ISyE 6202 Supply Chain Facilities

CoPal Demand and Resource Requirements Modeling and Planning

Professional Casework 1

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General Assumptions

For the entire case, we define the history calendar dates are from January 1st, 2014 to December 31, 2018, in order to match the most updated estimates of population and GDP given by US Census Bureau and the US Bureau of Economic Analysis respectively. Therefore, the estimation point starts on January 1st, 2019.

Also, we use WP # to stand for WorkPal # and MP # for MyPal #.

1 Task 1

1.1 Hypothesis/ Assumptions

1.1.1 Product Life Cycle (PLC)

All the products follow a typical product life cycle. That is, there are four stages: introduction, growth, maturity and decline and the sales fluctuates as time goes by. The following picture demonstrates this cycle. The difference is the duration of the stage of each product.

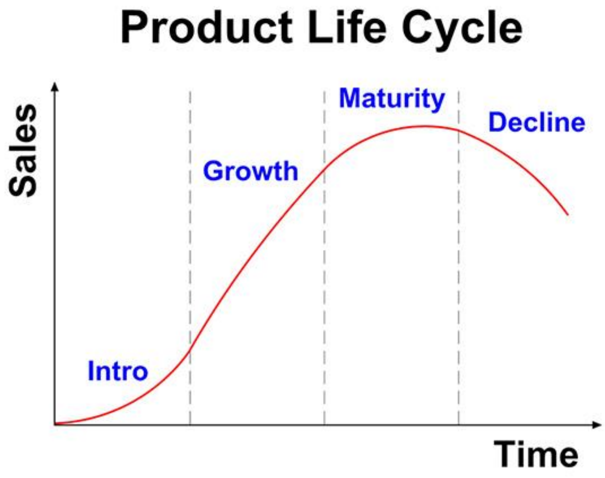


Figure 1 Product Life Cycle

1.1.2 Relationship among the products

Based on the daily sales history of the past five years, there are different trends for different products. Some ends at some point while the others started being sold around the same time. We assume the latter product is the substitute or an upgraded version of the previous one.

Specifically, we assume that
WP 2 was substituted by WP 17, 18, 19, and 20;

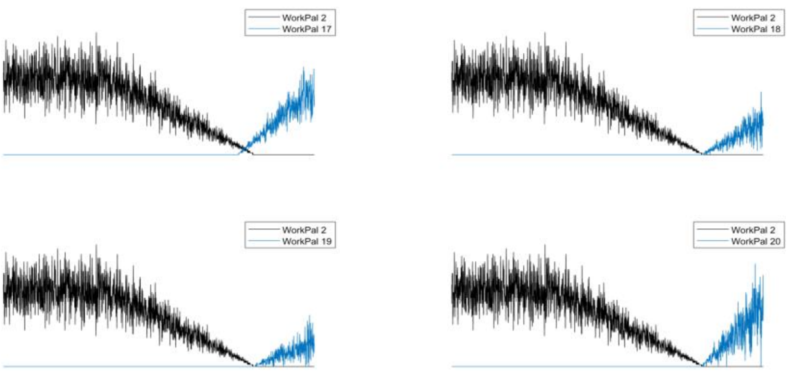


Figure 2 Substitution of Product WP 2

WP 3 was substituted by WP 11, 12, and 13;

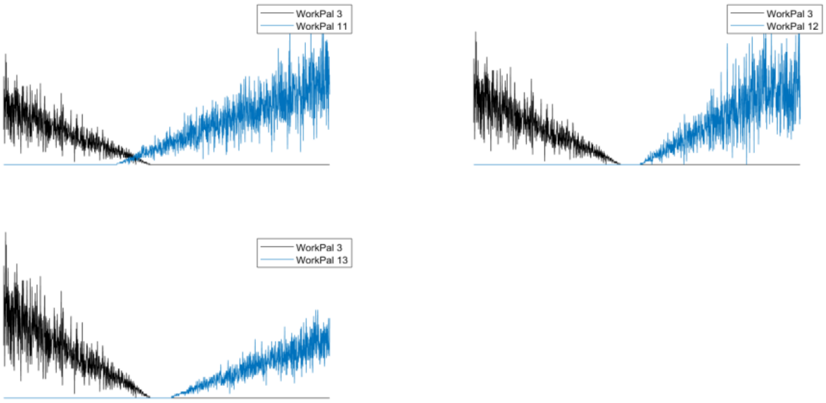


Figure 3 Substitution of WP 3

WP 14, 15, 16 are new and independently developed products during the past 5 years.

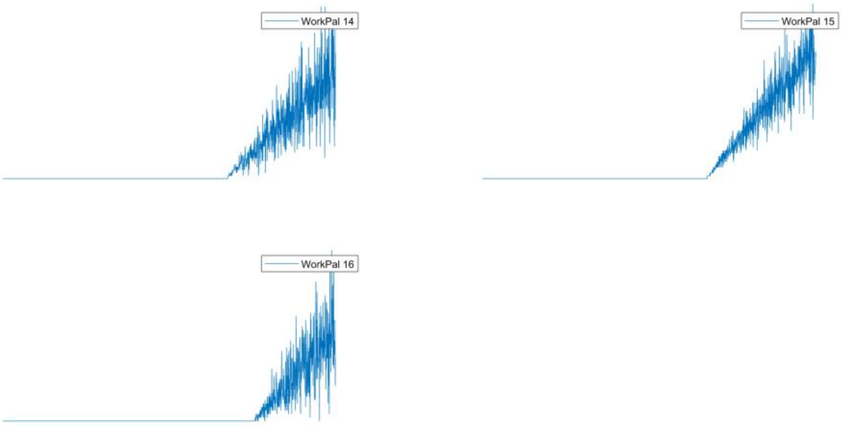


Figure 4 Independent Development of WP 14,15 and 16

Thus, when forecasting, we eliminated the demand of WP 2 and 3.
For WP11 to 20, since they are introduced later, we are removing the days where the demand equals zero.

1.1.3 Stable Ratio of Population and GDP among States and Megaregions

We first found the GDP and population for each state and each megaregion. Since both of the ratios are pretty stable, we decided to use each average ratio of population and GDP among states and megaregions as the ratios to forecast demands.

1.1.4 Additive Demand Constituents

We assume that the demand consists of four elements:

a) Level, the average of the history horizon
b) Trend, the increasing, decreasing or stable trend
c) Seasonality, the repetitive pattern within a year
d) Error, the residual of the forecasted demand

That is,

Demand = Level + Trend + Seasonality + Error.

1.2 Methodology & Quantitative Analysis for Forecasts

Since we had noticed trend and seasonal patterns in the dataset in MP and/or WP, we will use Triple Exponential Smoothing

1.2.1 About Triple Exponential Smoothing

Triple exponential smoothing has 3 parameters α, β and γ where….

1. α refers to the data smoothing factors and $0 \leq \alpha \leq 1$. The higher the value of α, the more weight is being put on the recent observations
2. β refers to the trend estimate and $0 \leq \beta \leq 1$
3. γ refers to the seasonal changes and $0 \leq \gamma \leq 1$

At a high level, triple exponential smoothing filters the data 3 times. First, it smoothens the data and then, it estimates the trend, and then seasonality.

The formula that is being used to find Day-In-Week factor is as follows

$$Day\ of\ the\ Week\ Factor = \%\ of\ sales\ on\ that\ day\ of\ the\ week$$

The formula used for Monthly factor is as follows (Feb is an example)

$$Monthly\ Factor\ for\ Feb = \%\ of\ sales\ on\ in\ Feb\ for\ all\ 5\ years$$

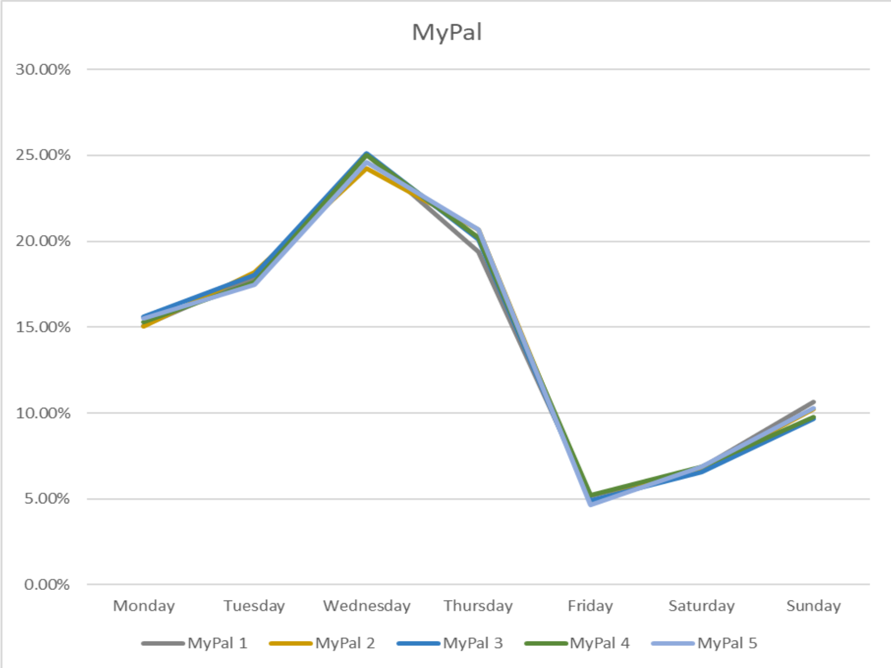


Figure 5 Day-In-Week Factors for MP Products

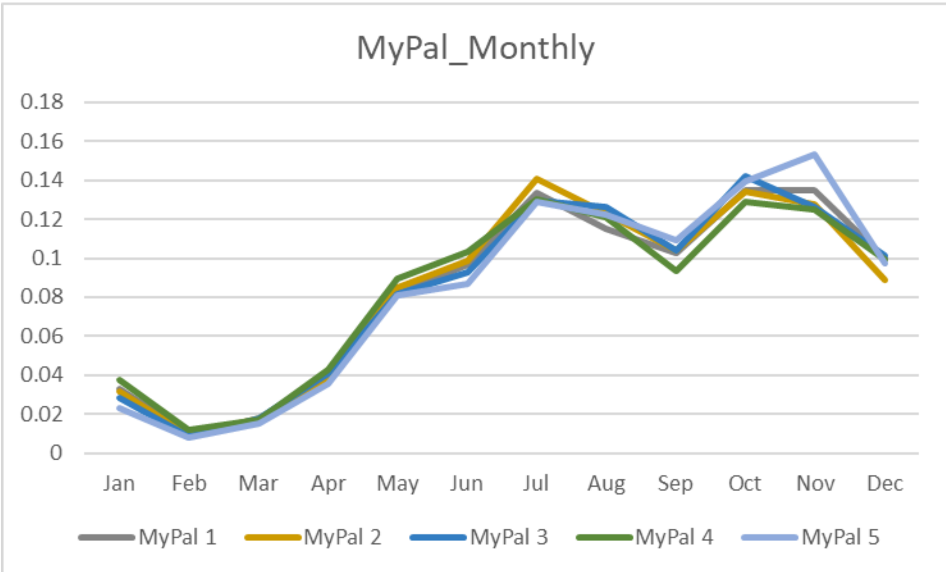


Figure 6 Monthly Factors for MP

As we can see from the figures above that MP products show daily as well as monthly seasonality. So, we can use triple exponential smoothing.

For products, where we don't have a profound seasonality the γ factor will be close to zero.

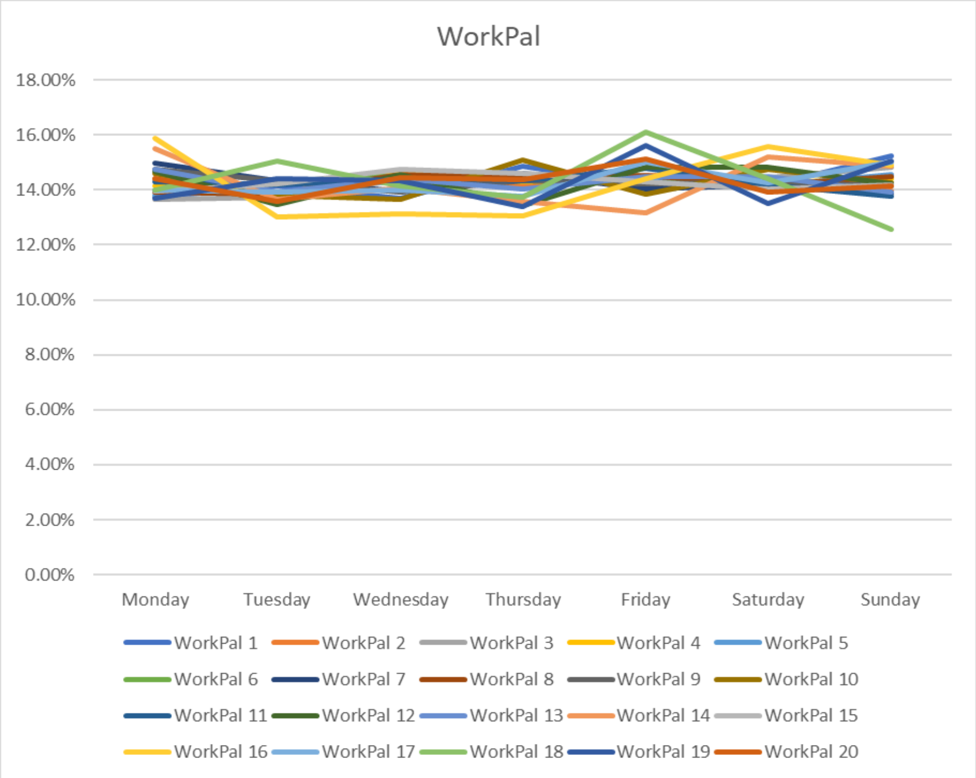


Figure 7 Week-of-the-Day Effect for WP

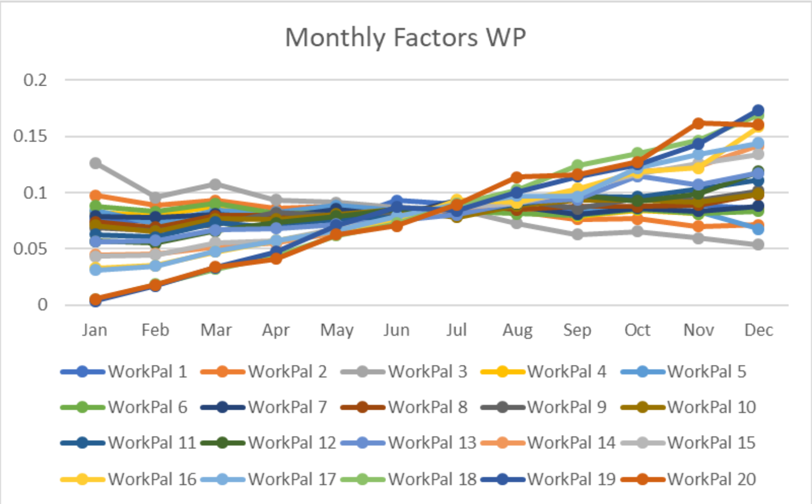


Figure 8 Monthly Factors for WP

As we can see from the figures above that WP products do not show any significant daily and monthly factors.

Although, we do see some periodic pattern in WP 18,19 and 20 but that is due to the relative new introduction of WP18,19 and 20.

We use Microsoft Excel to apply Triple Exponential Smoothing.

1.2.2 Existing Products

First, we have plotted all the WP and MP and applied Excel's built-in capability to produce forecasts.

For our study, we can divide the existing WP and MP products into 3 groups.

1.2.2.1 Products in the growing stage:

There is an increasing trend in the demand of WP1, 9-20 and MP 1-3, and 5.

