Module 4 Project — A Prescriptive Model for Strategic Decision-Making

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Introduction

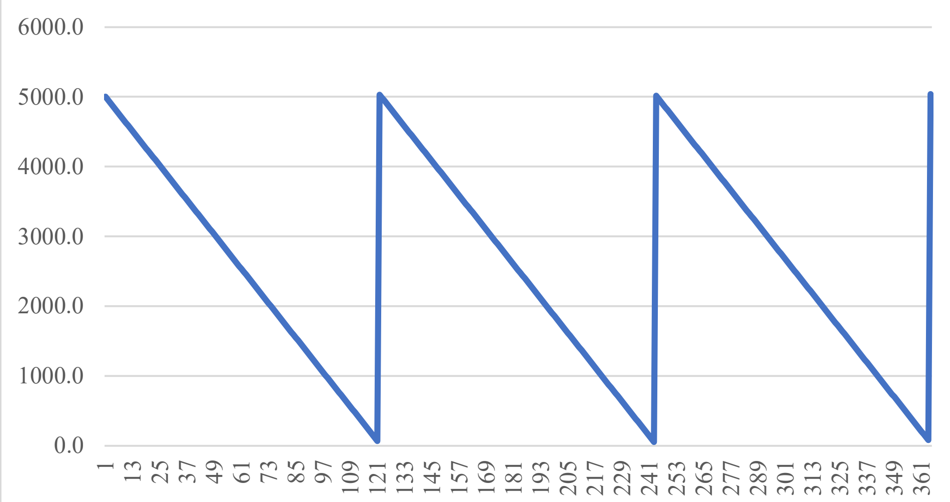
An engine manufacturing company wants to manage the inventory of a key engine component so that their total inventory costs are minimized and they also have enough inventory to meet the demand. The managers have data regarding the annual demand, its probability distribution, opportunity cost of capital, and ordering cost per order. As a consultant, I will build a model to compute the total inventory costs and determine the economic order quantity (EOQ) for components for the least inventory costs. Since a point estimate tells little about risks, e.g., losing business if demand unexpectedly rises, I will perform simulations of the model as per the probability distribution of demand, and report key metrics with their expected values, range, and fitted distribution if validated.

Analysis

Microsoft Excel will be used to build the decision model. For arriving at the point estimate of quantity, the one-way data table will be used for estimating optimum order quantity, and the Solver GRG Nonlinear engine will be used for the exact solution. Using a two-way data table, we will also understand model outcomes' sensitivity to changes in model parameters. Finally, Oracle's Crystal Ball add-in for Excel will be used for Monte Carlo simulation of the model as per demand distribution and to evaluate key output metrics for their statistics and distribution.

The annual demand is 15,000 units, which is constant throughout the year and must be met with sufficient inventory. For simplicity of the model, I have assumed that the order is placed sufficiently in advance to receive on time. Further, an order of quantity ‘Q’ is received just before the inventory level tends to zero such that demands are always fulfilled. An example of the inventory level over a year for ‘Q’ of 5000 is given in figure 1.

Figure 1. Inventory Levels for Order Quantity of 5000



This also simplifies the computation of the average inventory level as ‘Q/2’. The optimum value of ‘Q’ is to be solved such that the total inventory cost is minimum.

Part 1: Point Estimate

1. Define the data

The given data is defined below for building the model.

- Model parameters – Ordering Cost per Order (K), Unit Cost
- Uncontrollable variables – Annual Demand (D), Opportunity Cost (% of Unit Price)
- Decision variable – Order Quantity (Q)
- Objective function – Total Inventory Cost (to be minimized)

Other fields are computed fields and need not be defined in the above groups.

2. Mathematical functions

The following mathematical functions are computed for building the model.

$$Holding\ Cost\ Per\ Unit = Opportunity\ Cost \times Unit\ Price$$

$$Average\ Inventory = \frac{Order\ Quantity}{2}$$

$$Annual\ Ordering\ Cost\ (AOC) = Cost\ per\ Order \times \frac{Annual\ Demand}{Order\ Quantity}$$

$$Annual\ Holding\ Cost\ (AHC) = Holding\ Cost\ Per\ Unit \times Average\ Inventory$$

$$Total\ Inventory\ Cost = AOC + AHC$$

Unit cost is excluded from total cost as this model is not concerned with unit cost, selling, and profit. Also, since the unit price is constant, it will not impact the solution.

