The Problem - ‘I am sceptical about the efficacy of operations of strategy’.

- V-ertilisers, a major fertiliser wholesaler, want to change their current inventory management practices with a more rational and complex planning model. They want to minimise the chances of running out of raw material stock by making better purchase decisions and develop an inventory rationalisation model that they could adapt to manage the inventory planning for the future.

- Fertilising is key when it comes to maintaining WA’s agriculture production, due to WA’s proximity to the Outback and the harsh summer climate. WA is the nation’s largest grain-producing region, with exports around $8.5 billion in agriculture and food products as of 2017. Hence, V-ertilisers problem to deal with stock outs is crucial. One week of delay can result in multi-million dollar revenue losses due to the sheer size of the farming stations in the Wheat belt.

- V-ertilisers sold two main types of fertilisers: cropping and pasture. They had a simple operating policy, ensuring that there’s sufficient opening inventory every Monday that meets or exceeds the demand for the following 4 weeks. The forecast sales for a coming week were assumed to be an 8 weeks moving average of historical weekly demand. They always held high inventory stock levels in the fear of not being able to supply to the customer.

- Giovanni Visa, a well seasoned supply chain analyst, was employed by V-ertilisers on a 6-month contract to tackle the current inventory management issues. His main objective was to reduce the inventory levels, while maintaining a high customer service level in sales. He was asked to focus only on ammonia at the main yard and not the rest of the business, since it was his second day at the work.

The Problem

- From the available data, he was able to figure out that the company held an average ending inventory of $5.1 million worth of all raw materials, fertilisers and related by-products, to maintain average monthly sales of $300,000. He knew that the distribution to the end customer is direct since it was a vertically integrated business. From the yard manager, he learnt that the maximum yard capacity is 15,000 tonnes of raw material and finished products.

- Inventory ordering had to follow a procedure known as “Pre-planned delivery system”, where a raw-material order is placed before 10:00 AM Monday, allowing for 6 full days before delivery to the main yard. The raw material requires less than 24 hours to be transformed to finished products.

- If each Monday’s opening inventory did not meet the forecasted demand for the following 4 weeks, a new purchase order is placed before 10AM, with a fixed amount of 1300 tonnes at $740 per tonne. Also, every tonne of unmet demand associated with a cost equal to 70% of the material price. Furthermore, the cost of capital used to procure stock was estimated at 10% per year, or 0.19% per week. The opening stock of ammonia inventory on Monday, 06.09.2021 was 2,858.877 tonnes.

- With all this information, after initial analysis, Giovanni felt that a different forecasting model would perform better than the current 8 point moving average estimate. So the main objective is to find a better forecasting model that would positively outperform the existing one and a new inventory model that would reduce the total inventory and stock out costs across various Service Level Agreement (95%, 99% and 99.9%).

Method and Assumptions

Given that we need to figure out which model to use to forecast the demand for next period, the main method that we will focus on is the forecast model, which helps to identify the best model to use for specific inventory model for deterministic demand and probabilistic demand.

Forecasting Models:

- Before getting started with weighted moving average and simple exponential smoothing forecasts, we first identified the weights and the value of "alpha" to use by manual calculation and using "StatTools" respectively.
- From the time series graph, we identified an 8 weeks pattern before an increase in demand. This led to the conclusion of using 8 weights to calculate Weighted Moving Average forecast.
- We then performed Holt's exponential smoothing on StatTools to get an insight of various factors that would affect the choice of the forecasting model to use. The analysis yielded a "beta" value of 1. This is insightful, as we don't have to use linear regression but SES.
- Knowing that we are better off with SES, we performed the same in StatTools, which gave us the value of "alpha".
- We then calculated the mean and standard deviation of all the models using the forecasted values.
- We identify the various errors, namely MAE, MSE, RMSE and MAPE, of 8MA, WMA and SES forecasts to the original demand.