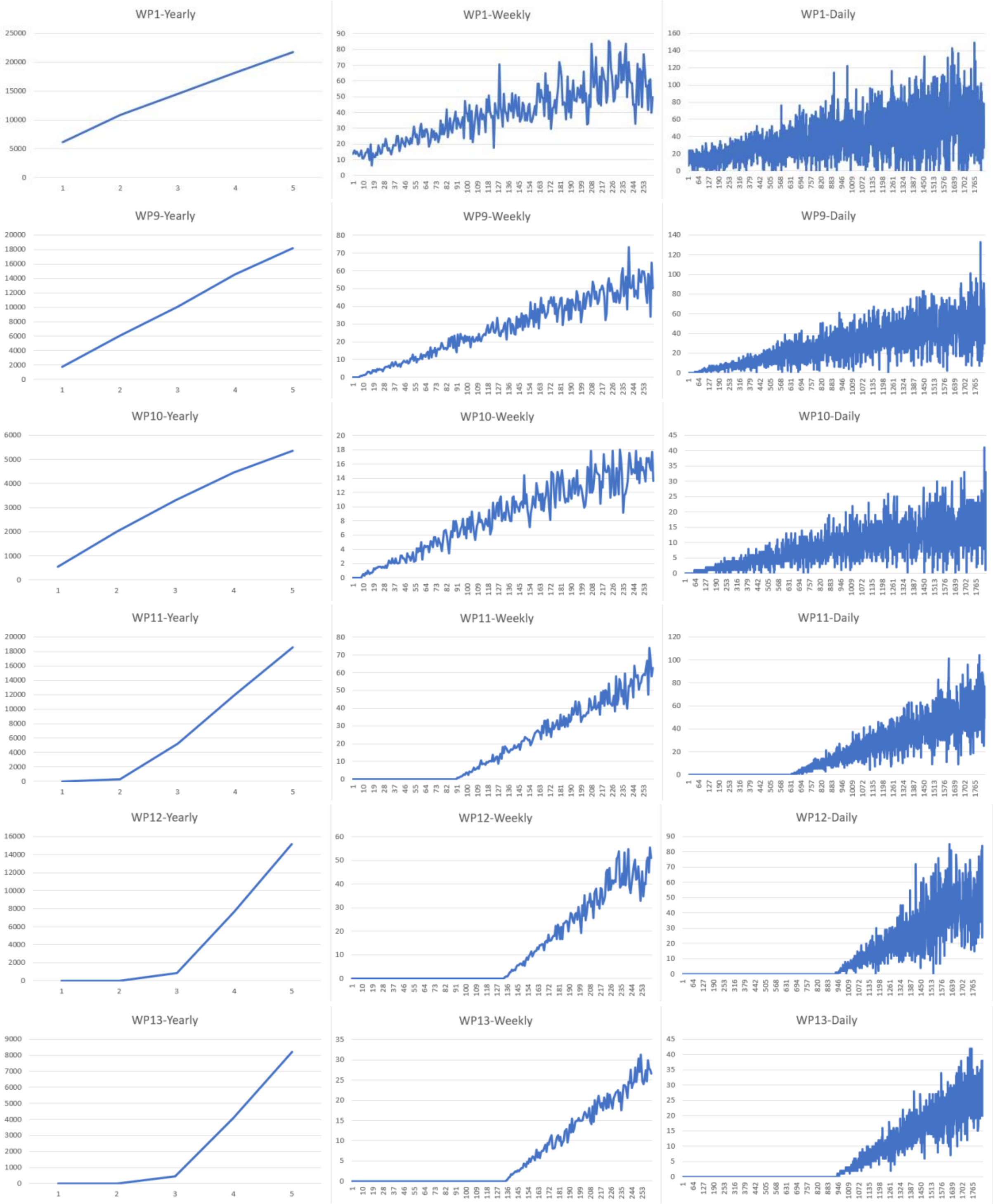


Figure 9 Growing Products

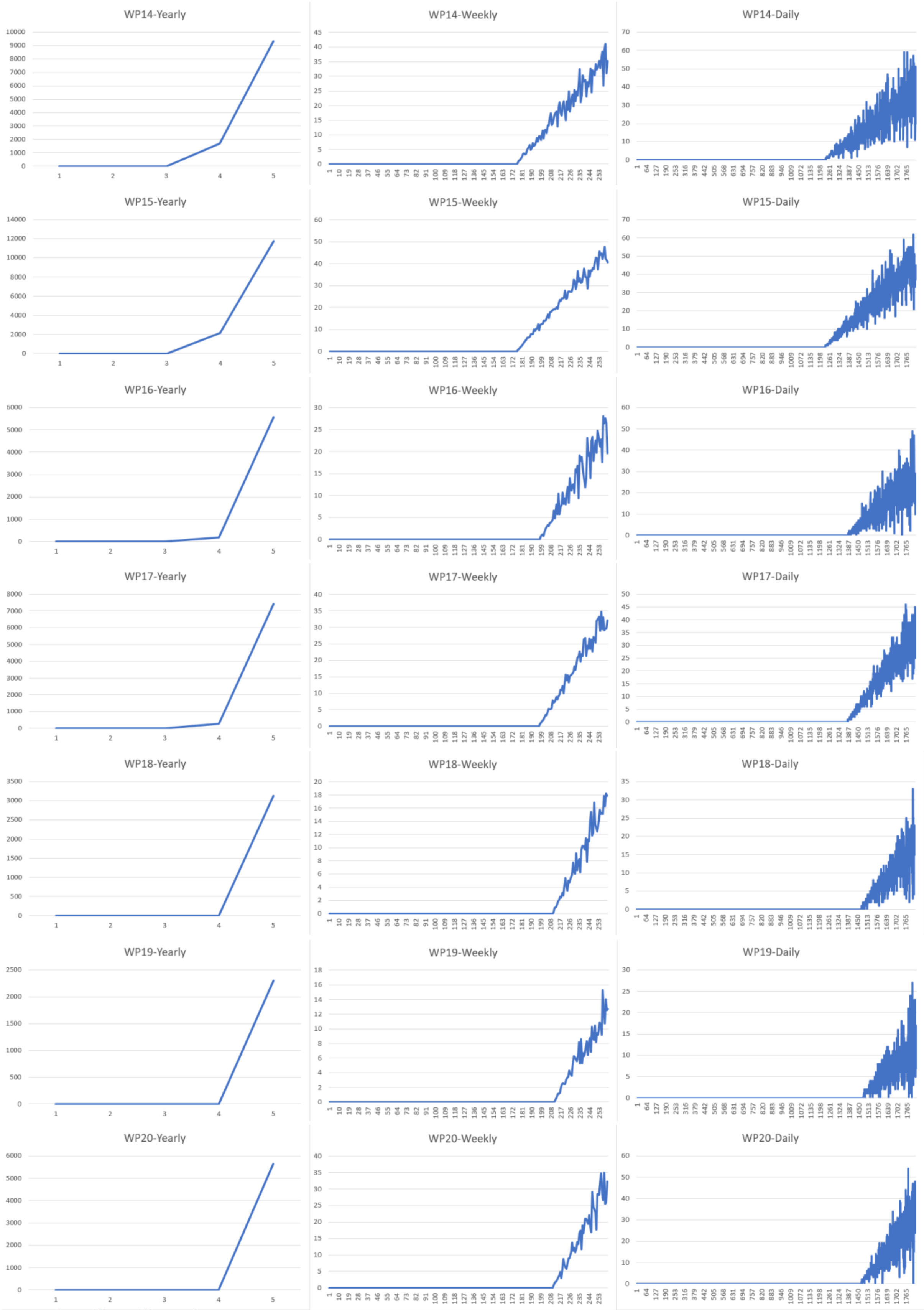


Figure 10 Growing Products

There is also a seasonal pattern in the demand of MP 1-3 and 5

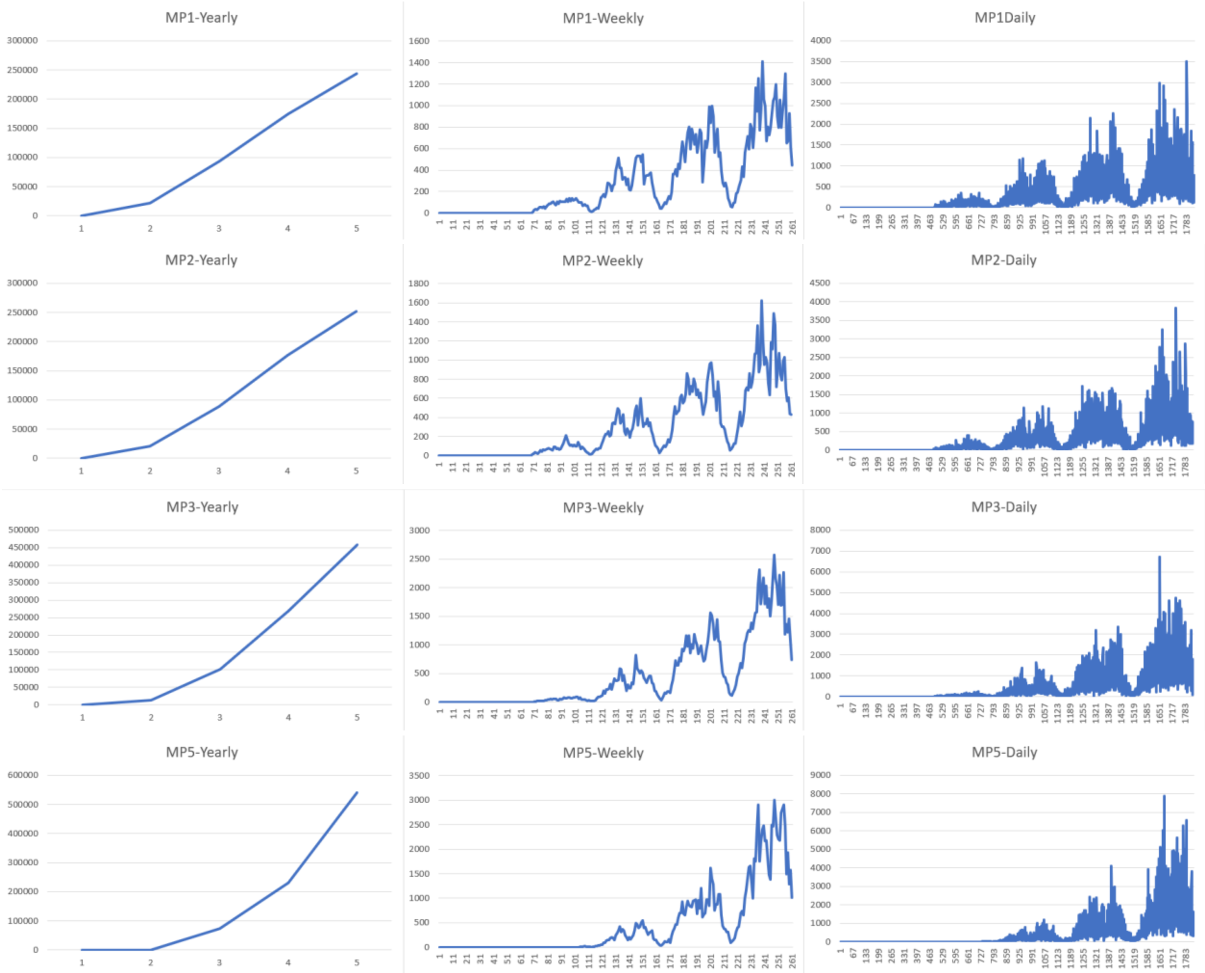


Figure 11 Seasonal Patterns in MP

1.2.2.2 Products in the mature stage:

The demand of WP4, WP8 stays stable.

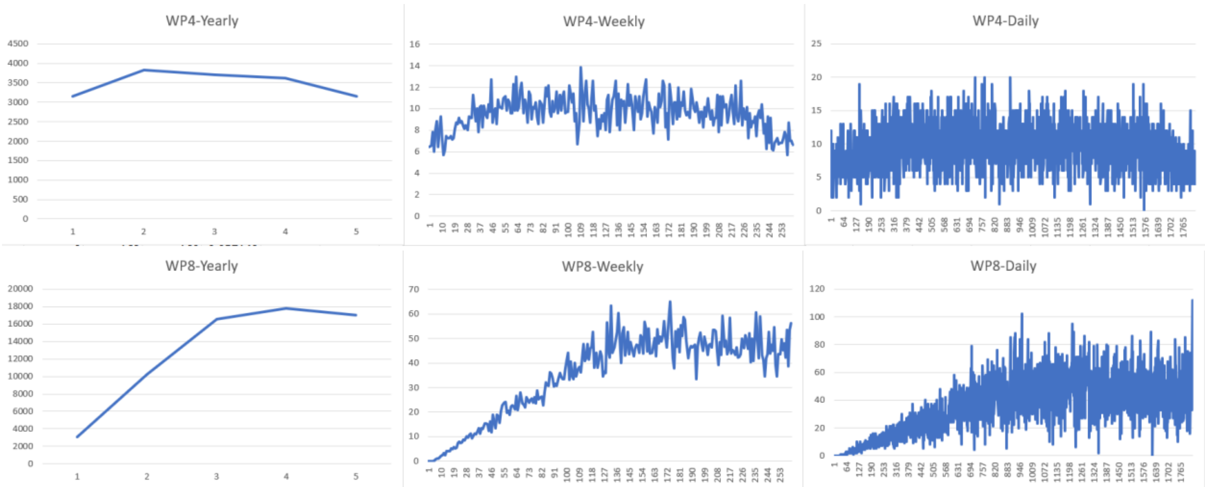


Figure 12 Products in Mature Stage

1.2.2.3 Products in the declining stage:

There is a decreasing trend in the demand of WP2,3,5 - 7 and MP 4. Particularly, MP4, 7 and MP4 just enters this stage; there is a sharp drop in the demand of WP5 from 2017 to 2018; WP6 enters the declining stage with 0 duration at the maturity stage. There is also a seasonal pattern in the demand of MP4.

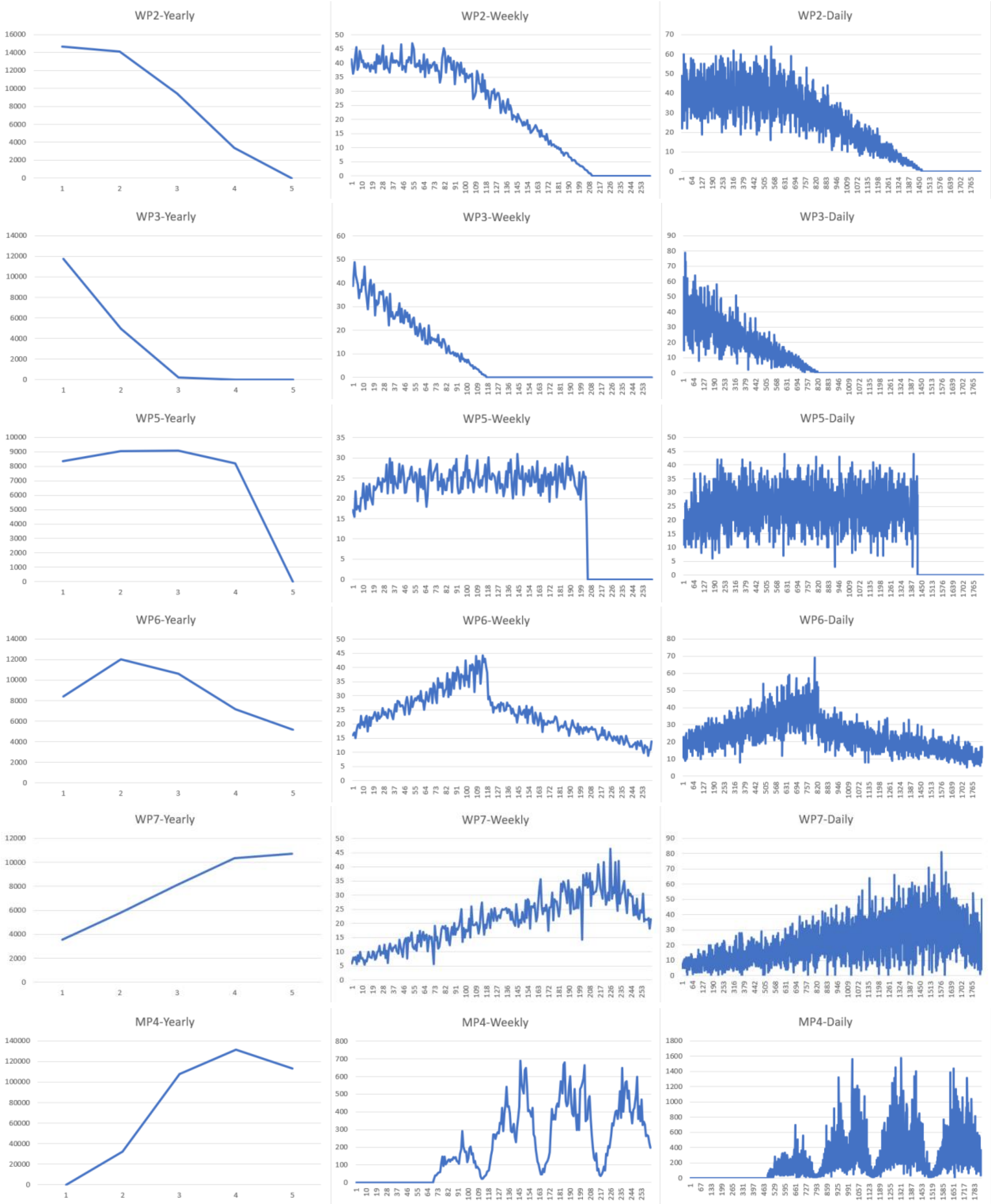


Figure 13 Products in Declining Stage

Besides visual inspection, we also applied the FORECAST.ETS.SEASONALITY function in Excel to test the seasonal pattern. Except for WP5, 9 and all MP's, there is no seasonality in the demand for the other products.

