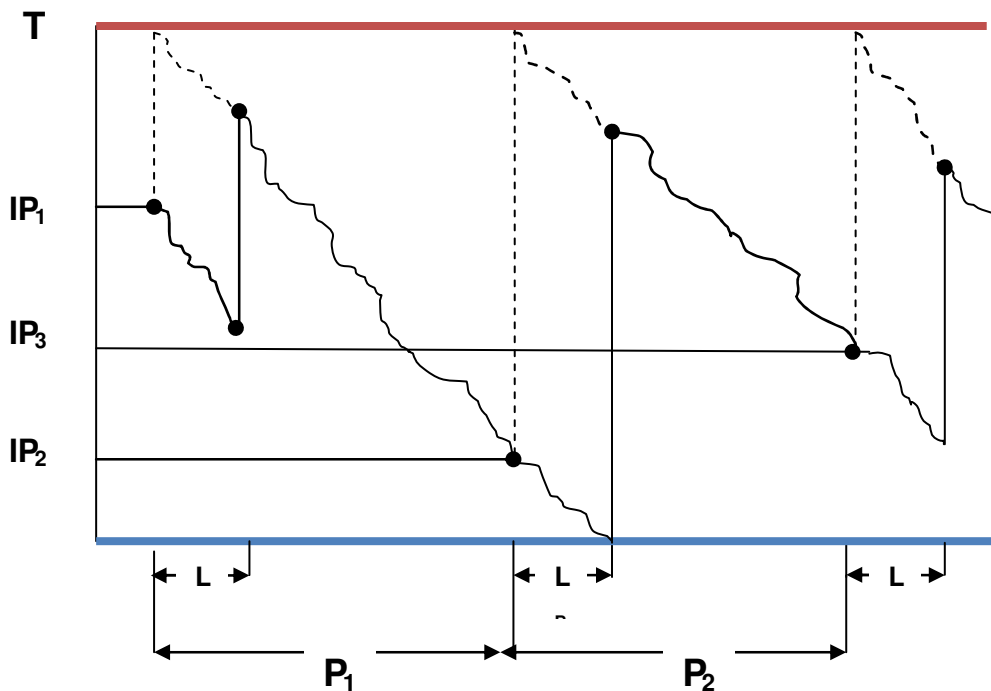
1. Introduction

Every introductory undergraduate and graduate Operations Management course is likely to spend a significant amount of time covering the basic principles of finished goods inventory control. Within this discussion, two major questions that are addressed are "how do firms know when to order?" and "how much do they order?" Understanding these concepts requires the students to be familiar with topics such as lot sizing rules, reorder points, target inventory levels, and protection intervals.

Often, these topics are discussed within the context of two inventory management systems - the Continuous Review (Q) system and the Periodic Review (P) system. In a Continuous Review (Q) system, an organization perpetually monitors its inventory levels and places an order for a fixed quantity (Q) when the inventory drops below a predetermined reorder point. In this kind of system, orders can be placed at any time because they are dependent on the actual demand. A Periodic Review (P) system is used when organizations only monitor their inventory levels on a periodic basis or want to establish a consistent order and delivery frequency with their suppliers. This policy usually requires a person to observe the current inventory level at a consistent point in time (e.g., the end of a work week) and to place an order to return the current inventory position to a predetermined order-up-to level, often referred to as the Target Inventory Level. This desired order-up-to level is designed to cover the demand for the product over the order lead time (L) plus the length of the review period (P). This time period, computed as (P+L), is referred to as the *protection interval* because it is the period of time that a firm must rely on its safety stock to "protect" against a stockout [9]. This teaching brief focuses on the importance of the protection interval in a periodic review system.

Within academic literature, the periodic review system has been well-researched, including the major reasons for its implementation. Many of these studies emphasize the ease in which it can be managed and coordinated and low transportation and ordering costs as motivating factors; while the downside of implementing a periodic review system is the increased time period (and, therefore, inventory) that is necessary to protect against stockouts [13], [14], [15]. Research has addressed such issues as the cost comparisons of implementing a periodic review system versus a continuous review system [2], the use of stochastic review intervals [15] or stochastic lead times [10], the option of placing emergency orders when stockouts are pending [14], and the effect of a fluctuating environment on periodic-review decision making [11]. In addition, two of these concepts (i.e., lot sizing and inventory management decision making) have been the subject of pedagogical articles to enable students to better understand these ideas [5], [12]. Several authors (e.g., [1], [4], [6]), have recently developed in-class simulation activities to help students understand the dynamics of inventory management.