3. Model Implementation

The model is implemented in Excel using the above functions, as demonstrated in table 2.

Model Attributes			
Annual Demand Units (D)		15000	Uncontrollable variable
Order Quantity (Q)		5000	Decision variable
Ordering Cost			
Ordering Cost per Order (K)		220	Model parameter
Annual No. of Orders (D/Q)		3.0	
Annual Ordering Cost (K*D/Q)	**$**	**660.0**	
Holding Cost			
Unit Cost	$	80.0	Model parameter
Opp Cost as % of unit price		18%	Uncontrollable variable
Annual Holding Cost per unit (h)	$	14.4	
Average Inventory Level (Q/2)		2500	
Annual Holding Cost (h*Q/2)	**$**	**36,000.0**	
Total Cost			
Total (Inventory) Cost	**$**	**36,660.0**	Objective to minimize

Table 2. Model Implementation with random Q = 5000

Order Qty	Total Cost
	$ 36,660.00
200	$ 17,940.00
250	$ 15,000.00
300	$ 13,160.00
350	$ 11,948.57
400	$ 11,130.00
450	$ 10,573.33
500	$ 10,200.00
550	$ 9,960.00
600	$ 9,820.00
650	$ 9,756.92
700	$ 9,754.29
750	$ 9,800.00
800	$ 9,885.00
850	$ 10,002.35
900	$ 10,146.67
950	$ 10,313.68
1000	$ 10,500.00
1050	$ 10,702.86
1100	$ 10,920.00
1150	$ 11,149.57
1200	$ 11,390.00
1250	$ 11,640.00
1300	$ 11,898.46
1350	$ 12,164.44
1400	$ 12,437.14
1450	$ 12,715.86
1500	$ 13,000.00

4. Order Quantity approximation using one-way data tables

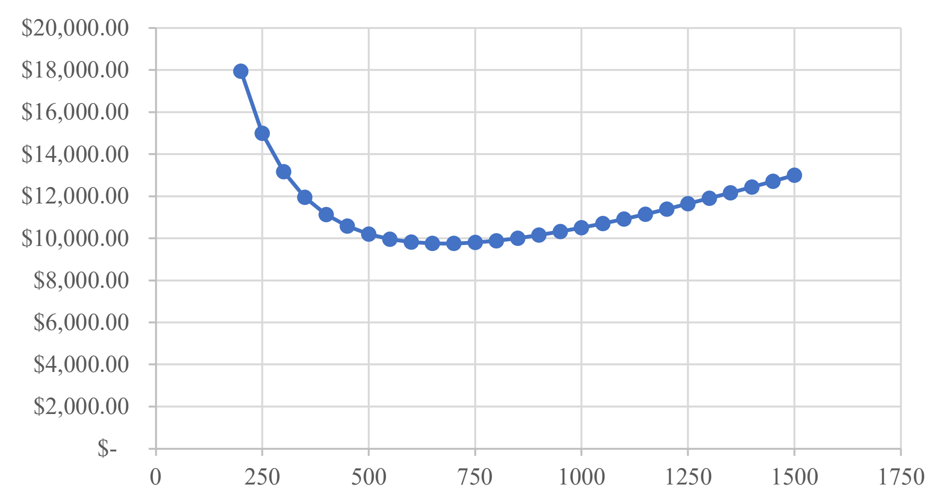
The total cost from the model is computed for a varied range of Order Quantity 'Q' as given in table 3 on the right. The total cost is colored as per conditional formatting so that the minimum value can easily be identified and seems to be between 600 and 900. Let us assume the approximate order quantity for the minimum cost to be around 600.

Table 3. Data Table of Total Cost vs. Order Qty

5. Total Cost versus Order Quantity

The total cost for a range of order quantities is plotted in figure 4. We see that it is nearly a convex graph because as order quantity decreases, holding cost decreases but ordering cost increases due to the increased number of orders. Similarly, as quantity increases, holding cost increases. There is a balance at around 600 quantities for the minimum total cost.

