IE376 Production Information Systems
Project 1

Simge Çınar, 21901465
Sena Ceren Göktaş, 21704202
Hüseyin Şahan, 21802932
Yağız Yaman, 21702889

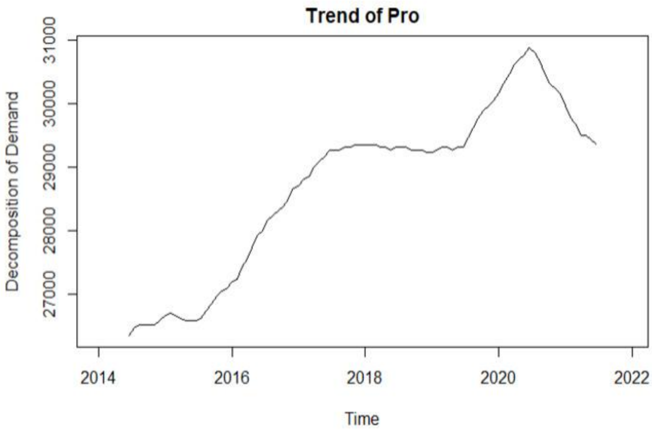
Master Production Scheduling at Apple

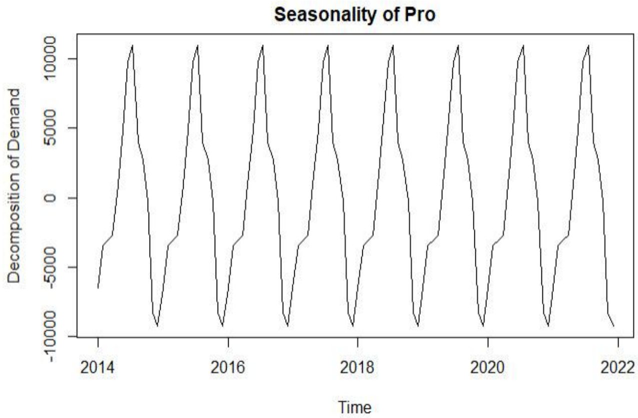
This project focuses on the MPS of the 13” Macbook Air and Pro products for a quarter (planning horizon is 13 weeks). The historical data is provided by Apple containing the data between 2014 and 2021 for 13 weeks.

Data Analysis:

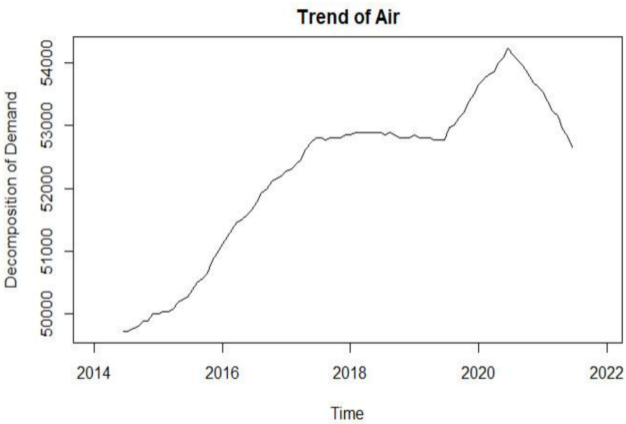
First, an analysis of the data is conducted in order to proceed with the correct forecasting method via Excel and Rstudio. The data is decomposed in order to see the trend and seasonality effects. It is already known that the demand heavily depends on the time of the year and sales are increasing rapidly as the school season gets closer.

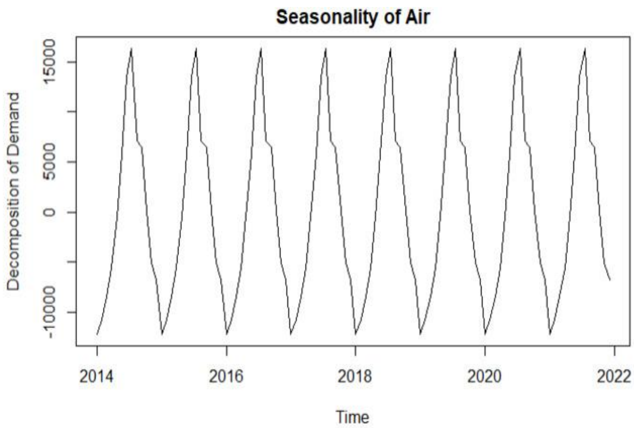
- **Decomposition of Additive Time Series for Macbook Pro**





- **Decomposition of Additive Time Series for Macbook Air**





In both of the products, when the historical decomposition is done, a trend effect was noticed in the data with the huge seasonality effect. Then we have plotted historical data in Excel as well to investigate trend effects more. The slope of the graphs were low compared to the demand since it is in thousand units, yet, it still existed. Nevertheless, we encouraged ourselves to implement Winter’s method for forecasting; however, it would be better to see what seasonal forecasts will give and compare it with Winter’s output for the 2021st season.