After removing the seasonality, we can focus only on the level and trend components. We define the level as the average of the demand during the past 5 years and the trend as the growth rate of the demand.

The weekly and yearly demand were studied in a similar way. And the charts and summary tables are in Appendix.

Based on the estimates of the demand constituents, we can simulate the demand taking the life cycle stage into consideration as well as forecasting the demand over the following five-year horizon.

Trend Component (Growth Rate)

Year	2015	2016	2017	2018
WorkPal 1	0.78	0.34	0.25	0.19
WorkPal 2	-0.04	-0.33	-0.65	-1.00
WorkPal 3	-0.58	-0.95	-1.00	
WorkPal 4	0.22	-0.03	-0.02	-0.13
WorkPal 5	0.08	0.01	-0.10	-1.00
WorkPal 6	0.43	-0.11	-0.32	-0.28
WorkPal 7	0.61	0.42	0.27	0.04
WorkPal 8	2.33	0.62	0.07	-0.05
WorkPal 9	2.45	0.68	0.43	0.25
WorkPal 10	2.61	0.65	0.35	0.20
WorkPal 11		19.29	1.29	0.55
WorkPal 12			8.06	0.97
WorkPal 13			7.96	1.02
WorkPal 14				4.49
WorkPal 15				4.46
WorkPal 16				29.51
WorkPal 17				26.32
MyPal 1		3.31	0.87	0.40
MyPal 2		3.33	0.99	0.43
MyPal 3		7.24	1.63	0.71
MyPal 4		2.33	0.22	-0.14
MyPal 5			2.14	1.34

Table 1 Growth Trends

For all the blacks in the table, we haven’t introduced the product yet.

Day-In-Week Factor for MP and WP

Weekday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
WPal 1	13.74%	14.13%	13.69%	14.86%	14.18%	14.14%	15.26%
WPal 2	14.42%	13.83%	14.65%	14.18%	14.51%	14.44%	13.97%
WPal 3	13.67%	13.72%	14.38%	14.60%	14.38%	14.44%	14.82%
WPal 4	14.15%	13.76%	14.67%	14.31%	14.42%	14.28%	14.42%
WPal 5	13.82%	14.37%	14.25%	14.46%	14.39%	14.15%	14.56%
WPal 6	13.95%	14.31%	14.51%	14.47%	14.25%	14.24%	14.27%
WPal 7	14.97%	14.35%	13.97%	14.61%	14.03%	14.19%	13.88%
WPal 8	13.91%	13.84%	14.55%	14.50%	14.51%	14.19%	14.50%
WPal 9	14.75%	14.33%	13.93%	14.33%	14.24%	14.28%	14.14%
WPal 10	14.60%	13.79%	13.64%	15.11%	13.86%	14.74%	14.26%
WPal 11	14.30%	14.20%	14.42%	14.33%	14.80%	14.17%	13.79%
WPal 12	14.68%	13.46%	14.55%	13.43%	14.84%	14.83%	14.21%
WPal 13	14.73%	13.92%	14.40%	14.05%	14.50%	14.48%	13.92%
WPal 14	15.51%	13.65%	14.07%	13.57%	13.17%	15.19%	14.84%
WPal 15	13.94%	14.20%	14.73%	14.60%	14.31%	14.02%	14.20%
WPal 16	15.88%	13.02%	13.13%	13.06%	14.43%	15.57%	14.91%
WPal 17	14.01%	13.92%	14.01%	13.79%	15.01%	14.27%	15.01%
WPal 18	13.99%	15.04%	14.15%	13.74%	16.09%	14.41%	12.56%
WPal 19	13.71%	14.40%	14.32%	13.41%	15.61%	13.49%	15.05%
WPal 20	14.41%	13.57%	14.46%	14.38%	15.12%	13.94%	14.13%
MPal 1	15.08%	17.87%	25.06%	19.39%	5.15%	6.80%	10.65%
MPal 2	15.03%	18.20%	24.24%	20.67%	4.87%	6.77%	10.21%
MPal 3	15.63%	18.03%	25.12%	20.09%	4.90%	6.58%	9.65%
MPal 4	15.29%	17.63%	25.02%	20.21%	5.21%	6.85%	9.79%
MPal 5	15.51%	17.45%	24.59%	20.66%	4.67%	6.85%	10.27%

Table 2 Day-In-Week Factors

The forecast values along with confidence interval and details of parameters of exponential smoothing is available in the Task 1 subfolder.

The following charts show the daily, weekly and annual forecasts of MP product line and the charts of other products as well as the numeric results that are summarized into three tables are in Appendix.

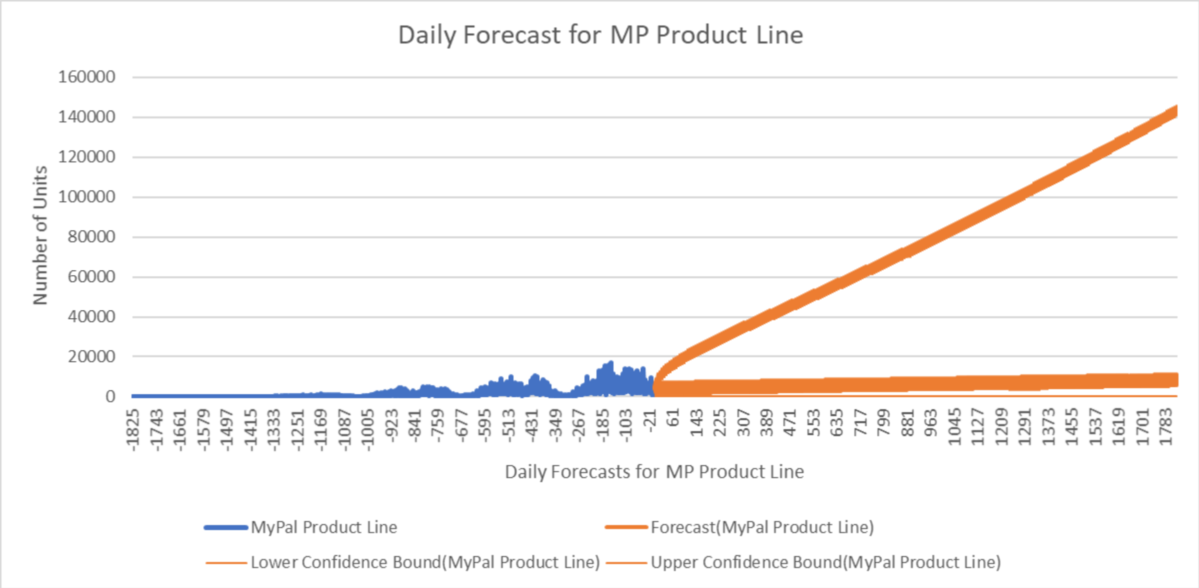


Figure 14 Daily Forecast for MP Product Line

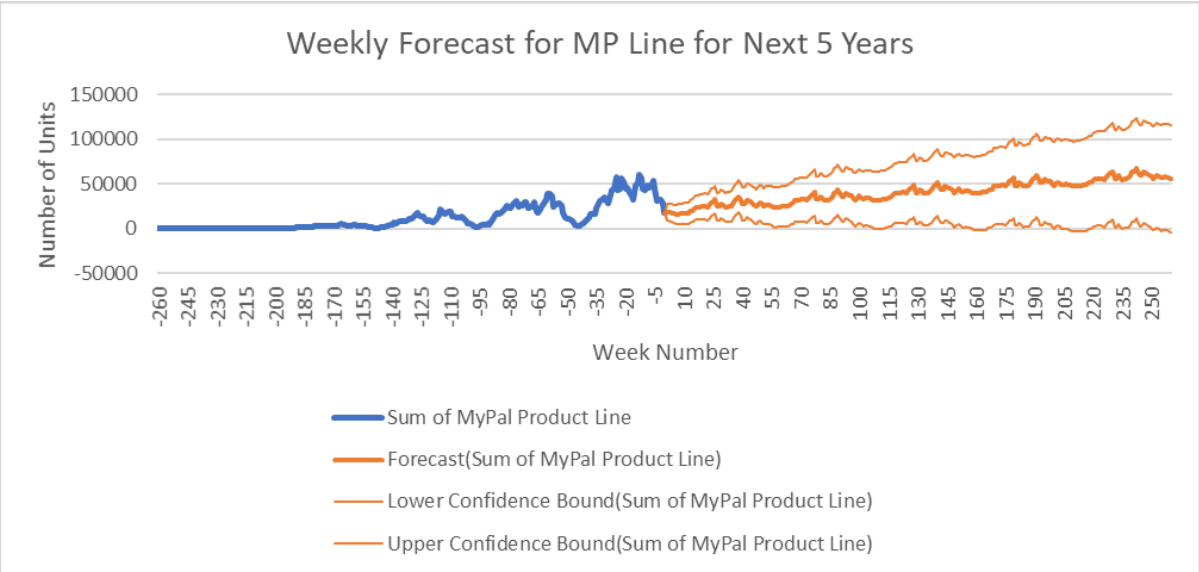


Figure 15 Weekly Forecast for MP Line for Next 5 years

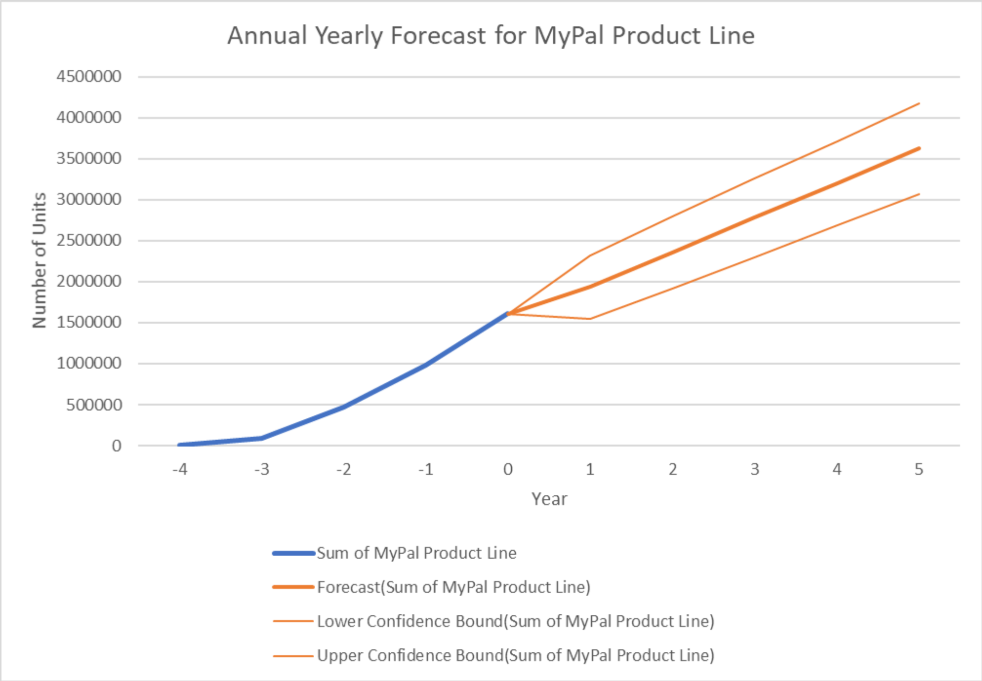


Figure 16 Annual Forecasts for MyPal Product Line

1.2.3 New Products Introduction

Based on the PLC theory and the performance of the existing products, we forecast the demand of new products. We took the average of the demand of existing products at the same time circle. Notice that we different products may have different starting time. For example, MyPal 1-4 start from the second year, the first-year circle is from year 2 to year 3; but the MyPal 5 starts from the third year, the first-year circle is from year 3 to year 4. Thus, we need to take the average of the demand at the same time circle.