Figure 4. Total Cost vs. Order Quantity



6. Solution using Excel Solver

Using the defined model, Excel Solver was used to compute the optimum quantity with a seed value of 600 and the additional constraint that the quantity should be an integer value.

The optimum order quantity obtained is 677, resulting in about 22 orders in a year and a total inventory cost of $9749. This is the accurate solution and almost near the earlier estimate of 600, considering that the theoretical range of order quantity is huge (1 to 15,000).

7. Model Sensitivity to changes in Model Parameters.

To determine sensitivity, the two model parameters were varied in a two-way data table. The ordering cost was varied between 195 to 245 and unit cost was varied between $70 to $90. The result is given in figure 5.

		Ordering Cost per Order										
	$ 9,749	$ 195	$ 200	$ 205	$ 210	$ 215	$ 220	$ 225	$ 230	$ 235	$ 240	$ 245
	$ 70	$ 8,586	$ 8,696	$ 8,807	$ 8,918	$ 9,029	$ 9,140	$ 9,250	$ 9,361	$ 9,472	$ 9,583	$ 9,693
	$ 71	$ 8,647	$ 8,757	$ 8,868	$ 8,979	$ 9,090	$ 9,200	$ 9,311	$ 9,422	$ 9,533	$ 9,644	$ 9,754
	$ 72	$ 8,707	$ 8,818	$ 8,929	$ 9,040	$ 9,151	$ 9,261	$ 9,372	$ 9,483	$ 9,594	$ 9,705	$ 9,815
	$ 73	$ 8,768	$ 8,879	$ 8,990	$ 9,101	$ 9,212	$ 9,322	$ 9,433	$ 9,544	$ 9,655	$ 9,765	$ 9,876
	$ 74	$ 8,829	$ 8,940	$ 9,051	$ 9,162	$ 9,272	$ 9,383	$ 9,494	$ 9,605	$ 9,716	$ 9,826	$ 9,937
	$ 75	$ 8,890	$ 9,001	$ 9,112	$ 9,223	$ 9,333	$ 9,444	$ 9,555	$ 9,666	$ 9,777	$ 9,887	$ 9,998
	$ 76	$ 8,951	$ 9,062	$ 9,173	$ 9,284	$ 9,394	$ 9,505	$ 9,616	$ 9,727	$ 9,837	$ 9,948	$ 10,059
	$ 77	$ 9,012	$ 9,123	$ 9,234	$ 9,344	$ 9,455	$ 9,566	$ 9,677	$ 9,788	$ 9,898	$ 10,009	$ 10,120
	$ 78	$ 9,073	$ 9,184	$ 9,295	$ 9,405	$ 9,516	$ 9,627	$ 9,738	$ 9,849	$ 9,959	$ 10,070	$ 10,181
	$ 79	$ 9,134	$ 9,245	$ 9,356	$ 9,466	$ 9,577	$ 9,688	$ 9,799	$ 9,909	$ 10,020	$ 10,131	$ 10,242
Unit Cost	$ 80	$ 9,195	$ 9,306	$ 9,416	$ 9,527	$ 9,638	$ 9,749	$ 9,860	$ 9,970	$ 10,081	$ 10,192	$ 10,303
	$ 81	$ 9,256	$ 9,367	$ 9,477	$ 9,588	$ 9,699	$ 9,810	$ 9,921	$ 10,031	$ 10,142	$ 10,253	$ 10,364
	$ 82	$ 9,317	$ 9,428	$ 9,538	$ 9,649	$ 9,760	$ 9,871	$ 9,981	$ 10,092	$ 10,203	$ 10,314	$ 10,425
	$ 83	$ 9,378	$ 9,489	$ 9,599	$ 9,710	$ 9,821	$ 9,932	$ 10,042	$ 10,153	$ 10,264	$ 10,375	$ 10,486
	$ 84	$ 9,439	$ 9,549	$ 9,660	$ 9,771	$ 9,882	$ 9,993	$ 10,103	$ 10,214	$ 10,325	$ 10,436	$ 10,546
	$ 85	$ 9,500	$ 9,610	$ 9,721	$ 9,832	$ 9,943	$ 10,053	$ 10,164	$ 10,275	$ 10,386	$ 10,497	$ 10,607
	$ 86	$ 9,561	$ 9,671	$ 9,782	$ 9,893	$ 10,004	$ 10,114	$ 10,225	$ 10,336	$ 10,447	$ 10,558	$ 10,668
	$ 87	$ 9,621	$ 9,732	$ 9,843	$ 9,954	$ 10,065	$ 10,175	$ 10,286	$ 10,397	$ 10,508	$ 10,618	$ 10,729
	$ 88	$ 9,682	$ 9,793	$ 9,904	$ 10,015	$ 10,126	$ 10,236	$ 10,347	$ 10,458	$ 10,569	$ 10,679	$ 10,790
	$ 89	$ 9,743	$ 9,854	$ 9,965	$ 10,076	$ 10,186	$ 10,297	$ 10,408	$ 10,519	$ 10,630	$ 10,740	$ 10,851
	$ 90	$ 9,804	$ 9,915	$ 10,026	$ 10,137	$ 10,247	$ 10,358	$ 10,469	$ 10,580	$ 10,690	$ 10,801	$ 10,912