Deterministic Models:

- Given that there are three different forecasting models that we would want to compare, 8MA, WMA, and SES, 3 different calculations were performed to find the value of "EOQ" and reorder point for each model.
- To calculate the values of EOQ and reorder point, few assumptions were considered with the following data:
    - The annual demand that will be used were different to each forecast and would be the mean of the three forecasted results multiplied by 52 (total number of weeks per year).
    - Unit cost and cost to order are assumed to be the same, $740 per tonne and unit holding rate is 10% per year of the unit cost, which is $74.
    - It has an average ending inventory of $5.1 million worth of all raw materials, fertilisers and related by-products, to maintain average monthly sales of $300,000.

Method and Assumptions

- As it takes 6 days for orders to be delivered, lead time is assumed as 6 days and is always constant.
- We also assumed that there's no expiration date for the product and there will be no disruptions to the supply chain.
- It is also assumed that V-ertilisers care about service to customers more than that of the costs incurred. (Name over cost.)

Probabilistic Models:

- We observed a varying trend when we performed Holt's analysis on the given data using StatTools, so we decided to use Multi-period continuous model.
- The next step is to find the reorder point and the corresponding safety stock for each level of service.
- Given that there are three CSLs (95%, 99%, and 99.9%) to analyse across three different inventory models for deterministic demand, we ran 9 Multi-period continuous inventory models to get the required results.
- Probabilities of stock outs and no stock outs are as follows:
  - 95% CSL = 0.95 probability of no stock out, and 0.05 probability of stock out.
  - 99% CSL = 0.99 probability of no stock out, and 0.01 probability of stock out.
  - 99.9% CSL = 0.999 probability of no stock out, and 0.001 probability of stock out.

Simulation for Inventory Decision:

- To find the total inventory and shortage costs, we constructed a simple simulation, which works based on the ending inventory of the week.
- If the ending inventory is less than the reorder point to maintain service level, an order is placed. Since an order takes a week to be ready and shipped, beginning inventory levels go up only after the next week.
- Since the yard size is only 15,000 tonnes, inventory levels are maintained below that.
- To compare the three different models across three different CSLs, we ran three separate simulations of each inventory model for probabilistic demand.

V-ertilisers current Inventory Plan (8 point Moving Average)

The current inventory plan that V-ertilisers used to manage inventory is based on 8 point moving average forecasted values with EOQ of 1300 tonnes with a reorder point that was uncertain (an order is placed only if Monday's opening stock does not meet the forecasted demand for the next 4 weeks.). With this inventory model, they always held an inventory level that was worth $5.1 million dollars.

With this forecasted data, we tried to find the inventory costs across various CSL's so that we will be able to compare Vertilisers' current inventory model with other inventory models.

Deterministic model:

- As for the deterministic model, the yearly demand that we assumed is from the mean multiplied by 52 of the forecasted weekly demands from 8MA, and the economic ordering quantity that we identified is 823.4 tonnes.
- The reorder point was found to be at 557.26 tonnes, and with a daily demand of 92.87 tonnes.
- Also, we were able to identify that this model would have a cycle time of 9 days per year and 41 cycles/orders per year.

Multi-period Continuous Model (Probabilistic model):

- Mean and standard deviation were found to be 651.92 and 159.07 respectively.
- 95% CSL - To maintain service level, reorder point is 913.57 tonnes and 356.74 tonnes would be the safety stock.
- 99% CSL - To maintain service level reorder point is 1021.97 tonnes and 464.74 tonnes would be the safety stock.
- 99.9% CSL - To maintain service level reorder point is 1143.48 tonnes and 585.74 tonnes would be the safety stock.

V-ertilisers current Inventory Plan (8 point Moving Average)

Inventory Decision:

- 95% CSL - Total cost (inventory plus shortage) is $20.1 Million with 0 shortages.
- 99% CSL - Total cost (inventory plus shortage) is $20.1 Million with 0 shortages.
- 99.9% CSL - Total cost (inventory plus shortage) is $21 Million with 9 shortages.

As we can see from the total cost to maintain inventory, V-ertilisers who care about customer satisfaction (the brand name) over the cost incurred, will fail to optimise their spendings as well as customer satisfaction. Thus, we can conclude that Giovanni's gut feeling was right indeed.