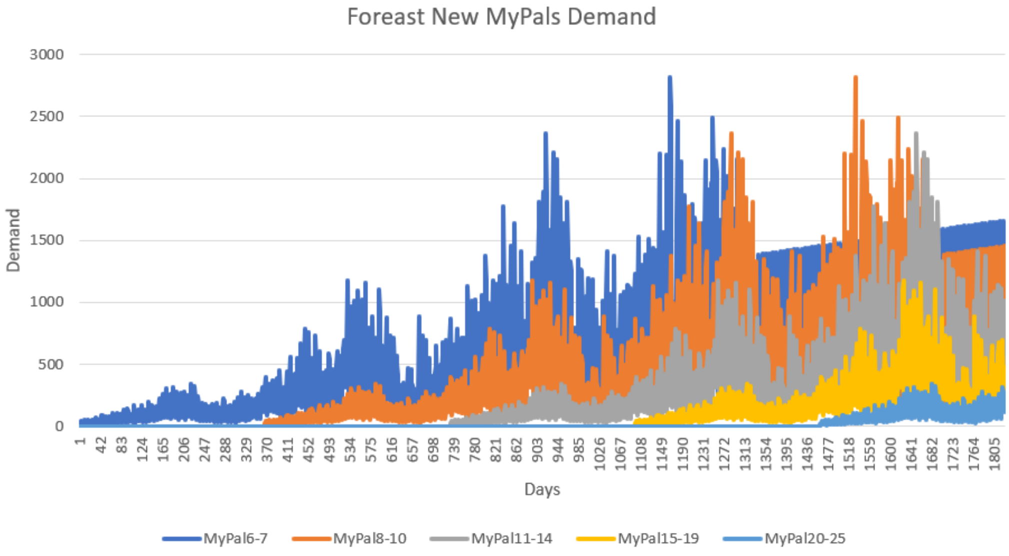


Figure 17 Daily Forecasts for New MyPals

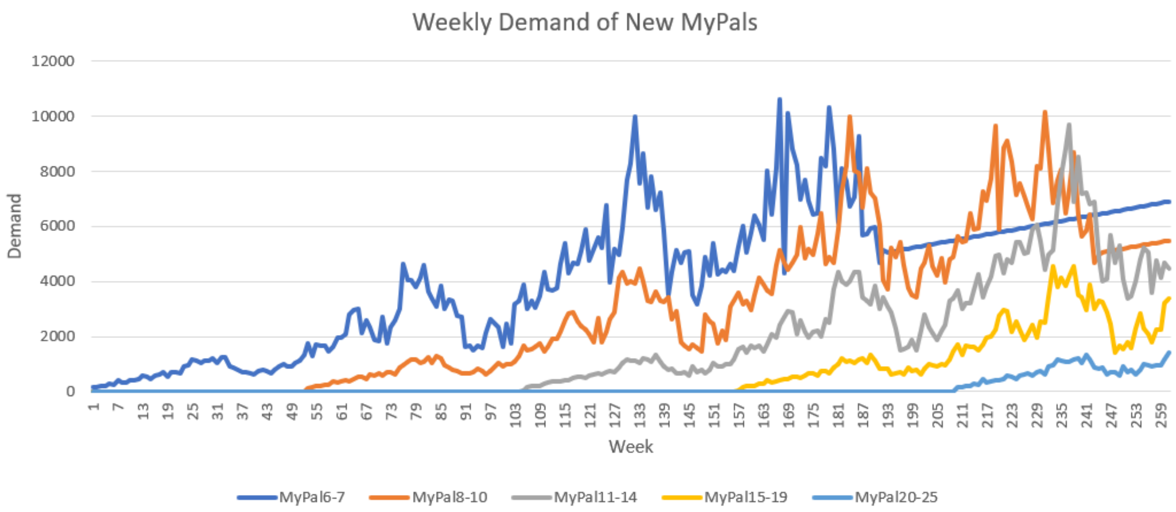


Figure 18 Weekly Demand Forecasts for MP

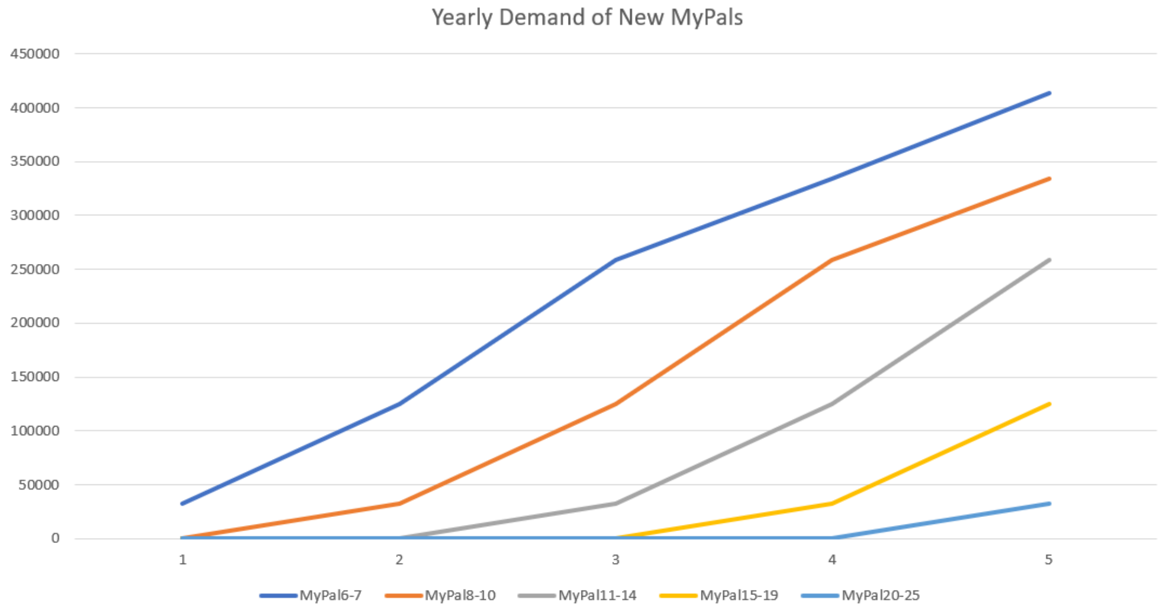


Figure 19 Annual Forecasts for MP

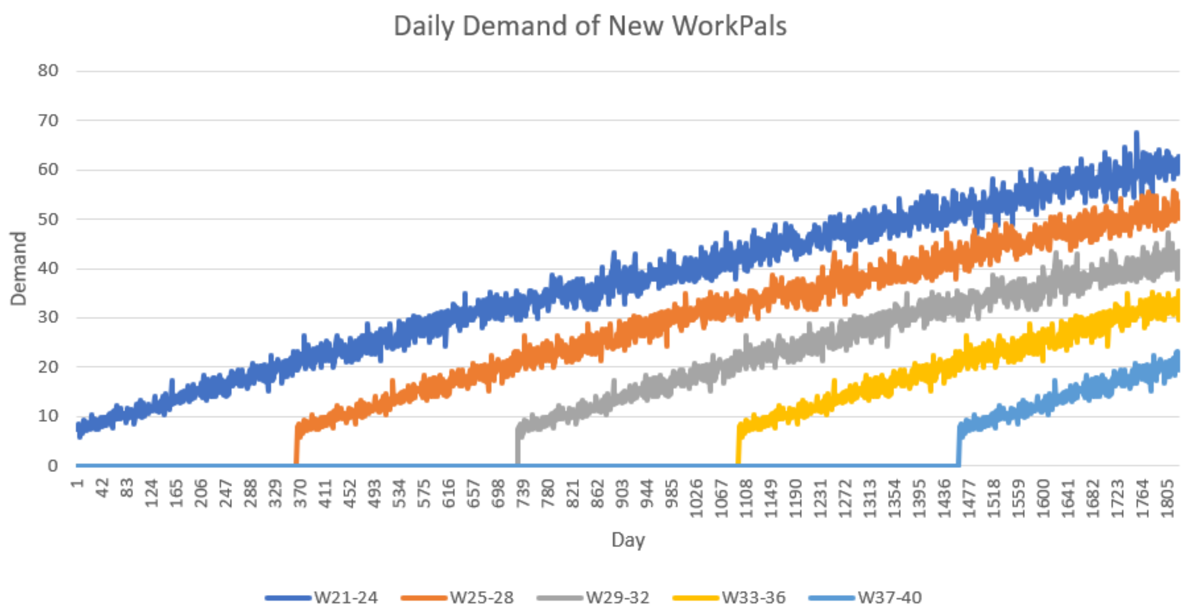


Figure 20 Daily Demand for New WP

The picture above shows the forecast daily demand for WorkPal 21-40 in the next five years.

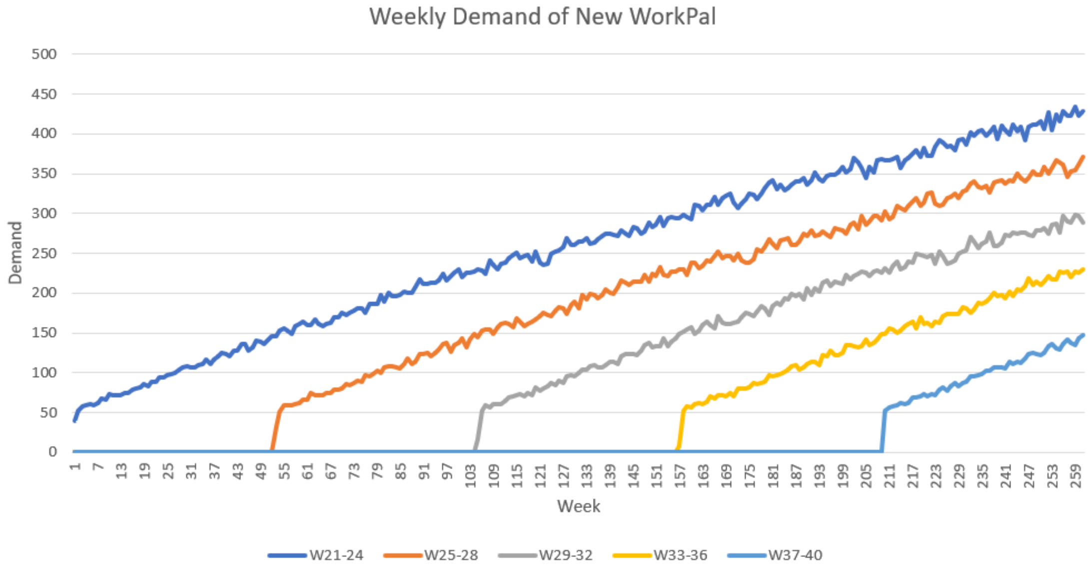


Figure 21 Weekly Forecasts for New WP

The graph above presents the forecast weekly demand for the following five years.

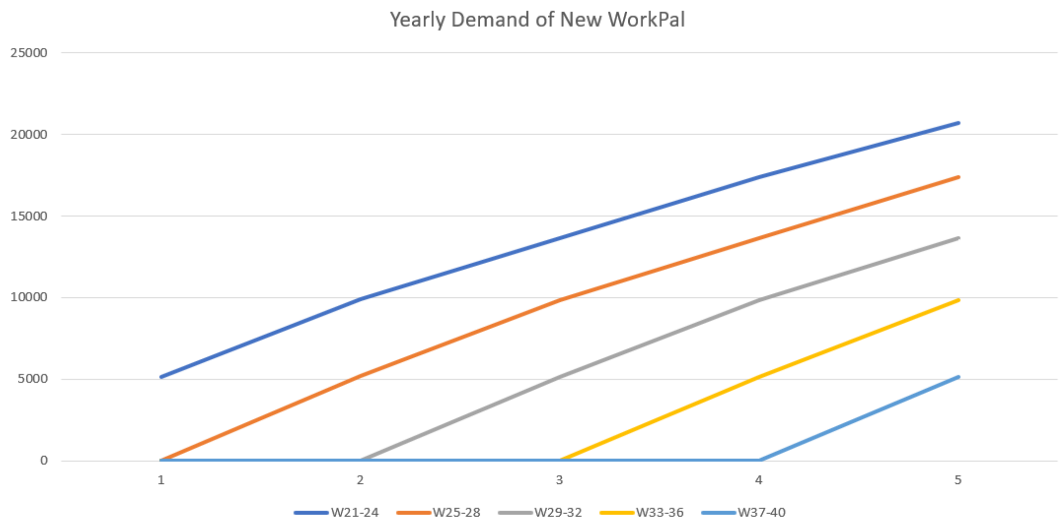


Figure 22 Annual Forecast for New WP

The pictures show the forecast yearly demand for WorkPal 21-40 in the next five years.

1.2.4 Product Line Level

The study process is the same as the one for the product level except that, before the visual inspection and rigorous statistics estimation, we need to add up the demand of all products of each product line, i.e. WP and MP. But notice that for WorkPal product line, we need to go down to the state level based on GDP, and for MyPal product line we need to go down to the megaregion level based on urban population.

The data for GDP in each state comes from official website of Bureau of Economic Analysis. The data table is attached below:

	A	B	C	D	E	F	G	H	I
1	**SAGDP2N Gross domestic pro**								
2	Gross domestic product (GDP) by								
3	Bureau of Economic Analysis								
4	State or DC								
5									
6	**GeoFips**	**GeoName**	**2014**	**2015**	**2016**	**2017**	**2018**		
7	00000	United State:	17521747	18219297	18707189	19485394	20494079		
8	01000	Alabama	194059.7	200460.8	203398.4	211665.9	221126.3	20245082.1	0.01092247
9	02000	Alaska	55547.4	50615	49429.4	51686.7	54011.2	20245082.1	0.00266787
10	04000	Arizona	284573.8	297095.9	311396.6	326539.2	346791.9	20245082.1	0.01712969
11	05000	Arkansas	117339.1	118525.9	120090.2	123713.7	128081.7	20245082.1	0.00632656
12	06000	California	2396552.1	2558171.2	2663395.6	2809922.4	2968117.6	20245082.1	0.14660931
13	08000	Colorado	306362	318230.4	329097.3	347195.7	368795.1	20245082.1	0.01821653
14	09000	Connecticut	248954.2	259697.9	262978.6	265535.4	274179.5	20245082.1	0.01354302
15	10000	Delaware	67178.9	70896.2	70379.8	72167.2	74973.3	20245082.1	0.00370328
16	12000	Florida	839706	894044	938370.3	979464.6	1036323.2	20245082.1	0.05118889
17	13000	Georgia	484915.4	512693.8	538237.5	562120.5	588171.7	20245082.1	0.02905257
18	15000	Hawaii	77972.5	82751.2	85866.9	89043.5	92027.1	20245082.1	0.00454565
19	16000	Idaho	63614.9	66338.9	69312.5	72442.4	77004.2	20245082.1	0.0038036
20	17000	Illinois	765910.2	792614	805434.1	825810.5	864587.3	20245082.1	0.04270604
21	18000	Indiana	325040.6	329725.1	338227	351072	366706.7	20245082.1	0.01811337
22	19000	Iowa	171512.5	177964.5	180350.6	182978.7	190150.3	20245082.1	0.00939242
23	20000	Kansas	148276.1	151651.8	155682	160083.4	167041.9	20245082.1	0.00825099
24	21000	Kentucky	186694.5	192019.3	195080	200990.8	208339.9	20245082.1	0.01029089
25	22000	Louisiana	237876.9	234344.1	228086.8	238138.4	252117.3	20245082.1	0.01245326
26	23000	Maine	55875.1	57484.9	59604	61720.1	64350.7	20245082.1	0.00317858
27	24000	Maryland	352524.3	367226.1	384155.8	398415.6	412920.9	20245082.1	0.02039611
28	25000	Massachuset	473454.4	502677.7	519741.1	540948.9	567254.8	20245082.1	0.02801939
29	26000	Michigan	448964.4	473987.7	490183.4	505844.8	528008.4	20245082.1	0.02608082

Figure 23 GDP for Each State

We used the GDP in recent fives and calculate the average of GDP proportion for each state, then used total forecast demand of WorkPal to time this average proportion, we can get the WorkPal demand for each state.

Similarly, the megaregion urban population data is attached below:

	A	B	C	D	E	F	G	H	I	J	K	L	M
1													
2	Population	2014	2015	2016	2017	2018		2014	2015	2016	2017	2018	average
3													
4	Arizon Sun Corridor	2091422	2120699	2151412	2176763	2206247		0.03604281	0.03616503	0.03638714	0.03663107	0.0369697	0.03643915
5	Cascadia	1531849	1562954	1599171	1625333	1647499		0.02639933	0.02665361	0.02704701	0.02735148	0.02760685	0.02701166
6	Florida	1977220	2017378	2061618	2094031	2126302		0.0340747	0.03440306	0.03486844	0.03523883	0.03563007	0.03484302
7	Front Range	1747590	1774574	1798586	1814966	1834010		0.03011733	0.03026244	0.03041975	0.03054266	0.03073219	0.03041487
8	Great Lakes	5682286	5679245	5673467	5665231	5658863		0.09792646	0.09685019	0.09595617	0.09533581	0.09482458	0.09617864
9	Gulf Coast	2852686	2903465	2928126	2932931	2938107		0.04916216	0.04951382	0.04952382	0.04935603	0.04923335	0.04935784
10	Northeast	11951686	12007634	12035260	12012300	11982419		0.20597104	0.20477045	0.2035541	0.20214574	0.20078731	0.20344573
11	Northern California	2995997	3034886	3060752	3083221	3102033		0.05163193	0.05175499	0.05176694	0.05188515	0.05198023	0.05180385
12	Piedmont Atlantic	1919043	1955570	1992483	2027600	2049720		0.03307209	0.03334903	0.03369915	0.03412092	0.0343468	0.0337176
13	Southern California	9709019	9804290	9881112	9933946	9982468		0.16732173	0.16719605	0.16712068	0.16717072	0.16727448	0.16721673
14	Texas Triangle	15567253	15778790	15943621	16057637	16149504		0.26828041	0.26908132	0.26965678	0.2702216	0.27061443	0.26957091
15	Total	58026051	58639485	59125608	59423959	59677172							

Figure 24 Population in each megaregion

1.2.5 Megaregion and State Level

We first searched for GDP for each state and each megaregion, then calculated the average GDP for each state and each megaregion as the demand ratio. We also searched for population for each state and each megaregion, then calculated the average population for each state and each megaregion as the demand ratio.

The following map gives you a visual perception about megaregions.

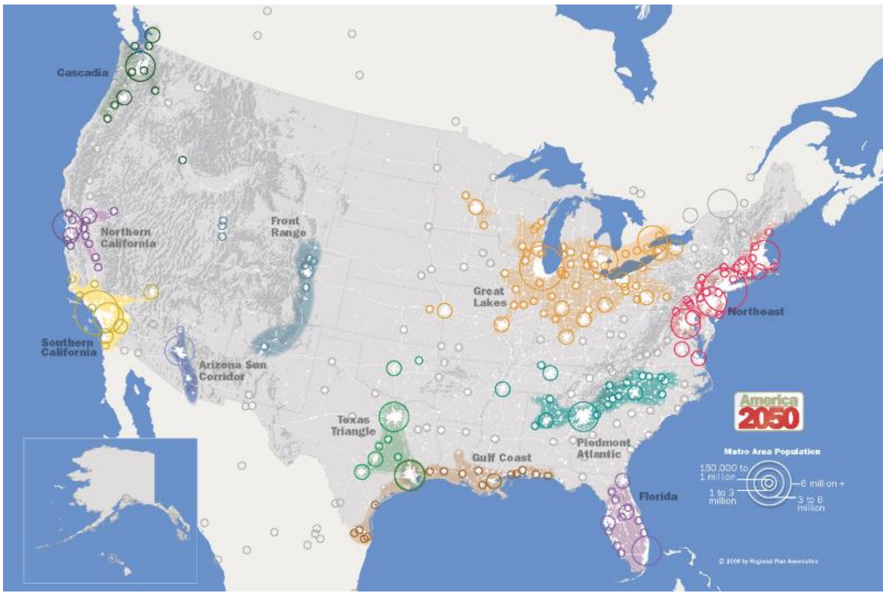


Figure 25 US Megaregions

	Alabama	Alaska	Arizona	Arkansas	California	Colorado	Connectici	Delaware	Florida	Georgia	Hawaii	Idaho	Illinois	Indiana	Iowa	Kansas	Kentucky	Louisiana	Maine	Maryland	Massachu:	Michigan	Mi
1	6	2	10	4	87	11	8	2	30	17	3	2	25	11	6	5	6	7	2	12	17	15	
2	6	2	10	4	87	11	8	2	30	17	3	2	25	11	6	5	6	7	2	12	17	15	
3	7	2	10	4	88	11	8	2	31	17	3	2	26	11	6	5	6	7	2	12	17	16	
4	7	2	11	4	90	11	8	2	31	18	3	2	26	11	6	5	6	8	2	13	17	16	
5	7	2	10	4	87	11	8	2	30	17	3	2	25	11	6	5	6	7	2	12	17	16	
6	7	2	10	4	87	11	8	2	30	17	3	2	25	11	6	5	6	7	2	12	17	16	
7	7	2	10	4	88	11	8	2	31	17	3	2	26	11	6	5	6	7	2	12	17	16	
8	7	2	11	4	90	11	8	2	31	18	3	2	26	11	6	5	6	8	2	13	17	16	
9	7	2	10	4	88	11	8	2	31	17	3	2	26	11	6	5	6	7	2	12	17	16	
10	7	2	10	4	88	11	8	2	31	17	3	2	26	11	6	5	6	7	2	12	17	16	
11	7	2	10	4	88	11	8	2	31	18	3	2	26	11	6	5	6	8	2	12	17	16	
12	7	2	11	4	90	11	8	2	32	18	3	2	26	11	6	5	6	8	2	13	17	16	
13	7	2	10	4	88	11	8	2	31	17	3	2	26	11	6	5	6	7	2	12	17	16	
14	7	2	10	4	88	11	8	2	31	17	3	2	26	11	6	5	6	7	2	12	17	16	
15	7	2	10	4	89	11	8	2	31	18	3	2	26	11	6	5	6	8	2	12	17	16	
16	7	2	11	4	91	11	8	2	32	18	3	2	26	11	6	5	6	8	2	13	17	16	
17	7	2	10	4	88	11	8	2	31	17	3	2	26	11	6	5	6	7	2	12	17	16	
18	7	2	10	4	88	11	8	2	31	17	3	2	26	11	6	5	6	7	2	12	17	16	
19	7	2	10	4	89	11	8	2	31	18	3	2	26	11	6	5	6	8	2	12	17	16	
20	7	2	11	4	91	11	8	2	32	18	3	2	26	11	6	5	6	8	2	13	17	16	
21	7	2	10	4	88	11	8	2	31	18	3	2	26	11	6	5	6	8	2	12	17	16	
22	7	2	10	4	88	11	8	2	31	18	3	2	26	11	6	5	6	8	2	12	17	16	
23	7	2	10	4	89	11	8	2	31	18	3	2	26	11	6	5	6	8	2	12	17	16	
24	7	2	11	4	91	11	8	2	32	18	3	2	27	11	6	5	6	8	2	13	17	16	
25	7	2	10	4	89	11	8	2	31	18	3	2	26	11	6	5	6	8	2	12	17	16	
26	7	2	10	4	89	11	8	2	31	18	3	2	26	11	6	5	6	8	2	12	17	16	
27	7	2	10	4	90	11	8	2	31	18	3	2	26	11	6	5	6	8	2	12	17	16	
28	7	2	11	4	91	11	8	2	32	18	3	2	27	11	6	5	6	8	2	13	17	16	

Daily Weekly Yearly

Figure 26 Forecast of Daily WorkPal demand for each state.