2. Protection Interval Graph

Many Operations Management textbooks use an inventory graph such as the one in Figure 1 to explain the rationale for the using the protection interval to determine the optimal size of the order quantity.

Figure 1: Inventory levels over time under periodic review (adapted from [9])

Unfortunately, it has been our experience that many students at all levels have difficulty understanding this concept. In the first period represented in Figure 1, the reasoning behind using the protection interval (P+L) to determine the order quantity is clear. At the beginning of the period (P_1) an order is placed and the Inventory Position (IP $_1$) immediately increases up to the Target Inventory Level (T). Then throughout the duration of the period (P), the inventory decreases and continues to decrease beyond that point to include the subsequent lead time (L_B). This is because the order placed at the beginning of P_2 will not be received until the end of the lead time (L_B); therefore the inventory level will continue to decrease until the lead time expires [9]. Because of this, firms must use safety stock to protect themselves against stockouts. For example, if at the beginning of a review period (i.e., P_1) demand for a product is unusually great, then the amount of safety stock must be sufficient to not only cover until the inventory is reviewed again (P_2) but also until the order placed at P_2 is received [8].

The major point of misunderstanding for students that we have found comes from the fact that the lead-time overlaps the length of the review period. For example, at the beginning of P_2, another order should be placed and the order quantity should cover the protection interval, which would be $(P_2 + L_c)$. However, the order that was placed at the beginning of P_1 already considered L_B, so many students argue that the subsequent protection interval should not "recount" L_B and should be $(P_2 + L_c - L_B)$ or simply (P_2) to take into account this overlap. We developed the simulation model discussed in the next section to help explain why the protection interval must be P+L to provide sufficient protection against stockouts.
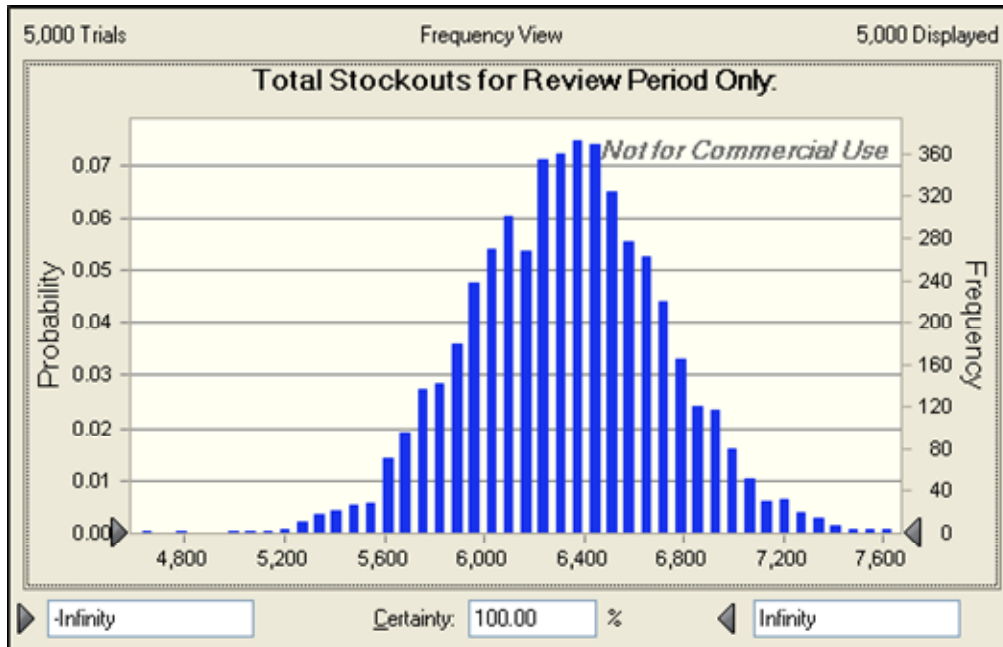
3. **Simulation Model of a Periodic Order System**