	PRO		AIR	
	Seasonal	Winter's	Seasonal	Winter’s
2021 MAD	1828,571	521,9962	1357,143	939,2407

	842,8571	1784,752	757,1429	1321,685
	100	2231,473	800	849,7131
	142,8571	1403,666	171,4286	1279,182
	971,4286	3,519034	1171,429	316,8648
	542,8571	232,3165	1428,571	216,1141
	228,5714	1208,41	2071,429	1006,888
	628,5714	519,0602	400	1451,103
	1628,571	1175,944	285,7143	802,4786
	142,8571	0,001022	257,1429	26,0611
	1571,429	1273,285	228,5714	125,5545
	1271,429	665,7991	557,1429	887,8249
	1700	1529,519	200	488,6652
AVERAGE:	892,3077	965,3647	745,0549	747,0288

Seasonal forecast seems better for both of the products. However, since there is a very small difference compared to production amounts in between those 2 methods we can proceed with Winter's method because Winter's method allows us to include trends into our forecasts. Also, parameters α, β, γ are restricted between 0.1 and 0.2 as a conservative approach and then optimized in Winter's method, in other words without restriction we would reach less MAD values in this method.[1] Moreover, we initialized 3 seasons to get above values, if we initialize more we have a chance to obtain less errors. Another idea behind this choice is to be able to include new demand points into our forecast method in the upcoming weeks. Accordingly we may prefer to change our future forecasts as new demands are realized. And followingly MPS is open to be changed but very carefully.

With the chosen Winter's method, 2022 demand forecasts for each period calculated as follows (Excel calculations can be viewed from the .zip files);

Period	PRO	AIR
2022-1	22309,79	39713,47
2022-2	25521,66	40937,73
2022-3	25949,58	43036,13
2022-4	26393,24	45708,58
2022-5	30008,61	50966,65
2022-6	33865,52	56794,9
2022-7	39254,77	64328,55
2022-8	40360,84	66672,75
2022-9	33866,02	57664,24
2022-10	32082,29	57106,87

[1] Nahmias, Steven, and Ye Cheng. 85

2022-11	29638,12	50778,76
2022-12	21558,56	45655,98
2022-13	20238,11	43886,58

MPS As Linear Model:

In order to determine the optimal production amounts for Macbooks in each period and procurement amounts of the M1 chips, we have decided to model the MPS with the objective that minimizes the related costs given. Then, we solved the model with Xpress IVE while keeping in mind that the first week is the frozen zone. Relating results (.mos file) can also be viewed from the .zip file.

Decision Variables:

I_{At}: $Inventory\ level\ of\ Air\ at\ the\ end\ of\ period\ t$

I^{+}_{At}: $Inventory\ on\ hand\ of\ Air\ at\ the\ end\ of\ period\ t$

I^{-}_{At}: $Backorder\ of\ Air\ at\ the\ end\ of\ period\ t$

I_{Pt}: $Inventory\ level\ of\ Pro\ at\ the\ end\ of\ period\ t$

I^{+}_{Pt}: $Inventory\ on\ hand\ of\ Pro\ at\ the\ end\ of\ period\ t$

I^{-}_{Pt}: $Backorder\ of\ Pro\ at\ the\ end\ of\ period\ t$

P_{At}: $Production\ quantity\ of\ Air\ in\ period\ t$

P_{Pt}: $Production\ quantity\ of\ Pro\ in\ period\ t$

O_{t}: $Overtime\ working\ hours\ used\ in\ period\ t$

Q_{Tt}: $Procurement\ amount\ of\ Chip\ from\ Taiwan\ in\ period\ t$

Q_{Ct}: $Procurement\ amount\ of\ Chip\ from\ China\ in\ period\ t$

I_{Ct}: $Inventory\ level\ of\ chips\ at\ the\ end\ of\ period\ t$

Parameters:

SS_{At}: $Safety\ stock\ required\ for\ Air\ for\ period\ t$

SS_{Pt}: $Safety\ stock\ required\ for\ Pro\ for\ \ period\ t$

h_{A}: $Inventory\ holding\ cost\ of\ Air\ per\ unit\ per\ period$

h_{P}: $Inventory\ holding\ cost\ of\ Pro\ per\ unit\ per\ period$

π_{A}: $Backorder\ cost\ of\ Air\ per\ unit\ per\ period$

π_{P}: $Backorder\ cost\ of\ Pro\ per\ unit\ per\ period$

p_{A}: $Production\ time\ of\ Air\ per\ unit$

p_{P}: $Production\ time\ of\ Pro\ per\ unit$

o: $Overtime\ cost\ per\ hour$

C_{t}: $Regular\ labor\ hours\ for\ period\ t$

$\overline{I_{A0}}$: $Starting\ inventory\ level\ of\ Air$

$\overline{I_{P0}}$: $Starting\ inventory\ level\ of\ Pro$

D_{Pt}: *Demand of Pro in period t*

D_{At}: *Demand of Air in period t*

pc_{TB}: *Procurement cost of the Taiwan factory before week* 5

pc_{TA}: *Procurement cost of the Taiwan factory after week* 5 *included*

pc_{C}: *Procurement cost of the China factory*

τ: *Lead time of the Taiwan factory*

w: *holding cost of the chips*

Model:

$$min\ 100 * I^{-}_{A,13} + 130 * I^{-}_{P,13} + 10 * I^{+}_{A,13} + 13 * I^{+}_{P,13} + \sum_{1}^{4}(o * O_t/60 + w * I_{Ct} + pc_{TB} * Q_{Tt} + pc_C * Q_{Ct} + h_A * I^{+}_{At} + \pi_A * I^{-}_{A,t} + h_P * I^{+}_{Pt} + \pi_P * I^{-}_{P,t}) + \sum_{5}^{13}(o * O_t/60 + w * I_{Ct} + pc_{TA} * Q_{Tt} + pc_C * Q_{Ct} + h_A * I^{+}_{At} + \pi_A * I^{-}_{A,t} + h_P * I^{+}_{Pt} + \pi_P * I^{-}_{P,t})$$

s.t

$p_A * P_{At} + P_{Pt} * p_p \le C_t + O_t \quad \forall t$

$p_A = 2$

$p_P = 2.5$

$C_t \le 45 * 60 * 65 \quad for\ t = 1, 2, 3, 4, 5$

$C_t \le 45 * 60 * 70 \quad for\ t = 6, 7, 8, 9, 10, 11, 12, 13$

$O_t \le 20 * 60 * 65 \quad for\ t = 1, 2, 3, 4, 5$

$O_t \le 20 * 60 * 70 \quad for\ t = 6, 7, 8, 9, 10, 11, 12, 13$

$I_{At} = I_{A,t-1} + P_{At} - D_{At} \quad \forall t$

$I_{Pt} = I_{P,t-1} + P_{Pt} - D_{Pt} \quad \forall t$

$I_{At} = I^{+}_{At} - I^{-}_{At} \quad \forall t$

$I_{Pt} = I^{+}_{Pt} - I^{-}_{Pt} \quad \forall t$

$I_{At} \ge SS_{At} \quad \forall t$

$I_{Pt} \ge SS_{Pt} \quad \forall t$

$I_{A0} = 1100$

$I_{P0} = 1500$

$I_{Ct} = I_{C,,t-1} + Q_{Tt-2} + Q_{C,t} - P_{At} - P_{Pt} \quad \forall t$

$Q_{Tt} \le 75000 \quad \forall t$

$pc_{TB} = 78$

$pc_{TA} = 67$

$pc_C = 85$

$w = 0.1$

$o = 11.75$

$h_A = 0.25$

$$h_P = 0.28$$
$$\pi_A = 0.5$$
$$\pi_B = 0.58$$
$$I^+_{At}, I^-_{At}, I^+_{Pt}, I^-_{Pt}, P_{At}, P_{Pt}, O_t, I_{Ct}, Q_{Ct}, Q_{Tt} \geq 0 \quad \forall t$$

Complete MPS and Predicted Costs:

According to the MPS that is created using the outputs of Xpress, the predicted total cost is $62,760,186.59.