	Alabama	Alaska	Arizona	Arkansas	California	Colorado	Connectici	Delaware	Florida	Georgia	Hawaii	Idaho	Illinois	Indiana	Iowa	Kansas	Kentucky	Louisiana	Maine	Maryland	Massachu:	Michigan	Mi
1	42	10	66	25	569	71	53	14	199	113	18	15	166	70	36	32	40	48	12	79	109	101	
2	43	11	68	25	578	72	53	15	202	115	18	15	168	71	37	33	41	49	13	80	111	103	
3	43	11	68	25	583	72	54	15	204	116	18	15	170	72	37	33	41	50	13	81	111	104	
4	44	11	68	25	585	73	54	15	204	116	18	15	170	72	37	33	41	50	13	81	112	104	
5	44	11	69	25	588	73	54	15	205	116	18	15	171	73	38	33	41	50	13	82	112	105	
6	44	11	69	25	589	73	54	15	206	117	18	15	172	73	38	33	41	50	13	82	113	105	
7	44	11	69	26	592	74	55	15	207	117	18	15	172	73	38	33	42	50	13	82	113	105	
8	44	11	70	26	597	74	55	15	208	118	19	15	174	74	38	34	42	51	13	83	114	106	
9	45	11	70	26	598	74	55	15	209	118	19	16	174	74	38	34	42	51	13	83	114	106	
10	45	11	70	26	603	75	56	15	211	119	19	16	176	74	39	34	42	51	13	84	115	107	
11	45	11	71	26	604	75	56	15	211	120	19	16	176	75	39	34	42	51	13	84	115	107	
12	45	11	71	26	605	75	56	15	211	120	19	16	176	75	39	34	42	51	13	84	116	108	
13	45	11	71	26	607	75	56	15	212	120	19	16	177	75	39	34	43	52	13	84	116	108	
14	45	11	71	26	610	76	56	15	213	121	19	16	178	75	39	34	43	52	13	85	117	108	
15	46	11	71	26	612	76	56	15	214	121	19	16	178	76	39	34	43	52	13	85	117	109	
16	46	11	72	27	615	76	57	16	215	122	19	16	179	76	39	35	43	52	13	86	118	109	
17	46	11	72	27	618	77	57	16	216	122	19	16	180	76	40	35	43	52	13	86	118	110	
18	46	11	72	27	620	77	57	16	216	123	19	16	181	77	40	35	44	53	13	86	118	110	
19	47	11	73	27	624	78	58	16	218	124	19	16	182	77	40	35	44	53	14	87	119	111	
20	47	11	73	27	624	78	58	16	218	124	19	16	182	77	40	35	44	53	14	87	119	111	
21	47	11	73	27	629	78	58	16	219	125	19	16	183	78	40	35	44	53	14	87	120	112	
22	47	11	74	27	630	78	58	16	220	125	20	16	184	78	40	35	44	54	14	88	120	112	
23	47	12	74	27	635	79	59	16	222	126	20	16	185	78	41	36	45	54	14	88	121	113	
24	47	12	74	27	637	79	59	16	222	126	20	17	185	79	41	36	45	54	14	89	122	113	
25	48	12	75	28	640	79	59	16	223	127	20	17	186	79	41	36	45	54	14	89	122	114	
26	48	12	75	28	642	80	59	16	224	127	20	17	187	79	41	36	45	55	14	89	123	114	
27	48	12	75	28	645	80	60	16	225	128	20	17	188	80	41	36	45	55	14	90	123	115	
28	48	12	76	28	649	81	60	16	226	129	20	17	189	80	42	36	46	55	14	90	124	115	

Daily Weekly Yearly

Figure 27 Forecasts Weekly for WorkPal for Each State

	Alabama	Alaska	Arizona	Arkansas	California	Colorado	Connectici	Delaware	Florida	Georgia	Hawaii	Idaho	Illinois	Indiana	Iowa	Kansas	Kentucky	Louisiana	Maine	Maryland	Massachu:	Michigan	Mi
1	2232	545	3500	1293	29959	3723	2767	757	10460	5937	929	777	8727	3701	1919	1686	2103	2545	650	4168	5726	5330	
2	2948	720	4624	1708	39575	4917	3656	1000	13818	7842	1227	1027	11528	4889	2535	2227	2778	3362	858	5506	7563	7040	
3	3826	935	6001	2216	51360	6382	4744	1297	17932	10178	1592	1332	14961	6345	3290	2890	3605	4363	1114	7145	9816	9137	
4	4868	1189	7635	2820	65344	8119	6036	1651	22815	12949	2026	1695	19034	8073	4186	3677	4587	5550	1417	9091	12488	11624	
5	6055	1479	9495	3507	81270	10098	7507	2053	28375	16105	2520	2108	23673	10041	5206	4574	5705	6903	1762	11306	15532	14457	

Figure 28 Forecast Yearly WorkPal Demand for Each State

	A	B	C	D	E	F	G	H	I	J	K	L	M
1		Arizon Sun	Cascadia	Florida	Front Rang	Great Lake	Gulf Coast	Northeast	Northern (	Piedmont ,	Southern (	Texas Triangle	
2	1	195	144	186	163	514	264	1088	277	180	894	1442	
3	2	263	195	252	220	695	357	1471	375	244	1209	1949	
4	3	237	176	227	198	626	321	1325	337	220	1089	1755	
5	4	85	63	82	71	225	116	477	121	79	392	631	
6	5	60	44	57	50	157	81	333	85	55	273	441	
7	6	84	62	80	70	221	113	467	119	77	384	619	
8	7	133	99	127	111	352	180	744	189	123	612	986	
9	8	195	145	186	163	515	264	1089	277	180	895	1443	
10	9	264	196	253	221	698	358	1476	376	245	1213	1956	
11	10	237	176	227	198	626	321	1325	337	220	1089	1755	
12	11	87	65	83	73	230	118	486	124	81	400	644	
13	12	60	44	57	50	158	81	334	85	55	275	443	
14	13	84	62	80	70	222	114	470	120	78	386	622	
15	14	134	99	128	112	354	181	748	190	124	615	991	
16	15	196	145	187	164	517	265	1094	279	181	899	1450	
17	16	265	197	254	221	700	359	1480	377	245	1217	1961	
18	17	239	177	228	199	631	324	1334	340	221	1097	1768	
19	18	87	65	84	73	231	119	488	124	81	401	647	
20	19	60	45	58	50	159	82	336	86	56	277	446	
21	20	85	63	81	71	225	115	476	121	79	391	630	
22	21	135	100	129	112	355	182	752	191	125	618	996	
23	22	197	146	188	164	519	266	1098	280	182	902	1455	
24	23	265	197	254	221	700	359	1481	377	246	1218	1963	
25	24	240	178	229	200	632	324	1337	340	222	1099	1772	
26	25	87	65	83	73	230	118	486	124	81	400	644	
27	26	62	46	59	52	163	84	345	88	57	284	458	
28	27	86	64	82	72	226	116	479	122	79	393	634	
29	28	135	100	129	113	357	183	755	192	125	621	1001	

Figure 29 Forecast Daily MyPal Demand for Each Megaregion

	A	B	C	D	E	F	G	H	I	J	K	L	M
1		Arizon Sun	Cascadia	Florida	Front Rang	Great Lake	Gulf Coast	Northeast	Northern (	Piedmont ,	Southern (	Texas Triangle	
2	1	780	578	746	651	2059	1057	4356	1109	722	3581	5772	
3	2	730	541	698	610	1928	989	4078	1038	676	3352	5404	
4	3	705	522	674	588	1860	955	3935	1002	652	3234	5214	
5	4	673	499	644	562	1777	912	3759	957	623	3089	4980	
6	5	660	489	631	551	1743	894	3686	939	611	3030	4885	
7	6	636	471	608	531	1678	861	3550	904	588	2917	4703	
8	7	614	455	587	512	1620	831	3426	872	568	2816	4539	
9	8	600	445	574	501	1584	813	3351	853	555	2754	4440	
10	9	609	451	582	508	1608	825	3400	866	564	2795	4506	
11	10	635	471	607	530	1677	860	3547	903	588	2915	4699	
12	11	635	471	607	530	1677	860	3547	903	588	2915	4700	
13	12	644	478	616	538	1700	873	3597	916	596	2956	4766	
14	13	653	484	625	545	1724	885	3647	929	604	2997	4832	
15	14	674	499	644	562	1778	912	3761	958	623	3091	4983	
16	15	653	484	624	545	1723	884	3644	928	604	2995	4829	
17	16	742	550	709	619	1958	1005	4141	1054	686	3404	5487	
18	17	777	576	743	649	2051	1053	4338	1105	719	3566	5748	
19	18	864	641	826	721	2281	1170	4824	1228	800	3965	6393	
20	19	822	610	786	686	2170	1114	4591	1169	761	3773	6083	
21	20	883	655	844	737	2331	1196	4930	1255	817	4052	6533	
22	21	867	642	829	723	2287	1174	4838	1232	802	3977	6411	
23	22	900	667	861	751	2376	1219	5026	1280	833	4131	6660	
24	23	975	723	932	814	2573	1321	5444	1386	902	4474	7213	
25	24	954	707	913	797	2519	1293	5328	1357	883	4379	7060	
26	25	985	730	942	822	2600	1334	5500	1401	912	4521	7288	
27	26	987	731	943	824	2604	1337	5509	1403	913	4528	7300	
28	27	1010	749	966	843	2666	1368	5639	1436	935	4635	7472	
29	28	1045	775	999	872	2758	1415	5834	1486	967	4795	7730	

Figure 30 Forecasts Weekly for MP for each Megaregion

	A	B	C	D	E	F	G	H	I	J	K	L	M
1		Arizon Sun	Cascadia	Florida	Front Rang	Great Lake	Gulf Coast	Northeast	Northern (	Piedmont .	Southern (	Texas Triangle	
2	1	72676	53873	69493	60661	191824	98442	405762	103320	67248	333505	537646	
3	2	98299	72868	93994	82048	259455	133149	548822	139748	90958	451089	727204	
4	3	138223	102462	132168	115371	364829	187226	771719	196505	127899	634293	1022548	
5	4	193087	143132	184629	161165	509640	261542	1078037	274503	178666	886063	1428427	
6	5	265930	197129	254281	221965	701903	360209	1484728	378060	246068	1220332	1967304	
7													

Figure 31 Annual Demand Forecast for MyPal in Next 5 Years for Each Megaregion

1.3 Methodology for Demand Simulator

Here, we would discuss the methodology for generating simulator for MP and WP (new as well as existing products).

1.3.1 MyPal1 to MyPal5 (existing products which have historical data):

These products exhibit a lot of seasonality both monthly and daily. So, as first step we will remove daily and monthly factors. We define daily factors for each of the weekday i.e. from Monday to Sunday and it is a factor by which the average daily sales were higher or lower.

$$Daily\ Seasonality\ Factor = \frac{\%\ of\ sales\ on\ that\ day\ of\ the\ week}{average\ daily\ sales}$$

Similarly, we define monthly factors as follows

$$Monthly\ Seassonality\ Factor\ for\ Feb = \frac{\%\ of\ sales\ on\ in\ Feb\ for\ all\ 5\ years}{average\ monthly\ sales\ across\ all\ 5\ years}$$

Once we have these factors, we would divide our observed sales so we can get rid of daily and monthly factors and can fir trendline on the resulting data (so called ‘de-seasonalized data’).

To estimate the best fitting line for de-seasonalized data, we would fit the least square error line and use trendline functions SLOPE and INTERCEPT in excel.

Once we have SLOPE and INTERCEPT, we can estimate the trend value for a given day and if we remove this estimated value from de-seasonalized data, we would get the so-called ‘de-trended data’. At this point, it is the residual error that we talked earlier. From plotting the histogram of these errors, we observe that they are normally distributed around mean 0 and with some standard deviation.

Now, at this point we know the trendline information, seasonal factors and also residual error behavior for MyPal 1 to 5.

To simulate demand, we would use Monte Carlo simulation. We will draw from random uniform distribution in Excel using RAND() function and then use that as probability to take the normal inverse with mean and std deviation equal to that of the residual errors.

In Excel, it would be this formula: NORM.INV(RAND(), MEAN, STDEV)
Here, the MEAN and STDEV are from the mean and standard deviation of the residual errors.

1.3.2 MyPal6 to MyPal25 (New Products):

Since it is given that new products have equal market potential, we assumed that the random fluctuations in the new products will also be similar to the existing products and as we have 5 means and 5 std deviations for each of the MyPal's, we would take the average of the means and std deviation and use that as a random noise to simulate daily demand for future products

To add trend and daily & monthly factors, we would do the same exercise of taking the average of trends, daily and monthly factors of MP1 to MP5. To simulate, we would use the same function as listed above – first drawing samples from uniform and using them as probability for normal inverse with mean and std deviation as the average of the existing 5 products.

1.3.3 WorkPal1 to WorkPal20 (existing products which have historical data):

These products don't have any seasonality either daily or monthly. So, we can directly do trend estimation. Here, each of the WP is at the different stage in its life cycle. So, we will treat each one differently.

The following table summarizes the information for WP.

Product	**Behavior**	**Included/Not Included in the Analysis**
WorkPal1	Showing consistent yearly growth	Yes
WorkPal2	Demand has hit zero (Product is dying and has reached the end of lifecycle)	No
WorkPal3	Demand has hit zero (Product is dying and has reached the end of lifecycle)	No
WorkPal4	Product is matured and demand has started reducing	Yes (Use the behavior – trendlines for dying products to simulate the next 5 years)
WorkPal5	Demand has hit zero (Product is dying and has reached the end of lifecycle)	No
WorkPal6	Product has matured and demand has started reducing	Yes (Demand is declining since past 4 years – can use trendline information to simulate demand for next years)
WorkPal7	Demand is increasing and has stabilized in 2017	Yes (We will only use 2017/18 data for simulator purposes to avoid skewness in demand projections)
WorkPal8	Product has matured and demand has started reducing	Yes (can use the behavior of the dying products for simulating the demands for next years)
WorkPal9	Showing a strong consistent growth	Yes
WorkPal10	Showing a strong consistent growth	Yes

WorkPal11	Showing a strong consistent growth (introduced in Q3 2015)	Yes
WorkPal12	Showing a strong consistent growth (introduced in Q2 2016)	Yes
WorkPal13	Showing a strong consistent growth (introduced in Q2 2016)	Yes
WorkPal14	Showing a strong consistent growth (introduced in Q1 2017)	Yes
WorkPal15	Showing a strong consistent growth (introduced in Q1 2017)	Yes
WorkPal16	Showing a strong consistent growth (introduced in Q3 2017)	Yes
WorkPal17	Showing a strong consistent growth (introduced in Q3 2017)	Yes
WorkPal18	Showing a strong consistent growth (introduced in Q1 2018)	Yes
WorkPal19	Showing a strong consistent growth (introduced in Q1 2018)	Yes
WorkPal20	Showing a strong consistent growth (introduced in Q1 2018)	Yes

1.3.4 WorkPal21 to WorkPal40 (new products):

We use the behavior of the recently introduced products which are WP18,19 and 20.