After countless attempts to explain the interval overlapping issue (including Cachon and Terwiesch's [3] innovative "soup line example"), some students still would not believe that the protection level formulas were correct. It did not seem as if additional derivations of standard deviations from probability theory would convince them either. We then realized that this situation was a perfect opportunity to introduce the technique of simulation as a tool that can be used to analyze scenarios that are not analytically tractable for the decision maker. Through this simulation model, we decided to simply "try out" the two protection levels (P and P+L) to see which one worked better by building a spreadsheet simulation model. This was especially valuable in a course in which we do not usually have time to cover simulation techniques.
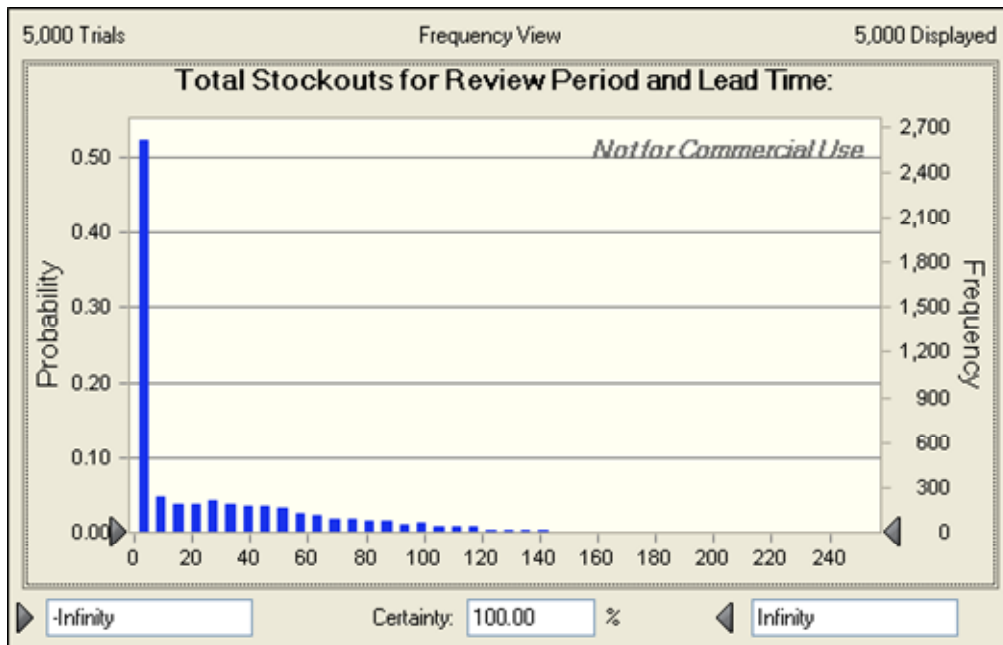
The inventory model provided in the Excel file Order-Up-To Simulations.xlsx[1] uses Crystal Ball to simulate one year's worth of daily demand observations and monitors the total daily stockouts accumulated over the year. We purposefully made the model as simple as we could because a more complex model, we feared, would make the protection interval even more confusing for our introductory students to understand. The model assumes IID normal daily demand with a review period of 10 days and a lead time of 6 days. Figures 2 and 3 depict the frequency distributions of total accumulated stockouts for the protection levels P and P+L, respectively, based on 5,000 replications. Figures 4 and 5 display the frequency distributions of the cycle service levels for the protection levels P and P+L, respectively, for the same 5,000 replications.

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[1] The simulation is available for instructor use by accessing the first author's website.