Figure 5. Sensitivity of Model to Model Parameters

This indicates that near the current values of the parameters, a $5 increase in ordering cost will increase the total cost by $111 and vice versa. Similarly, a one-dollar increase in unit cost (that impacts opportunity cost) will increase total cost by $61 and vice versa.

8. Results to VP of Operations

The analysis is outlined above. In summary, the economic order quantity for engine components is 677 units per order. At this quantity, we would be able to fulfill every demand and minimize the total inventory cost to just $ 9,749. We will have to order 22.2 times in a year, with ordering costs at $4,874 and holding costs at $4,874.

This model is calculated at a $220 ordering cost per order and an $80 unit cost that impacts the holding cost. Should the parameters change, the total cost will change by $111 per five-dollar change in ordering cost and by $61 per dollar change in unit cost, in the same direction.

Part 2: Simulation & Confidence Interval Solution

The annual demand does not have a fixed value but a triangular probability distribution, as shown in figure 6. Hence, the optimum order quantity for minimum total cost will also be a distribution that is unknown at this point. I will perform a Monte Carlo simulation to study the distribution of three metrics: minimum total cost (objective function), economic order quantity (decision variable), and the annual number of orders.

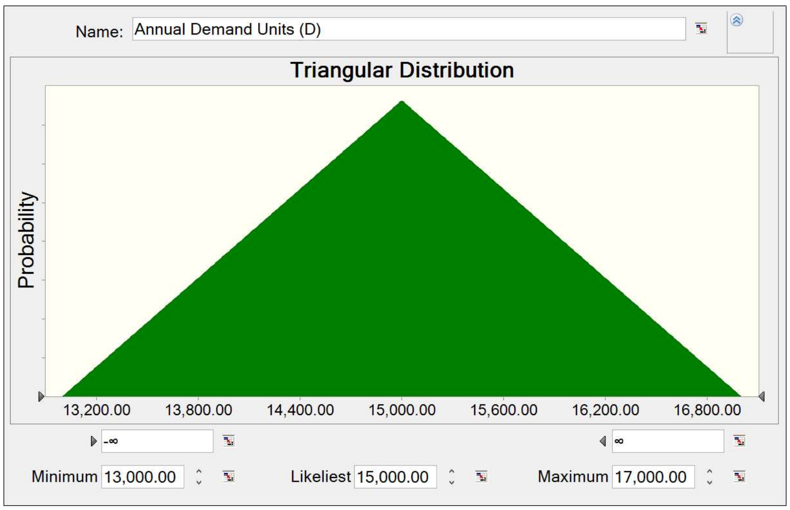


Figure 6. Annual Demand Probability Distribution

1. Monte Carlo Simulation of minimum total cost solution for 1000 occurrences

I will be performing the simulation for 1000 trials using Crystal Ball. Since the demand value will differ for each trail, the optimum order quantity will also be different. Order quantity is a decision variable that acts as an input to compute the total cost; hence during simulation, it will remain constant at the initial value. So, I will use the theoretical formula of Economic Order Quantity (EOQ) to find the optimal order quantity such that it is automatically populated for each simulated trail, and I can further analyze its distribution.

