Project #19: Use Monte Carlo simulation to develop a newsvendor problem application. Make it pretty and interesting to use.

Project Group 122:

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Abstract

The newsvendor problem is a classic optimization problem in supply chain management, where the goal is to determine the optimal inventory level to maximize profit when the demand is unknown, goods may be perishable or seasonal, understocking leads to lost sales, and overstocking results in additional holding cost.

The approach suggested to use is Monte Carlo simulation to model random demand, this way we can evaluate profits across a range of inventory levels. Simulated demand values are generated using a LCG implemented as we saw in class and by selecting a distribution we suspect the demand follows. By running multiple iterations of the simulation, we will calculate the optimal order quantity that maximizes profit.

The use case intended is to answer the question “I have observed a range of 0 to 80 products sold in the last 15 days and I believe the demand has a normal distribution; considering all cost variables, what would be the optimal inventory level to maximize profit.”

For the application component of our project, we decided to use Shiny, which is a free open- source R package that makes it easy for teams to build and deploy interactive web applications. We used shinyapps.io as server for deployment and hosting of the app.

Major finding ???

Background & Description of the problem

The newsvendor problem is a foundational concept in operations management, first introduced by Edgeworth (1888) in the context of a bank determining optimal cash reserves to meet customer demands. Edgeworth utilized the normal distribution to estimate the probability of meeting demand. The term "newsboy problem" was later coined by Morse and Kimball (1951), who applied marginal analysis to derive the critical fractile solution. In the following decades, the problem gained broader recognition under various names, including the "Christmas tree problem." By the 1980s, the term "newsvendor problem," suggested by Matt Sobel, became the standard nomenclature. The name stems from a hypothetical scenario where a newsvendor decides how many newspapers to purchase without knowing the exact demand for the day.[1]

The newsvendor problem is a mathematical model in operations management that addresses inventory decisions under uncertain demand. It involves determining the optimal order quantity to maximize profit when a decision must be made before observing demand. Key characteristics include random demand, fixed prices, and overage or underage costs associated with surplus or insufficient inventory. The model is particularly relevant for perishable products, where unmet demand results in lost sales, and unsold inventory is salvaged at a lower price.[2]

The basic formulation of the newsvendor problem considers two scenarios: when the inventory exceeds the demand (Q>D) therefore the demand is fully met but there is inventory remaining, and when demand exceeds the inventory (Q≤D) therefore there is no inventory left. According to [2], the profit function *R(Q)* is given as:

Here, *p* represents the product's selling price, *c* is the unit cost, *Q* is the order quantity, and *D* is the random demand or units sold.

To extend this model, we incorporate *v*, the salvage value of unsold products, and *h*, the holding cost for inventory that can be stored for future sales. These parameters address situations where products either become unsellable or incur storage costs. With these additions, the profit function becomes:

Monte Carlo simulation is often employed to evaluate outcomes across multiple demand scenarios.

Main Findings

The newsvendor problem has been approached using various methods beyond Monte Carlo simulation, each suited to specific scenarios. Analytical solutions, like the critical fractile method, provide exact results when demand distributions are known, while dynamic programming extends the model to multi-period settings. Stochastic programming and robust optimization handle uncertainty by optimizing expected outcomes or worst-case scenarios, respectively. Machine learning techniques, such as regression and reinforcement learning, leverage historical data to predict demand and optimize inventory dynamically. Game theory addresses interactions between multiple decision-makers, while extensions like multi-product models and service-level constraints tackle real-world complexities. Heuristic and metaheuristic algorithms, including genetic algorithms and simulated annealing, offer approximate solutions for high-dimensional or non-linear problems. [1][3]

In this project, the newsvendor problem is solved using Monte Carlo simulation, a technique that relies on repeated random sampling to model unknown demand. The demand for products is treated as a random variable to simulate and generate different outcomes.

Various probability distributions, such as normal, uniform, exponential, and others, are used to simulate the randomness of demand.

For instance:

* Normal Distribution: Used when demand is expected to center around a mean with symmetric variability.
* Uniform Distribution: The demand is evenly spread across a range. Useful when only the minimum and maximum of the demand is known.
* Exponential Distributions: Useful when the demand decreases exponentially, such as high initial demand that quickly tapers off.
* Poisson Distribution: Useful for small, discrete demand values, when modeling over time intervals.
* Binomial Distribution: Useful when the demand represents the number of successes (purchases) in a fixed number of independent trials (customer visits).
* Lognormal Distribution: The demand is positively skewed, such as for high value or infrequently purchased items.
* Triangular Distribution: Useful when historical demand data is limited but estimates for minimum, most likely, and maximum values are available.
* Weibull Distribution: Flexible distribution that can model various shapes of demand depending on its parameters, for example products with demand that changes over time (product lifecycle)

The demand values are generated using a Linear Congruential Generator (LCG), implemented the same way as we saw in class. Additionally, the demand values are scaled to specific ranges (e.g., 0 to 80 units) based on observed sales data.

Monte Carlo Simulation Process

1. Generating random demand: For each iteration, a random demand value is generated using the chosen probability distribution. These values mimic real-world fluctuations in demand.
2. Simulating profit for each Order Quantity: The generated demand values are used to calculate the profit for different inventory levels (order quantities). The profit function used is the one previously defined.
3. Iterating over many simulations: Multiple iterations are run to obtain a wide range of demand scenarios. This helps estimate the expected profit for each potential order quantity.
4. Identifying the Optimal Order Quantity: By comparing the average profit across all iterations for each order quantity, the optimal quantity that maximizes expected profit is determined.

The Monte Carlo simulation captures demand uncertainty, making it suitable for volatile environments. This implementation provides the ability to model demand using different distributions ensuring that the simulation can adapt to various real world scenarios. The final output (optimal order quantity and corresponding profit) intends to directly aid in the decision making for inventory management.

• Give illustrations of what you can learn from your code (e.g., whether a PRN generator is

any good, or whether a certain strategy will work better than others in blackjack). Make

sure to be statistically rigorous (e.g., estimates, confidence intervals, hypothesis tests, etc.)

if you’re carrying out Monte Carlo experiments.

Conclusions

What did you find/learn from the project? Provide ideas for future work that could be built using your project as a starting point.

References

[1] Porteus, E. L. (2008). The newsvendor problem. In S. Venkataraman (Ed.), Building intuition: Insights from basic operations management models and principles (pp. 115–136). Springer.

[2] Ekwegh, I. W. (2016). Newsvendor models with Monte Carlo sampling (Master’s thesis). Electronic Theses and Dissertations, Paper 3125. East Tennessee State University. <https://dc.etsu.edu/etd/3125>

**[3] Wikipedia contributors.** (n.d.). Newsvendor model. In Wikipedia. Retrieved November 29, 2024, from <https://en.wikipedia.org/wiki/Newsvendor_model>