Figure 2: Frequency distribution of total stockouts under protection level P

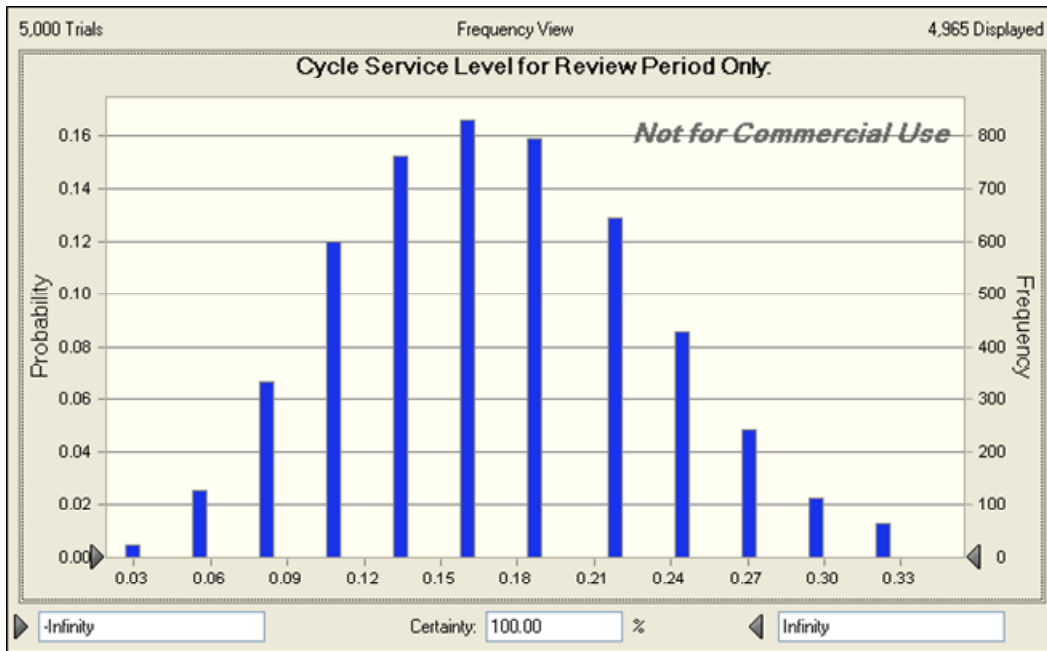**Figure 3:** Frequency distribution of total stockouts under protection level P+L

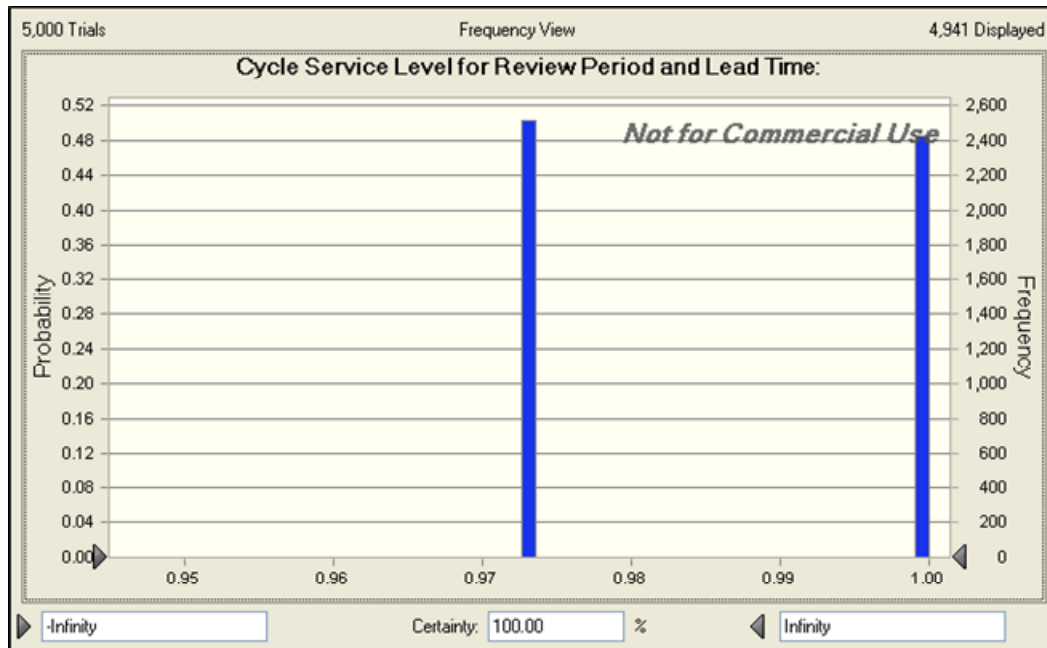**Figure 4:** Frequency distribution of cycle service level under protection level P

Figure 5: Frequency distribution of cycle service under protection level P

It is obvious from the simulation results that the protection level P+L does a much better job in meeting the desired service level of 98%. The protection level P results in an average accumulated annual stockout of approximately 6,300 units, which is quite large considering that the average daily demand is only 100 units. The cycle service level graphs are even more convincing. The P+L protection level never dips below a level of 97% in the replications shown, while the P protection level yields a service level no better than 33% in any of the replications displayed.