$$Economic\ Order\ Quantity = \sqrt{\frac{2DK}{h}}$$

After studying the metrics' frequency distribution histogram and descriptive statistics, I will construct a two-sided 95% confidence interval and try to fit the best probability distribution using Crystal Ball. To test the validity of fit, I will perform Chi-Squared Goodness-of-Fit tests with the below hypothesis that is common across the tests.

$$H_0 = Given\ distribution\ is\ a\ good\ fit\ for\ the\ stated\ freq\ distribution$$

$$H_1 = Given\ distribution\ is\ NOT\ a\ good\ fit\ for\ the\ stated\ freq\ distribution$$

(i) 'Minimum Total Cost' Metric

The sample analysis of the 'minimum total cost' objective variable is given in figure 7.

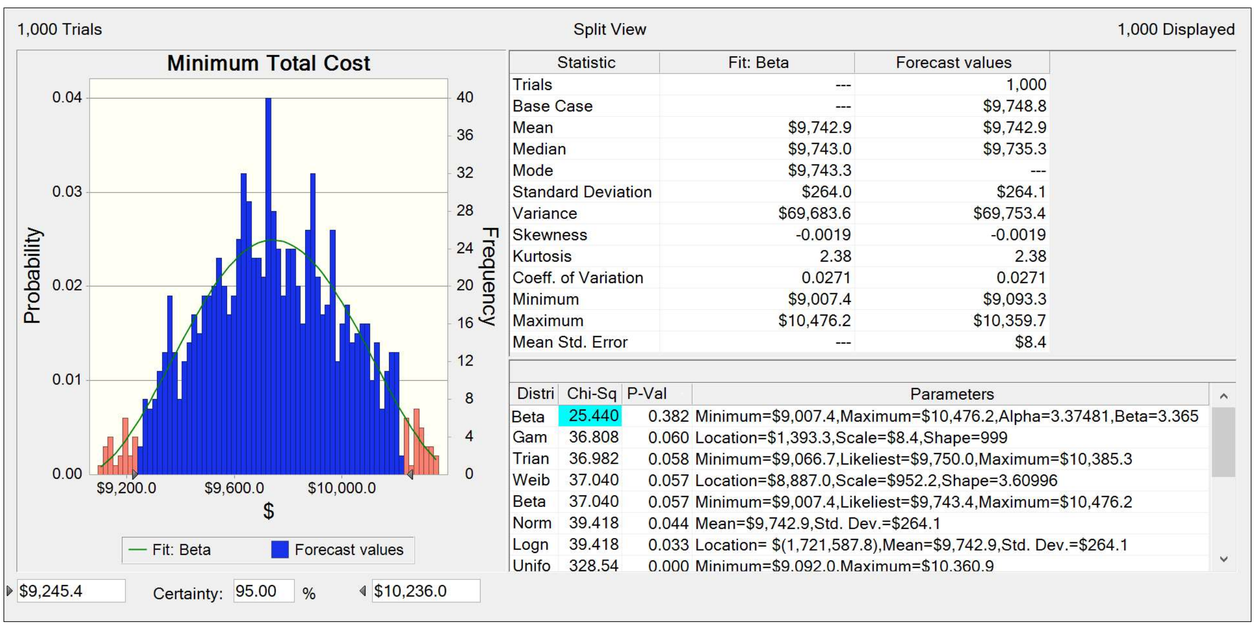


Figure 7. Simulation Result of 'Minimum Total Cost' Metric

The expected value of minimum total cost is $9,742.9, which is slightly lower than the part 1 point estimate of $9748.8, thus slightly better. 95% of the time, the minimum total cost for optimized order quantity will lie between $9245.4 and $10,236.0, and we must plan funds accordingly. Beta distribution has the least chi-squared statistic and hence is the best fit. The p-value is greater than α of 0.05; hence we do not have sufficient evidence to reject H_0 that this is beta distribution. We will consider it a beta distribution with the four parameters in figure 7.