For trend of each of the new WorkPal, we would draw from a uniform random distribution with the following formula in Excel:
RANDBETWEEN(MIN(SLOPE(WP18, WP19, WP20), MAX(SLOPE(WP18,WP19,WP20))

Similarly, for intercept:
RANDBETWEEN(MIN(INTERCEPT(WP18,WP19,WP20), MAX(INTERCEPT (WP18,WP19,WP20))

This would ensure that in each scenario different products are having different growth trends. It is very unlikely that all of the new products have same growth trends, so this approach makes more sense and is more realistic.

Both, MP and WP simulator are in Appendix and in the Excel file.

To generate new scenarios, press F9.

Figure below shows one of the simulated scenarios for MP.

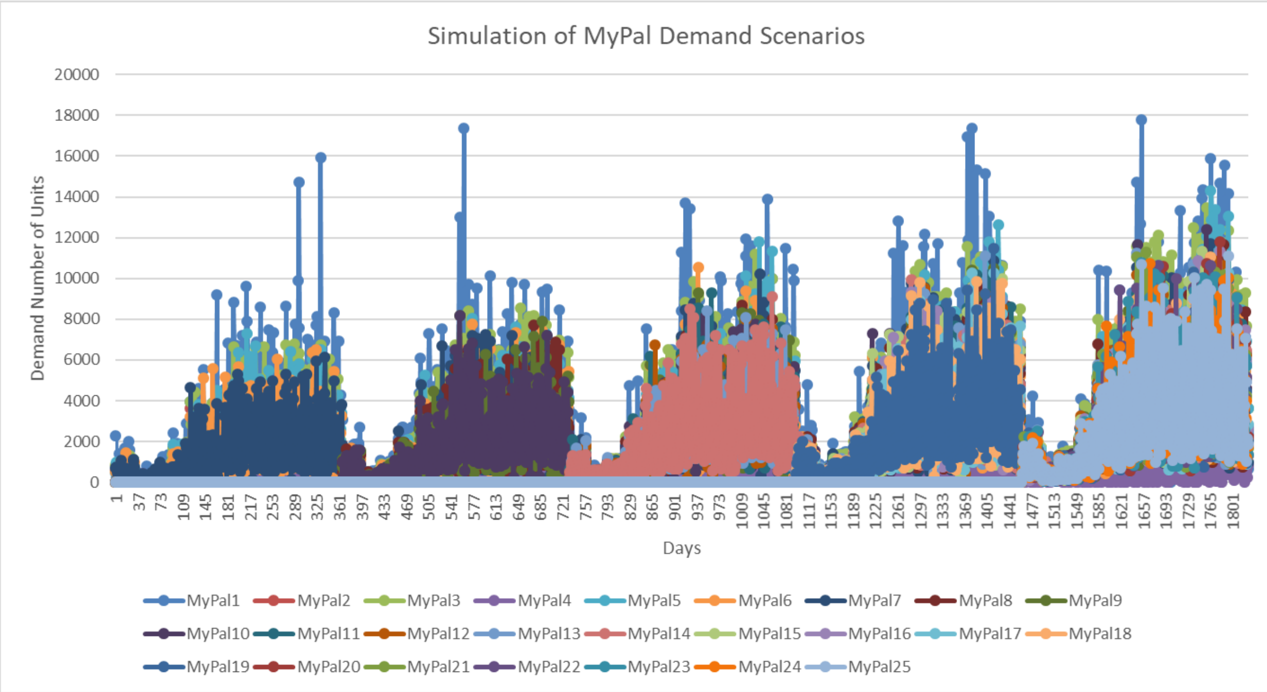


Figure 32 MyPal Demand Simulator

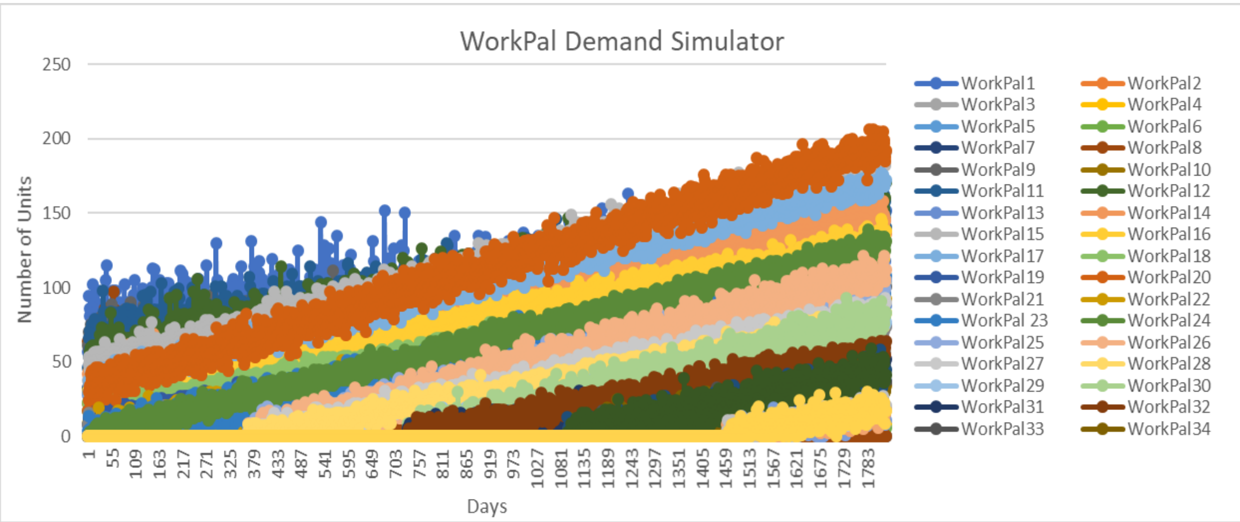


Figure 33 WorkPal Demand Simulator

1.3.5 Product Line & Global Demand Simulator

The WorkPal line is a special case. After deseasonalization, we can clearly see a stable shift of the mean of the demand each year. And by plotting the deviation of the demand from the demand of the respective year, we found that the deviation randomly distributed around the horizontal line equal zero, but with an expanding pattern.

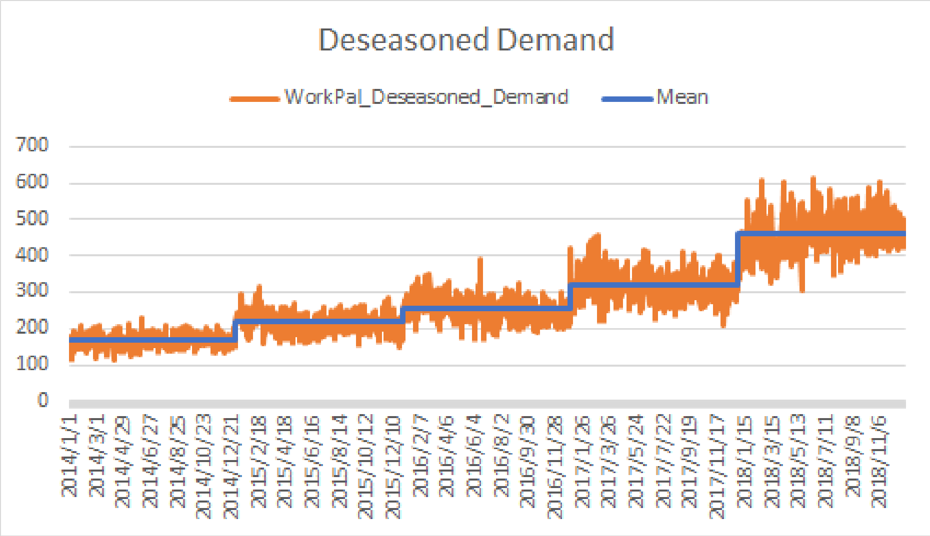


Figure 34 Deseasoned Demand at Product Line Level for WP

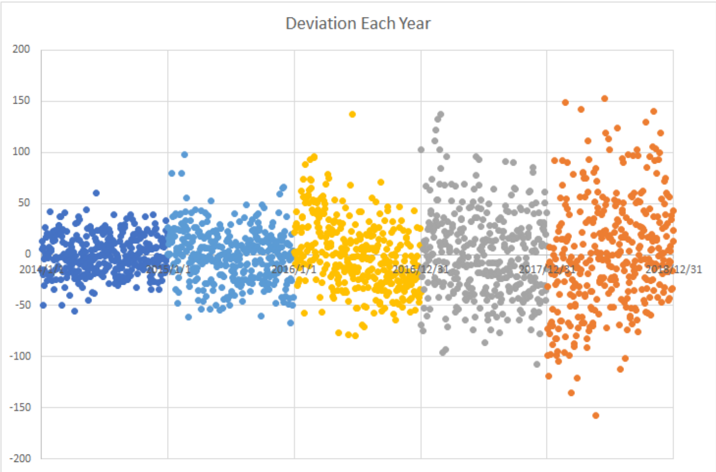


Figure 35 Deviation from Mean Each Year

Thus, we separately modeled the annual mean and annual standard deviation, identifying the slope and intercept.

Row Labels	Average of WorkPal Line	Standard Deviation of WorkPal Line
2014	168.06	18.45
2015	217.11	25.47
2016	253.90	34.16
2017	317.54	41.17
2018	460.31	53.54
Grand Total	283.37	107.46
intercept	420.37	51.74
slope	68.49	8.59

Table 3 Slope & Intercept for WP Product Line

Then, for each year, we predicted a yearly level and a yearly standard deviation and then add random numbers that follow the normal distribution with mean 0 and the yearly standard deviation.

We simulated this demand 100 times and got the following picture.

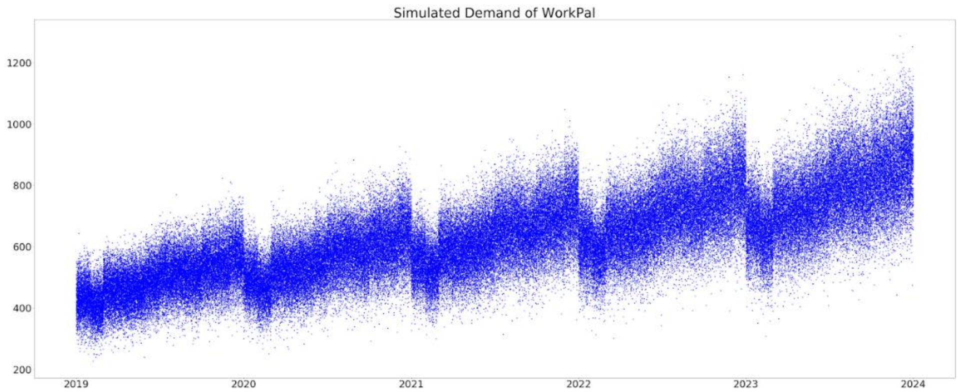


Figure 36 Simulated Demand for WP

We used Python to simulate the demand of the two production lines the global level. Here are the visualized results.

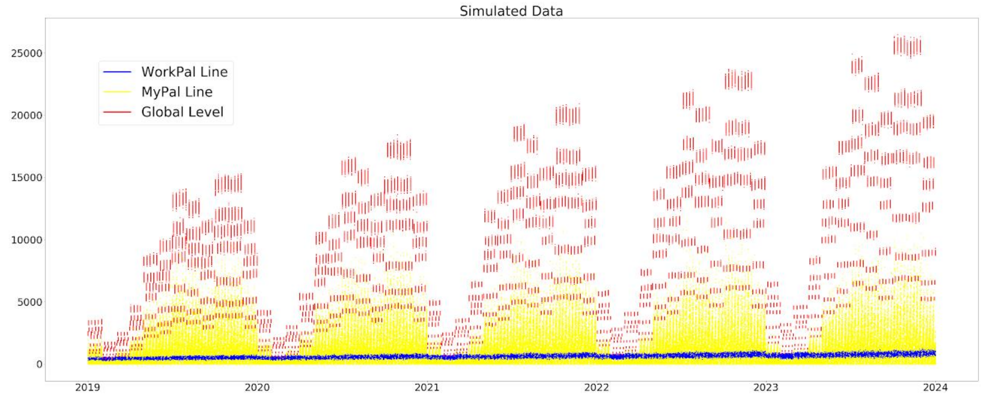


Figure 37 Simulated Data at PL & Global Level

Comparing the simulation results with the history data, we can see an overall growth in the three levels with the same seasonal and scale pattern.

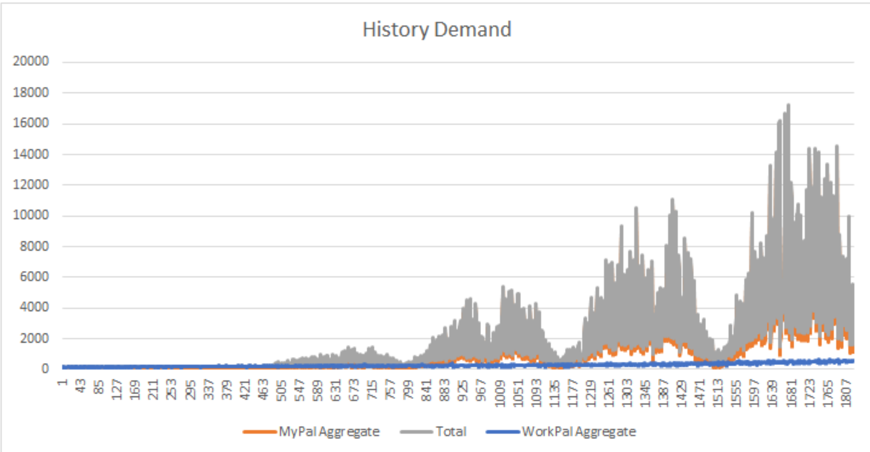


Figure 38 Demand History for Comparison with Figure 32

2 Task 2

2.1 Overall Methodology

We started with the calculation of the robust daily demand satisfaction requirements during target lead time given target service level.

Here is the formula we used:

$$D_{l,s} = \frac{1}{l}(d \times \frac{l}{b} + z_s \sqrt{\sigma_b{}^2 \times \frac{l}{b}})$$

where,

l is the target lead time, i.e. OTD days, which we chose 1, 2, 3, 4, 7, 12, 17 and 20 days, the median days of the OTD requirement range;

s is the target service level, which we are asked to study at 99% and we amplified for the sensitive analysis to a range from 95% to 99% with 1% increase and 99.9%, the last level;

$z_s$is the normal distribution z factor for s;

$D_{l,s}$ is the daily demand during the target OTD period;

b is the base period used to estimate demand distribution, which is 1 in our case since we plan for the daily demand requirement;

d is the average demand requirement by a certain customer share on a specific day;

$\sigma$is the standard deviation of the demand requirement by a certain customer share on a specific day;

Both d and σ are derived from the demand simulator developed in task 1. The simulation and calculation were done by Python.

The following is the general logic of the algorithm.

- First, we ran the simulation 100 times for each day and each product so that we can get the mean and standard deviation of the daily demand.
- Then based on the formula mentioned before, we calculated the daily demand satisfaction requirements for each day, each product on the requirement of 8 OTD length and 6 service levels.
- Finally, we export the results into 6 workbooks corresponding to service level at 95%, 96%, 97%, 98%, 99% and 99.9% and each workbook contains 8 worksheets with respect to different OTD length.

2.2 Example Code and Results

The methodology in 2.1 is applicable to the three levels, product, product line and global. We accomplished the analysis on 3 levels, individual products (40 WorkPals and 25 MyPals), product lines (WorkPal and MyPal) and the global level with 8 targeted OTD/OTS time at 7 different service levels.

Therefore, in the body of the report, the results of MyPals are shown as an example of all.

Below, we have shown one screenshot regarding 99% SL for different OTD.