Comparison Between 3 Suggested CSL - WMA

With Giovanni's gut feeling being right, we proceeded to find other inventory models that would reduce the total cost and also most importantly satisfy the customers. The next inventory model was based on the forecast of weighted moving average. Again, to get an annual demand, we multiplied the mean of the forecasted demand by 52.

Deterministic model:

- We first identified an EOQ of 821 tonnes with an annual demand of 33701 tonnes, calculated using the forecasted values.
- The demand per day is 92.33 tonnes and the reorder point is at 553.99 tonnes, which is slightly lower than their current model.
- But, they have the same cycle per year and cycle time as 8 point moving average forecast.

Multi-period Continuous Model (Probabilistic model):

- Mean and standard deviation were found to be 654.1 and 148.36 respectively.
- 95% CSL - To maintain service level, reorder point is 898.13 tonnes and 344.14 tonnes would be the safety stock.
- 99% CSL - To maintain service level reorder point is 999.237 tonnes and 445.25 tonnes would be the safety stock.
- 99.9% CSL - To maintain service level reorder point is 1112.57 tonnes and 558.57 tonnes would be the safety stock.

Inventory Decision:

- 95% CSL - Total cost (inventory plus shortage) is $18.87 Million with 2 shortages.
- 99% CSL - Total cost (inventory plus shortage) is $18.64 Million with 12 shortages.
- 99.9% CSL - Total cost (inventory plus shortage) is $18.57 Million with 11 shortages.

Although the total cost to maintain inventory is lower than 8MA, in fact WMA has the lowest total inventory maintenance cost of all the inventory models we simulated, customer service level cannot be satisfied with this inventory model. This conclusion could have been found earlier, as reorder points across different service levels were similar to that of 8MA with almost the same EOQ.

Comparison Between 3 Suggested CSL - SES

Moving forward with our final inventory simulation model, which is based on simple exponential smoothing's forecasted values, we did the same procedure as before to calculate an annual demand. Also, this was the model that was recommended from Holt's analysis, as it yielded "beta" value of 1.

Deterministic Model:

- Again we first identified an EOQ of 783.1 tonnes using the forecast's yearly demand of 30665 tonnes.
- The demand per day is 84.01 tonnes and the reorder point is at 504.08 tonnes.
- It has a different number of cycles per year as compared to 8 point moving average and weighted moving average with just 39 order per year.

Multi-period Continuous Model (Probabilistic model):

- Mean and standard deviation were found to be 589.71 and 197.88 respectively.
- 95% CSL - To maintain service level, reorder point is 915.19 tonnes and 411.11 tonnes would be the safety stock.
- 99% CSL - To maintain service level reorder point is 1050.05 tonnes and 545.96 tonnes would be the safety stock.
- 99.9% CSL - To maintain service level reorder point is 1201.21 tonnes and 697.12tonnes would be the safety stock.

Inventory Decision:

- 95% CSL - Total cost (inventory plus shortage) is $19.21 Million with 0 shortage.
- 99% CSL - Total cost (inventory plus shortage) is $20 Million with 16 shortages.
- 99.9% CSL - Total cost (inventory plus shortage) is $19.43 Million with 0 shortage.

Although the total cost to maintain inventory is higher than WMA at 99.9 CSL, there are no shortages. Another thing to note is that this total cost is lower than the total cost to maintain inventory using 8MA (V-ertilisers current inventory plan.). Thus, by adapting this model, V-ertilisers can reduce inventory maintenance cost as well as satisfy the customer.

Recommendations

- V-ertilisers can adapt the inventory model developed using Simple Exponential Smoothing' forecasted values to satisfy their customers while reducing their total inventory and shortage costs.

- Decreasing the order quantity to 783.1 tonnes from 1300 tonnes would reduce the number of orders and the ordering cost.

- Depending on a single reorder point rather than relying on the opening inventory of Mondays, which fluctuates with demand, would streamline the inventory management.

- It is also recommended to keep a safety stock level at 697.12 tonnes.

- With a bigger range and accurate data, such as a complete 52 weeks data for the previous year, the analysis could have resulted in a better forecast with a better inventory model. Providing more data benefits both the analyst and the client as the analyst would be able to make lesser assumptions and analyse accurately, and the client can get better results from this accuracy.