(ii) 'Order Quantity' Metric

Figure 8 summarizes the simulation result of 'Order Quantity' decision variable.

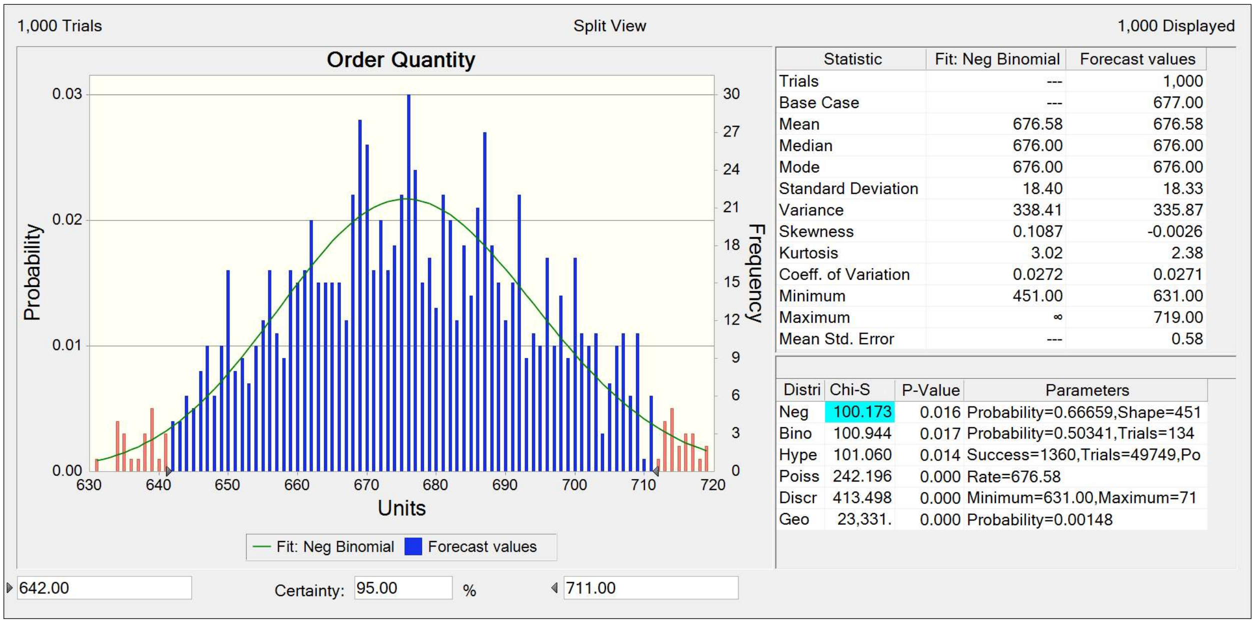


Figure 8. Simulation Result of 'Order Quantity' Metric

The expected value is 676.58, which, when rounded off, is equal to the part 1 point estimate of 677. However, the 95% confidence interval is wide from 642 to 711; our employees and equipment should be able to handle up to 711 orders at a time. The best fit curve as per the least chi-squared statistic is 'negative binomial distribution.' However, its p-value (0.016) is less than α (0.05); hence we have enough evidence to reject the H_0, which states this is a negative binomial distribution. In other words, we do not know if it fits any known probability distribution.

(iii)'Annual Number of Orders' Metric

The simulation result of the sample of 'Annual Number of Orders' is given in figure 9.