				MacBook Pro 13"					
Week	Starting Inventory	Amount Produced	Availabl e for Sales	Demand	Ending Inventor y	On Hand	Backorder	Inventory Carrying Cost	Backorder Cost
-1		0							
0		0							
1	1500	20.000	21500	22310	-810	0	810	$ -	$ 469,80
2	-810	26.332	25522	25522	0	0	0	$ -	$ -
3	0	25.950	25950	25950	0	0	0	$ -	$ -
4	0	33.634	33634	26393	7.241	7.241	0	$ 2.027,48	$ -
5	7241	26.470	33711	30009	3.702	3.702	0	$ 1.036,56	$ -
6	3702	30.164	33866	33866	0	0	0	$ -	$ -
7	0	39.255	39255	39255	0	0	0	$ -	$ -
8	0	40.361	40361	40361	0	0	0	$ -	$ -
9	0	33.866	33866	33866	0	0	0	$ -	$ -
10	0	32.082	32082	32082	0	0	0	$ -	$ -
11	0	29.638	29638	29638	0	0	0	$ -	$ -
12	0	21.559	21559	21559	0	0	0	$ -	$ -
13	0	20.238	20238	20238	0	0	0	$ -	$ -

				MacBook Air 13"							
Week	Starting Inventor y	Amount Produced	Availabl e for Sales	Demand	Ending Inventory	On Hand	Backorde r	Inventory Carrying Cost	Backorder Cost	Total Time Used	Ovetime Cost
-1		0									
0		0									
1	1100	38.000	39100	39714	-614	0	614	$0,00	$ 307,00	126.000	$0,00
2	-614	41.552	40938	40938	0	0	0	$0,00	$ -	148.934	$0,00
3	0	43.036	43036	43036	0	0	0	$0,00	$ -	150.947	$0,00
4	0	45.708	45708	45708	0	0	0	$0,00	$ -	175.501	$0,20
5	0	50.967	50967	50967	0	0	0	$0,00	$ -	168.109	$0,00
6	0	59.506	59506	56795	2.711	2.711	0	$677,75	$ -	194.422	$1.061,81
7	2711	61.618	64329	64329	0	0	0	$0,00	$ -	221.374	$6.339,81
8	0	66.673	66673	66673	0	0	0	$0,00	$ -	234.249	$8.861,16
9	0	57.664	57664	57664	0	0	0	$0,00	$ -	199.993	$2.152,80
10	0	57.107	57107	57107	0	0	0	$0,00	$ -	194.419	$1.061,22
11	0	50.779	50779	50779	0	0	0	$0,00	$ -	175.653	$0,00
12	0	45.656	45656	45656	0	0	0	$0,00	$ -	145.210	$0,00
13	0	43.887	43887	43887	0	0	0	$0,00	$ -	138.369	$0,00

			M1						
Week	Starting Inventory	Consumption	Purchase Order (Taiwan) Placed	Purchase Order (Taiwan) Received	Purchase Order (Nanjing) Received	**Ending Inventory**	M1 Related Costs	Period Cost	Cumulative Costs
-1			85000,00						
0			85000,00						
1	2000,00	58000,00	75000,00	85000,00	0,00	29000,00	$5.852.900,00	$5.853.676,80	$5.853.676,80
2	29000,00	67884,00	74996,00	85000,00	0,00	46116,00	$5.854.299,60	$5.854.299,60	$11.707.976,40
3	46116,00	68986,00	75000,00	75000,00	0,00	52130,00	$5.855.213,00	$5.855.213,00	$17.563.189,40
4	52130,00	79342,00	74996,00	74996,00	0,00	47784,00	$5.854.466,40	$5.856.494,08	$23.419.683,48
5	47784,00	77437,00	75000,00	75000,00	0,00	45347,00	$5.029.534,70	$5.030.571,26	$28.450.254,74
6	45347,00	89670,00	75000,00	74996,00	0,00	30673,00	$5.028.067,30	$5.029.806,86	$33.480.061,59
7	30673,00	100873,00	75000,00	75000,00	0,00	4800,00	$5.025.480,00	$5.031.819,81	$38.511.881,40
8	4800,00	107034,00	75000,00	75000,00	27234,00	0,00	$7.339.890,00	$7.348.751,16	$45.860.632,57
9	0,00	91530,00	75000,00	75000,00	16530,00	0,00	$6.430.050,00	$6.432.202,80	$52.292.835,37
10	0,00	89189,00	67215,00	75000,00	14189,00	0,00	$5.709.470,00	$5.710.531,22	$58.003.366,59
11	0,00	80417,00	64125,00	75000,00	5417,00	0,00	$4.756.820,00	$4.756.820,00	$62.760.186,59
12	0,00	67215,00	0,00	67215,00	0,00	0,00	$0,00	$0,00	$62.760.186,59
13	0,00	64125,00	0,00	64125,00	0,00	0,00	$0,00	$0,00	

How to React:

Preliminary thoughts:

To sum up with the process, MPS is a game in which trade-off between backlog and overproduction cost exists. Thus, we need to be prepared for both of the cases. To recover backorders we hold safety stocks but actual demand may be higher than our safety stock too. For that case and for the others too, we benefit from the results of our production planning model and MPS.