Column1	MyPal_1	MyPal_2	MyPal_3	MyPal_4	MyPal_5	MyPal_6	MyPal_7	MyPal_8	MyPal_9	MyPal_10	MyPal_11	MyPal_12	MyPal_13	MyPal_14	MyPal_15	MyPal_16	MyPal_17	MyPal_18
2019-01-01	363.86419	120.56538	91.339843	193.94346	101.26471	163.87755	162.11699	0	0	0	0	0	0	0	0	0	0	0
2019-01-02	482.26406	144.19025	125.38677	247.91124	144.28557	239.89132	248.61338	0	0	0	0	0	0	0	0	0	0	0
2019-01-03	406.59842	126.71632	105.71284	185.28009	121.3492	192.47635	201.8099	0	0	0	0	0	0	0	0	0	0	0
2019-01-04	106.20388	29.608424	24.515242	59.349469	29.957488	46.593853	53.086099	0	0	0	0	0	0	0	0	0	0	0
2019-01-05	136.01324	42.162168	33.837301	69.402277	41.090109	60.347597	63.76872	0	0	0	0	0	0	0	0	0	0	0
2019-01-06	31.640109	68.289843	50.120858	85.257893	63.265912	87.926208	80.303213	0	0	0	0	0	0	0	0	0	0	0
2019-01-07	309.42903	85.763774	80.527409	148.23811	87.940779	157.07661	144.15268	0	0	0	0	0	0	0	0	0	0	0
2019-01-08	361.31419	101.98864	99.302277	185.87047	115.50976	162.85643	172.62073	0	0	0	0	0	0	0	0	0	0	0
2019-01-09	465.5047	152.26324	121.70508	243.86031	151.25763	228.44627	221.05309	0	0	0	0	0	0	0	0	0	0	0
2019-01-10	363.35269	128.62688	112.59546	208.41833	132.36351	197.63878	183.35335	0	0	0	0	0	0	0	0	0	0	0
2019-01-11	101.40201	31.018986	23.30468	49.095725	27.056552	43.802542	44.542917	0	0	0	0	0	0	0	0	0	0	0
2019-01-12	133.82193	39.591045	29.525803	66.171528	44.861232	67.219656	69.070592	0	0	0	0	0	0	0	0	0	0	0
2019-01-13	26.688237	59.096661	48.530483	95.291449	61.044789	77.883025	75.852277	0	0	0	0	0	0	0	0	0	0	0
2019-01-14	286.48023	96.767518	80.357222	148.8583	92.142651	163.47942	149.21418	0	0	0	0	0	0	0	0	0	0	0
2019-01-15	359.644	112.29145	94.180217	169.92541	110.20789	168.19867	158.63624	0	0	0	0	0	0	0	0	0	0	0
2019-01-16	493.19575	143.70081	121.49452	258.88518	134.67126	253.40563	266.45162	0	0	0	0	0	0	0	0	0	0	0
2019-01-17	364.55363	123.37594	96.049469	198.14533	113.78677	209.54346	209.04346	0	0	0	0	0	0	0	0	0	0	0
2019-01-18	99.181824	30.598798	25.435429	55.858158	28.467114	47.643853	43.702542	0	0	0	0	0	0	0	0	0	0	0
2019-01-19	126.1095	41.001606	33.367114	64.331153	40.869922	75.142651	65.029281	0	0	0	0	0	0	0	0	0	0	0
2019-01-20	34.120858	64.86872	48.040109	97.181824	60.024601	76.942651	77.272464	0	0	0	0	0	0	0	0	0	0	0
2019-01-21	314.24922	94.997331	77.506286	150.63905	87.251341	161.17848	139.26043	0	0	0	0	0	0	0	0	0	0	0
2019-01-22	371.76794	111.48182	81.845725	166.3841	98.803213	178.98223	183.61391	0	0	0	0	0	0	0	0	0	0	0
2019-01-23	505.9908	149.28249	131.04827	233.12582	146.00575	241.79132	244.95188	0	0	0	0	0	0	0	0	0	0	0
2019-01-24	347.69895	115.34239	103.43209	196.62421	122.95014	194.90803	177.38129	0	0	0	0	0	0	0	0	0	0	0
2019-01-25	103.2222	26.957488	23.924867	52.457222	27.876739	46.083291	47.51404	0	0	0	0	0	0	0	0	0	0	0
2019-01-26	145.41605	44.463104	31.436365	79.876208	40.969922	57.876473	63.158158	0	0	0	0	0	0	0	0	0	0	0
2019-01-27	28.248798	62.967784	48.510296	99.902947	66.096661	76.132089	80.904149	0	0	0	0	0	0	0	0	0	0	0

OTD_20 | OTD_17 | OTD_12 | OTD_7 | OTD_4 | OTD_3 | OTD_2 | OTD_1

Figure 39 99 % SL with different OTD for MP

For the all the other cases, we have included them in the Task 2 subfolder.

2.3 Sensitive Analysis

2.3.1 Lead Time and Capacity Plan

According to the formula we used,

$$D_{l,s} = \frac{1}{l}\left(d * \frac{l}{b} + z_s * \sqrt{\sigma_b^2 * \frac{1}{b}}\right)$$

When l increased by $\delta l > 0$, then

$$D_{l+\delta l,s} = \frac{d}{b} + z_s\sqrt{\sigma_b^2 * \frac{1}{b * (l + \delta l)}} = \frac{d}{b} + z_s\sigma_b\sqrt{\frac{1}{b}}\sqrt{\frac{1}{l + \delta l}}$$

Thus,

$$\delta D = D_{l+\delta l,s} - D_{l,s} = z_s\sigma_b * \sqrt{\frac{1}{b}}\left(\sqrt{\frac{1}{1 + \delta l}} - \sqrt{\frac{1}{l}}\right)$$

Hence, δD is a function of l with the following properties.

1. $\delta D < 0$, that is $D_{l+\delta l,s}$<$D_{l,s}$. That is, keeping all the other variables (z_s, b, σ_b) the same, the extension of the targeted lead time leads to the decline in the capacity requirement during the longer lead time.
2. As l increases, δD decreases. That is, the larger increase in the targeted lead time, the more reduction in the capacity plan.

To illustrate the above vividly, we made a graph using the capacity plan of MyPal 1 at a service level of 95% on different targeted lead time from day 1 to day 7.

Each line shows the capacity plan at one OTD. The line of the shorter OTD is always above the one of the longer OTD. It shows that when the targeted OTD becomes smaller, capacities need to be bigger.

Also, if say we initially targeted on the OTD of 2 days (the dark blue line), if we increase it by 1 day, then it becomes what the green line shows; and if by 2 days, then the light blue line. And the gap between the line of OTD=2 and OTD=3 is less than that between OTD=2 and OTD=4. That is, as the customer's requirements becomes less strict, the less effort CoPal is to put on the capacity.

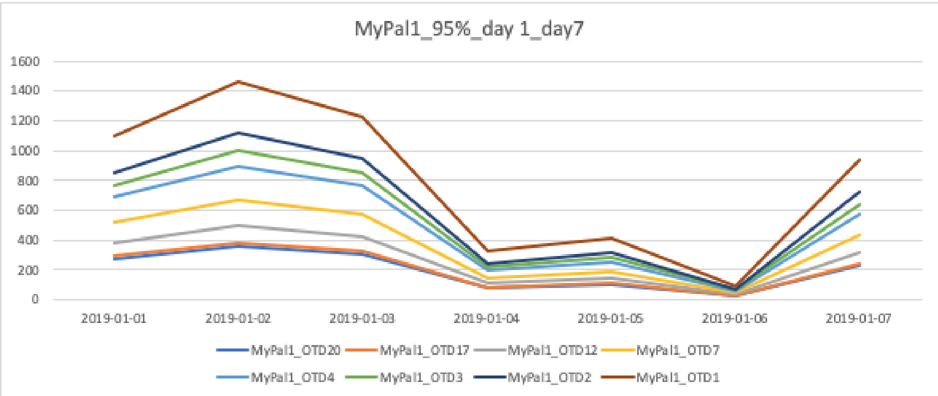


Figure 40 Effect of OTD on Capacity Requirement

Here's the graph using the capacity plan of MyPal 1 at a service level of 95% in 5 years, which tells the same story.

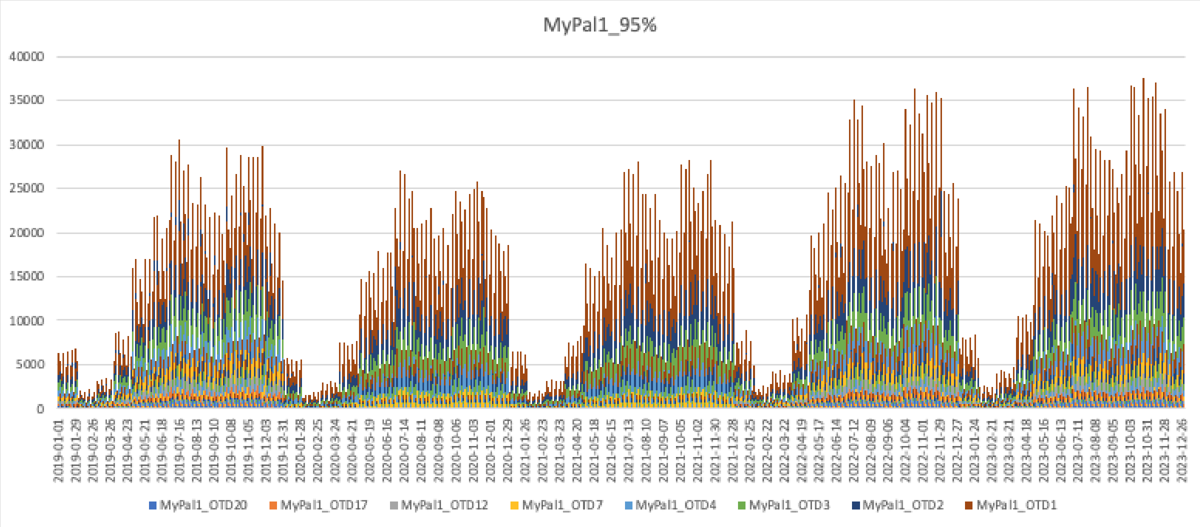


Figure 41 Capacity Plan of MyPal 1 at a Service Level of 95% in 5 years

2.3.2 Service Level and Capacity Plan

According to the formula we used again, when s is increased by δs, then

$$D_{l,s+\delta s} = \frac{d}{b} + z_{s+\delta s} * \sqrt{\sigma_b^2 * \frac{1}{bl}}$$

Thus, after simplification we will get

$$\delta D = (z_{s+\delta s} - z_s) * \sqrt{\sigma_b^2 * \frac{1}{bl}}$$

Hence, D is a function of s and here are its properties.

1. Since $z_{s+\delta s} - z_s > 0$ (shown in the following picture), $\delta D > 0$, i.e. $D_{l+\delta l,s} > D_{l,s}$. That is, keeping all the other variables (z_s, b, σ_b) the same, the higher service level results in the increment in the capacity requirement during the lead time.

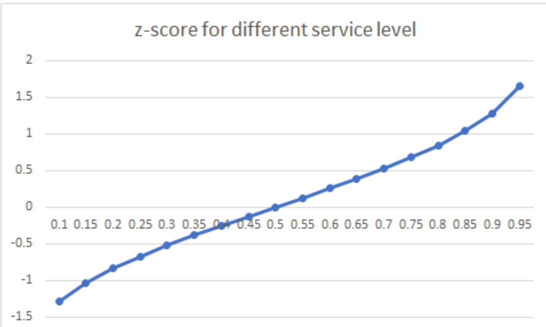


Figure 42 Z Score at Diff Service Levels

2. Focusing on the service level we studied, as s increases, δD increases as well (shown in the following picture).

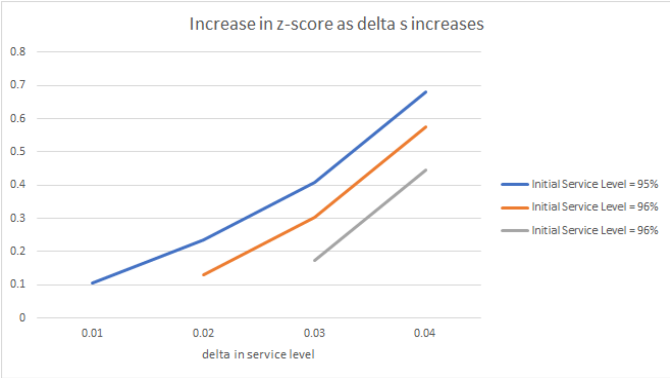


Figure 43 Increase in Z-score as Delta s Increases

We made a graph using the capacity plan targeted on the OTD of 7 days of MyPal 1 at different service levels from day 1 to day 7. It shows that:

1. When service levels become higher, capacities need to expand as well.
2. The gaps between a service level and another service level grow when the latter service level becomes higher.

The reason behind this result is that when we would like to cover more demand, capacities need to grow as well in order to provide the service.

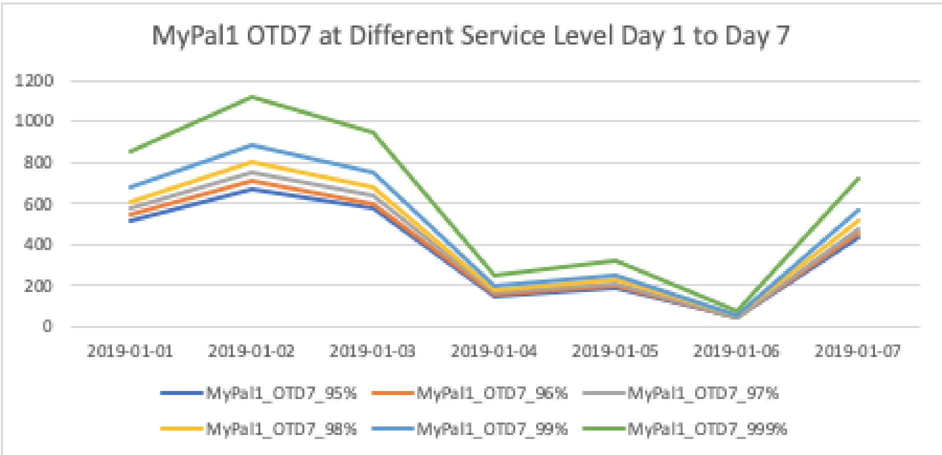


Figure 44 OTD of 7 days MyPal at different service level for Day 1 to Day 7

Here's the graph using OTD of 7 days of MyPal at different service levels in 5 years which tells the same story.

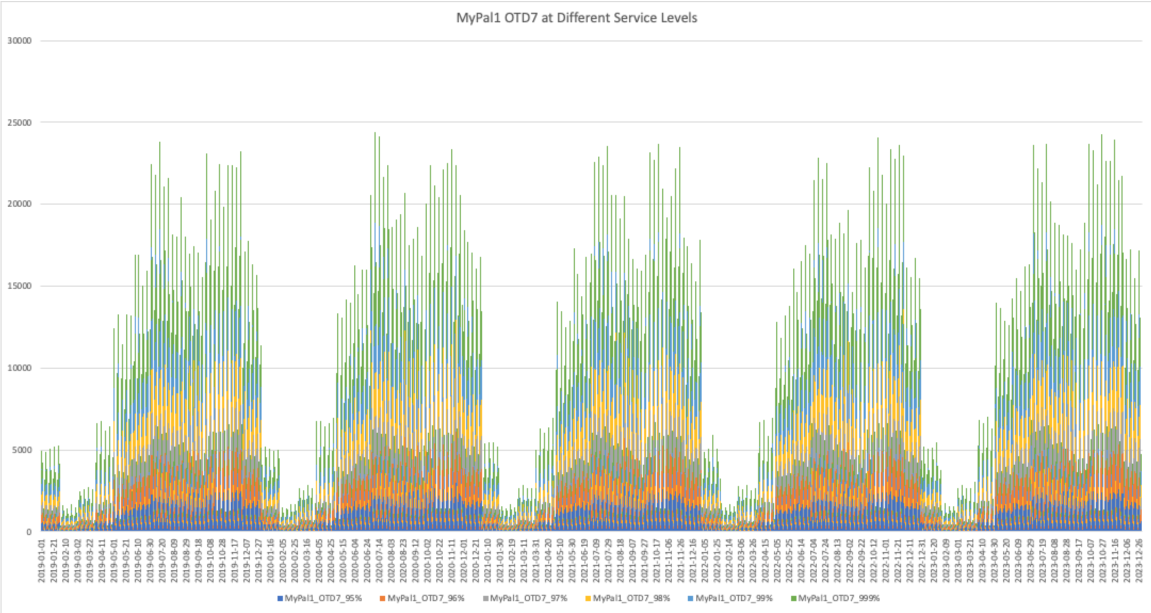


Figure 45 OTD of 7 days of MyPal at different service levels in 5 years

2.4 Validation

We simulated the demand 10,000 times for each day and count the number of times it is within the capacity plan for 99% service level. By doing this, we can calculate the percentage that the daily capacity plan meets the customers' daily demand, which is exactly the definition of service level.