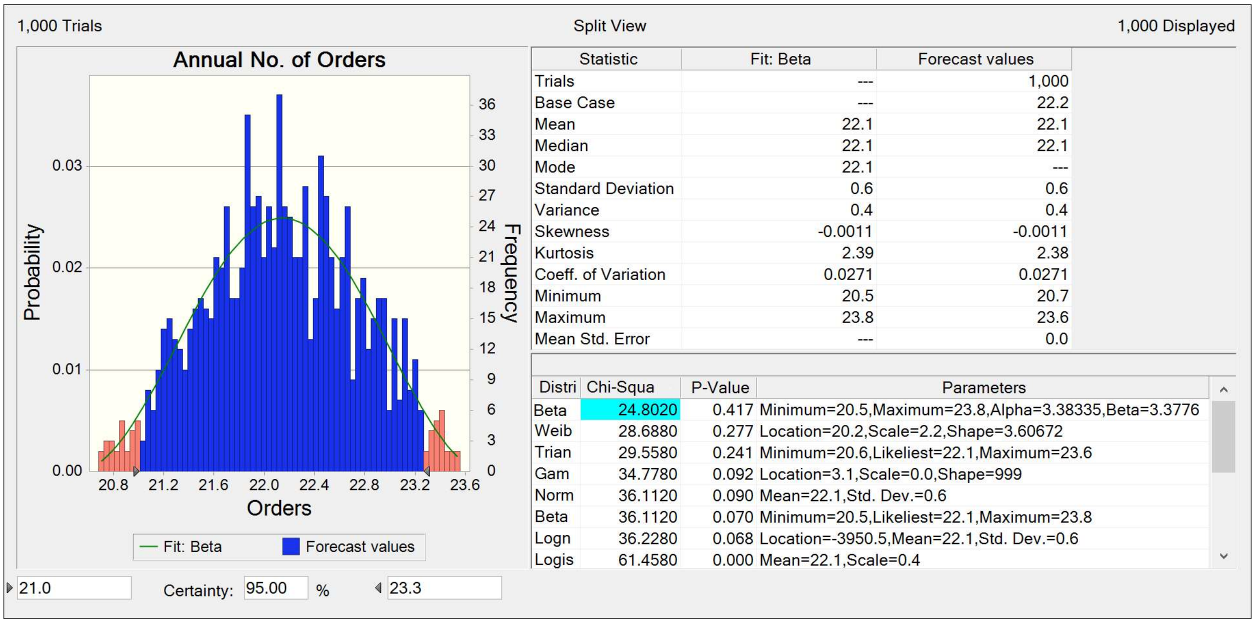


Figure 9. Simulation Result of 'Annual No. of Orders' Metric

The expected annual number of orders is 22.1, slightly lower than the part 1 estimate of 22.2. It can vary from 21.0 to 23.3, which may cause much difference in a year. Beta distribution has the least chi-square statistic with a p-value (0.417) greater than α. Hence, we do not have sufficient evidence to reject the null hypothesis that this is beta distribution. Thus, this can be said to be a beta distribution as defined by four parameters in figure 9.

2. Results to VP of Operations

Concluding from the above analysis, we realize that the optimum order quantity to meet the probabilistic demand can vary between 642 to 711 with 95% confidence. Hence to be on the safe side, we can maintain the order to be 711 or near the upper range. It will result in roughly only one more order per year (confidence interval from 21 to 23.3), but we will be assured not to lose any business. However, we must be comfortably prepared with funds up to $10,236.0 (interval $9245.4 to $10,236.0) for this decision. The minimum total cost and the annual number of orders follow the known beta distribution and can be used by other teams in their analysis.

Conclusion

Key results from this consulting exercise are highlighted in table 10.

Metric	Part 1:	Part 2: Simulated Interval Solution		
	Point Est	Expected Val	95% CI	Distribution
Optimal Order Quantity	677	676.58	642 to 711	Unknown
Minimum Total Cost	\$9748.8	\$9,742.9	\$9245.4 to \$10,236.0	Beta dist.
Annual Number of Orders	22.2	22.1	21.0 to 23.3	Beta dist.

Table 10. Summary of Results

The optimal order quantity for minimum inventory cost is 677. However, since demand is uncertain and delivery takes time, we should aim to maintain order quantity closer to the upper bound of 711, given that we can fund up to \$10,236 holding costs, to ensure we do not lose business due to increased demand. Our finances, employees, and equipment must be prepared to handle the confidence interval range as given in table 10.

Secondly, should model parameters of ordering cost and unit cost change, then our total cost will increase by \$111 per five-dollar increase in ordering cost and by \$61 per dollar increase in unit cost. These risks must be incorporated when budgeting to avoid the inability to place an order due to insufficient funds.

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