As it is seen in the results overtime working hours appear only in a few months approximately in the middle of the new season. For remaining periods we have a chance to extra labor hours to recover backlogged demand. However, for immediate production we need chips on-hand. When we look at the chips' orders in MPS, we see that orders from Taiwan are at its highest during periods. Thus, we need to order from China which has zero lead time to satisfy remaining demand. As a result we do not need to keep chip inventory after we use existing chip orders.

Another interesting point is the restriction of both chips and labor. According to output we can claim that labor is more restrictive than chips on-hand. Followingly, we need to do our calculations regarding this. Consequently, we know exactly our capacity and will keep in mind that while taking new orders.

For backorder cases we would have higher extra labor costs because we are already on the maximum of Taiwan chip orders till 10th week. Moreover, we need to consider our extra labor capacity by regarding extra labor usage on 6th to 10th weeks.

On the other hand, demand may be less than forecasted. It is good to see that we have enough space for holding as much as we plan (at least not stated, thus not included). However, in real cases we need to consider that too. **Less actual demand results in higher holding costs.**

What to do?

- At the very beginning it is crucial to consider real-world actions that have a chance to affect our demand.
    - Inflation, pandemic, competitors, market rates, pricing etc. are some of the general examples.
- One easy approach is to run a created model with new inputs to see how far away we are from the beginning plan for the remaining periods. Within this approach it is important to decide on new inputs.
    - Forecasting remaining periods is one option, however, we need to put attention to how the forecasting method works. For Winter's method, how much last datapoint is

included is an important aspect. For example, if we observe very high demand at one particular week, Winter may perceive this as a huge trend and give the remaining weeks accordingly. To prevent this situation, real-life thoughts and existing plans at the beginning need to be included into the decision-making process.

- Keeping safety stock is logical as it protects a company against the sudden demand changes and errors of a forecast. However, in our case there is no problem about finding raw materials. What we need is a chip to produce a Macbook and we have the opportunity to get this in the same day of order as lead time from the factory in China is zero. It looks a little bit costly compared to the factory in Taiwan; however, we almost used our all Taiwan purchase capacity which is 75000. So, in almost all cases, if there is a higher demand more than the forecasted, we have to buy from China, so price is not a matter. Also, by considering overtime working hours, on average there is a capacity of producing an extra 41000 units of Macbook Pro or 51000 of Macbook Air for a week. Considering the average forecasted demand values of Pro equal to 38100 and Air equal to 51000, even if the demand will be 1.5 times more than what we expect, we have the capacity to produce all of them without backorders. To sum up, it is concluded that there is no need to keep safety stock at that point. However, for the last 2 months, since we are under the order capacity of Taiwan we may consider keeping safety stocks but it is better to decide later.

Realization of the Demand in the Game:

As the realization of the demand occurs, we will update our MPS for the following weeks. Forecasts will be recalculated after taking into account the possible trends in the demand. To exemplify, if the actual demand information is increasing or decreasing in a certain way, there is no point in insisting on the previous forecasted demand. The forecast will be done after the observation of 2-3 weeks considering these points. Additionally, the game requires next week's production quantity for Macbooks and the procurement amount of the M1 chips. After it is decided, it would not be possible to change that information. Therefore, while calculating the next period’s quantities in Xpress IVE, we will treat the previous periods as a “frozen zone” as well. The Xpress will take those decided quantities as inputs and hence calculate the remaining information optimally.

References:

Nahmias, Steven, and Ye Cheng. “Production and Operations Analysis (Seventh Edition) / Sheng Chan Yu Yun Zuo Fen Xi (Di 7 Ban) / (MEI) Shidiwen Namiyasi Bian Zhu ; Cheng Ye Gai Bian.” *Amazon*, Qing Hua Da Xue Chu Ban She, 2018, https://www.amazon.com/Production-Operations-Analysis-Seventh-Nahmias/dp/1478623063.