The spreadsheet simulation model is flexible enough for instructors to conduct various kinds of sensitivity analysis that they deem appropriate. They can adjust the parameters of the spreadsheet model to analyze the impact of changes in variability, service level, or demand distribution. It is also possible to extend the model to one that monitors the total inventory and stockout costs over the year by computing average inventory per day and assigning a cost to each unit stocked out for a day. Instructors could also adjust the review period and lead time lengths, but that would involve copying and pasting the formulas in the "Units Ordered" and "Units Received" columns of the spreadsheet at the intervals appropriate for the new review period and lead time values.

This simulation model could be used in several different ways in a graduate or undergraduate course that covers inventory control, depending on the instructor's goals and objectives. At a minimum, an instructor could present the simulation output graphs after the initial discussion of the protection level for the periodic-review model to clear up confusion that students may have. An instructor could also ask the students how they could convince a colleague or manager who had doubts about the protection level value of P+L versus P. Hopefully the students (maybe with some guidance) could come to the idea of trying both values to see which is better. This would allow the instructor to explain how simulation modeling allows an analyst to "try" policies quickly without having to wait months and years for the results to materialize. Then the instructor could discuss this specific simulation model and the results.

The approach described here would work particularly well in Operations Management courses that spend some time emphasizing the "clockspeed" approach to operations strategy developed by Charles Fine in [7]. The concept of "trying" certain strategies and observing how they perform in simulated time correlates well to Fine's notion of studying the "fruit flies" of business.

Another possible application of our simulation could be in courses or programs that do teach simulation modeling. Here, students could be asked to create the periodic-review simulation model themselves with only limited understanding of the mechanics of the periodic review model (i.e., the inventory manager looks at the on-hand inventory at the end of the review period and places an order to increase the inventory level to a predetermined order-up-to level). In this case, it is probably better that the students *do not* know the analytic solution to the problem. That way, the

example better illustrates the power of simulation as a practical way to model problems that a manager cannot examine analytically. In our experience, this would be an excellent application in general management science or simulation methodology courses, which can always benefit from real-world applications of specific decision methodologies.

An instructor could present the students with the following managerial scenario and ask them to build a spreadsheet simulation model to investigate the optimal order-up-to level to achieve the desired service level with the minimum inventory investment. This could be used for either an in-class discussion or as an individual or group homework assignment.

> *The campus bookstore stocks a wide variety of office supplies to satisfy its students' last-minute needs. To minimize the effort required to manage the inventory, the store places orders at the end of business every other Friday. This corresponds to a review period of 10 days because the store is only open on weekdays. The average demand for notebooks is 100 per day with a standard deviation of 25 per day. Orders to the supplier take 6 days to arrive at the bookstore. The bookstore strives to manage its inventory of notebooks to ensure a cycle service level of 98%. Assume in your analysis that the bookstore currently has 500 notebooks on-hand. What order-up-to level should the bookstore use for notebooks?*

4. Classroom Experience

We presented this simulation model in our MBA Operations Management and Forecasting, Production Planning, and Inventory Control courses after our initial discussion of the periodic-review inventory model that included a depiction of the inventory dynamics *a la* Figure 1. Rather than just showing them the results in Figures 2 through 5, we discussed the idea of simulation models in general and demonstrated how to use Crystal Ball to build the model. The students reported that the model helped them understand why the protection level in the periodic review inventory model had to be P+L instead of just P. The simulation ended the confusion about the inventory graph in Figure 1, and at the same time it allowed us to display the power of simulation modeling to our students so that they can build simple simulation models in the future to "try out" certain policies if they cannot arrive at an analytical solution. This discussion utilized approximately 15 or 20 minutes of class time, but it was well worth it to clear up many students' misconceptions about periodic-review inventory control and to demonstrate the value of simulation in the analysis of problems that the students cannot solve analytically. This is a tool that will serve them well in their future

managerial careers, because they will often be faced with these kinds of complex decision scenarios.

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