This is an example of the validation results of MyPal 1 for the first 10 days.

	OTD_20	OTD_17	OTD_12	OTD_7	OTD_4	OTD_3	OTD_2	OTD_1
2019-01-01	100	100	100	100	100	100	100	100
2019-01-02	100	100	100	100	100	100	100	100
2019-01-03	100	100	100	100	100	100	100	100
2019-01-04	100	100	100	100	100	100	100	100
2019-01-05	100	100	100	100	100	100	100	100
2019-01-06	100	100	100	100	100	100	100	100
2019-01-07	100	100	100	100	100	100	100	100
2019-01-08	100	100	100	100	100	100	100	100
2019-01-09	100	100	100	100	100	100	100	100
2019-01-10	100	100	100	100	100	100	100	100

Table 4 Percentage of Times that Demand is Under Capacity Plan at 99% Service Level

	OTD_20	OTD_17	OTD_12	OTD_7	OTD_4	OTD_3	OTD_2	OTD_1
2019-01-01	100	100	100	100	100	100	100	100
2019-01-02	100	100	100	100	100	100	100	100
2019-01-03	100	100	100	100	100	100	100	100
2019-01-04	100	100	100	100	100	100	100	100
2019-01-05	100	100	100	100	100	100	100	100
2019-01-06	100	100	100	99.9	99.9	100	100	100
2019-01-07	100	100	100	100	100	100	100	100
2019-01-08	100	100	100	100	100	100	100	100
2019-01-09	100	100	100	100	100	100	100	100
2019-01-10	100	100	100	100	100	100	100	100

Table 5 Percentage of Times that Demand is Under Capacity Plan at 95% Service Level

The pictures here explain the quantitative results very well.

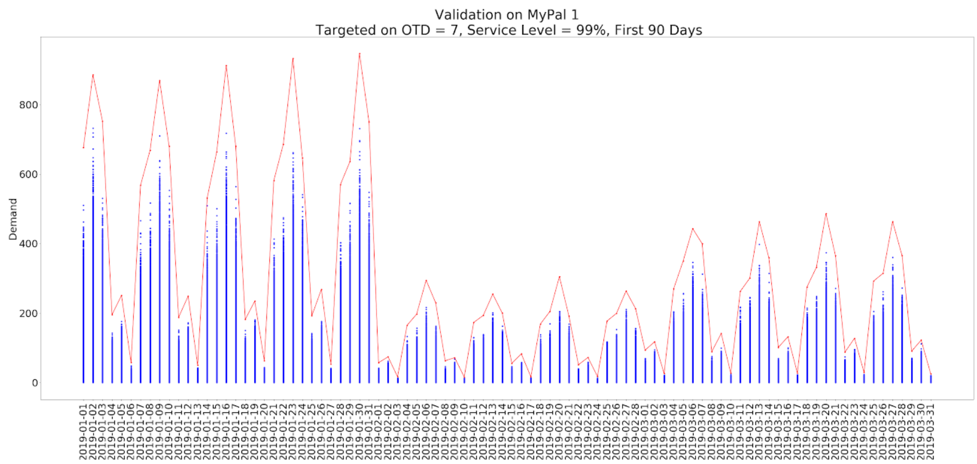


Figure 46 Validation on MyPal1 Service Level (SL) 99%

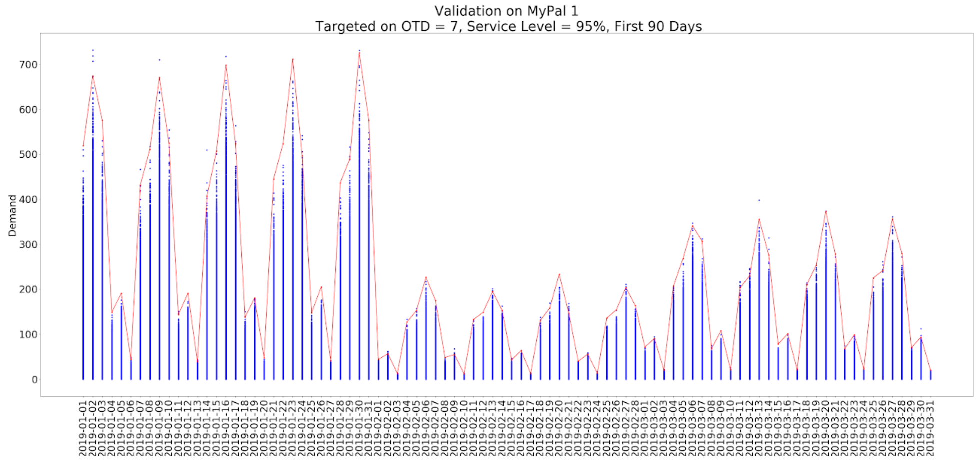


Figure 47 Validation on MyPal1 Service Level (SL) 95%

In conclusion, the daily capacity plan at 99% service level is extremely robust.

To speed up the simulation process, we implemented our simulator and finished the validation in Python. Codes are attached in the Task 2 subfolder.

3 Task 3

3.1 Assumption

1. For daily cell efficiency and weekly cell reliability, we assume that they are uniform variables, and in the long run (5-year horizon), we can use their means to calculate capacity plan.
2. For extending work, the constraint is that the maximum extended working time is less than 5 hours a week. We assume that the maximum extended working time is less than 5/7 hours per day.
3. When calculating the daily marginal cost, we assume the maintenance for a machine is 3000/30=100 dollars.

3.2 Methodology & Quantitative Analysis

The forecast daily dynamic capacity resource requirement with 99% service level is shown below from the Task 2.

	WorkPal1	WorkPal2	WorkPal3	WorkPal4	WorkPal5	WorkPal6	WorkPal7	WorkPal8	WorkPal9	WorkPal10	WorkPal11	WorkPal12	WorkPal13	WorkPal14	WorkPal15
1	178.03	0	0	28.10	0	60.14	98.29	133.32	121.39	39.05	133.45	124.76	56.16	75.58	79.60
2	181.95	0	0	28.37	0	58.69	94.17	130.78	133.66	39.76	117.32	111.87	54.35	79.21	84.67
3	176.03	0	0	27.14	0	57.31	103.79	139.57	128.79	42.33	122.41	118.72	53.33	79.82	84.04
4	180.43	0	0	28.58	0	59.57	100.11	133.84	124.35	40.29	117.91	118.90	55.40	76.87	79.77
5	177.68	0	0	27.57	0	63.37	107.89	141.40	124.34	41.03	130.91	122.81	56.55	74.38	85.22
6	188.23	0	0	28.89	0	60.65	108.97	127.14	124.63	42.84	124.48	116.32	54.81	78.02	83.86
7	189.93	0	0	28.74	0	67.81	98.78	128.87	133.84	41.57	118.00	116.72	54.08	78.78	83.54
8	199.93	0	0	27.33	0	64.62	99.52	139.50	125.82	40.90	126.71	113.11	54.67	78.43	81.86
9	201.13	0	0	27.12	0	55.09	97.33	129.01	129.01	43.32	133.65	111.53	54.63	79.31	86.40
10	185.52	0	0	26.01	0	57.38	93.79	129.79	130.69	40.62	126.39	114.25	52.92	77.71	82.03
11	178.25	0	0	26.20	0	58.01	98.24	122.51	126.70	40.37	122.20	115.19	54.92	74.87	81.49
12	182.28	0	0	26.62	0	62.39	98.80	131.64	125.66	42.20	119.89	109.46	54.85	81.66	82.43
13	187.28	0	0	27.78	0	54.35	104.87	129.30	135.95	41.11	132.43	115.16	55.32	78.15	81.90
14	169.01	0	0	30.00	0	62.30	95.15	134.67	126.64	40.41	119.49	116.31	54.39	79.19	84.05
15	187.37	0	0	26.54	0	56.41	95.68	122.97	120.78	40.63	123.47	119.06	52.35	76.71	82.77
16	187.50	0	0	29.35	0	55.13	95.73	122.63	129.45	45.67	123.50	115.00	55.93	78.31	83.28
17	186.86	0	0	29.15	0	59.14	105.41	133.59	128.73	41.21	122.54	122.74	54.40	80.41	82.76
18	200.19	0	0	28.33	0	65.83	94.19	141.84	133.97	42.03	126.92	121.46	59.45	77.27	85.19
19	172.81	0	0	26.59	0	60.72	100.66	137.27	119.57	44.01	122.18	114.35	54.85	76.93	85.63
20	192.54	0	0	28.40	0	56.98	102.55	127.44	128.50	39.22	126.65	121.39	56.88	75.71	86.75
21	189.20	0	0	28.01	0	62.95	97.30	130.50	123.76	42.14	128.20	117.02	56.84	80.49	81.92

Figure 48 Daily Dynamic Capacity Planning

3.2.1.1 Math Programming Model:

$$Min \sum_{r,t} P_{r,t} N_{p,r,t} + \sum_{p,r,t} C_{p,r} P_{p,r,t} + \sum_{p,r,t} C'_{p,r} P'_{p,r,t} Y_{p,r,t}$$

$$\sum_{r} \frac{P_{p,r,t} + P'_{p,r,t}}{q_t} \geq d_{p,t} \quad \forall p, t$$

$$P'_{p,r,t} \leq \frac{5 * 60}{7 * t_r} * Y_{p,r,t} * N_{p,r,t} \qquad \forall p, r, t$$

$$\left(P_{p,r,t} - \frac{10 * 60}{t_r}\right) * Y_{p,r,t} = 0, \qquad \forall p, r, t$$

$$N_{p,r,t+1} + \sum_{r'\neq r} NP_{p,r,r',t} + \sum_{\substack{p'\neq p,\\ p' \text{and } p \text{ in same group}}} NW_{p,p',r,t} + \sum_{\substack{p'\neq p,\\ p' \text{and } p \text{ not in same group}}} NO_{p,p',r,t}$$
$$= N_{p,r,t} + \sum_{r'\neq r} NP_{p,r',r,t} + \sum_{\substack{p'\neq p,\\ p' \text{and } p \text{ in same group}}} NW_{p',p,r,t} + \sum_{\substack{p'\neq p,\\ p' \text{and } p \text{ not in same group}}} NO_{p',p,r,t}$$
$$\forall p, r, t$$

$$\frac{P_{p,r,t}t_r}{q_t} \leq r' * e * \left(a * N_{p,r,t+1} - st_p * \sum NP_{p,r',r,t} - st_w * \sum NW_{p',p,r,t} - st_o * \sum NO_{p',p,r,t}\right) \forall p, r, t$$

$$A = \frac{dt_r}{Nqer'} \geq \frac{1500 * 2 * 60}{365}$$

3.2.1.2 Index:

p denotes for the types of product
r represents the types of working cells (20 min, 30 min and 40min)
t means each day (1-1826)

3.2.1.3 Parameters:

$N_{p,r,t}$: the number of working cells required for product p at pace r at time t
$P_{r,t}$: the installment cost of working cell at pace r per period at time t
$C_{p,r}$: the variable cost of working cell per hour for product p at pace r
$P_{p,r,t}$: the production amount of product p at pace r at time t during regular hours
$C'_{p,r}$: the variable cost of working cell per extending hour for product p at pace r
$P'_{p,r,t}$: the production amount of product p at pace r at time t during extending hours
$Y_{p,r,t}$: the binary variable equal to 1 if extending work is needed and equal to 0 otherwise
q_t: quality of production
r': reliability
e: efficiency
t_r: pace time for r
a: availability (here is 10*60)
$NP_{p,r,r',t}$: the number of working cells changing pace from r to r' for product p at time t
$NW_{p,p',r,t}$: the number of working cells changing over within group from product p to p' at pace r at time t
$NO_{p,p',r,t}$: the number of working cells changing over outside group from product p to p' at pace r at time t
st_p: setup time for changing pace
st_w: setup time for changeover within product group
st_o: setup time for changeover from outside product group

A: the average working time for each cell

3.2.1.4 Description of the Math Model:

1. The objective function is to minimize the total cost of production planning.
2. The first constraint is about demand satisfaction, the second constraint is for the limitation of extending working hours.
3. The third constraint represents the logic of extending: only after the regular working time has been fully used can we start to extend work.
4. The fourth constraint denotes the flow balance of working cells.
5. The fifth one means that the production amount should be less than capacity.
6. The last constraint demonstrates the work policy: every worker can work at least 1500 hours per year.

Although we built the model, we can see that the model is too hard to calculate, since the integer variable is too much (over 1826*40*3).

3.2.1.5 Basic idea:

Use the most cost-efficiency pace as much as possible. For those demands that are less than the one-day capacity of cell, use work options (extending work, changing pace, changeover within group, changeover from outside group and adding another work cell) to satisfy. See the logic process map below:

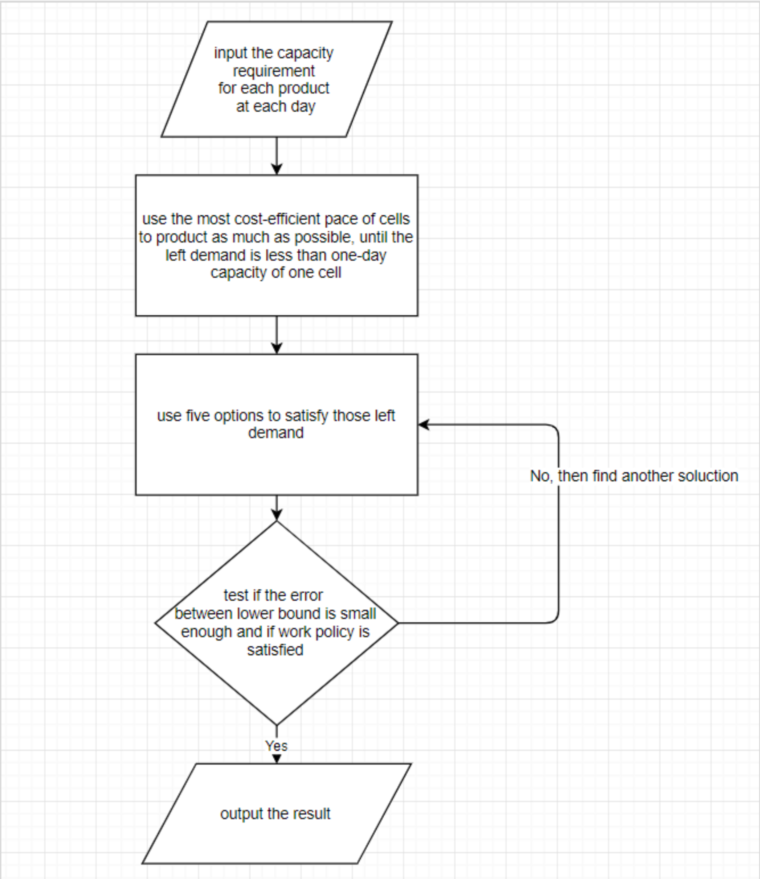


Figure 49 Graph of logic process map for task 3 algorithm

It is hard to use mathematical programming to find the optimal solution. Instead of building a mathematical programming model, we can use a heuristic way to find an approach to get a near-optimal solution.

3.2.1.6 Heuristic Approach:

1. Intuitively, we can try to let cells work at the most cost-efficient pace.
2. We notice that 40min pace is the slowest working pace, then we can set the throughput of 40min pace working cell as the “relative capacity unit”. For example, if we skip the reliability, efficiency and so on, in ten hours (or one day) a 40min pace cell can process 15 units of product, 30min pace cell can generate 20 units and 20min pace cell can create 30 units.
3. To simplify, we can set the throughput of 40min cell working for 10 hours(one day) as “1” relative unit of capacity, then, the 30min pace cell can produce “20/15=1.33” units of capacity and 20 min pace cell can create “30/15=2”units of capacity.
4. Then, we assume the company only use the 40min pace cells first.
5. Then, main steps are shown below.

3.2.1.7 Algorithm:

1. Calculate the relative capacity requirement Ct,pfor each day t and each product p
2. Determine the most cost-efficient pace rp for each product p and divide Ct,p by the relative capacity Rpof rp. Record the integer quotient as “base[t,p]” and the remainder as “left[t,p]”. i.e., if for a product p, the relative capacity requirement Ct,p=11.5 and the most cost-efficiency pace rp= 20min, then Rp=2, Ct,p/Rp=11.5/2=5+1.5, then the base[t,p]=5, the left[t,p]=1.5.
3. Determine the marginal cost for each option (extending work, changing pace, changeover within group, changeover from outside group and adding another work cell).
4. Eliminate “left[t,p]” by the following steps:
5. Set k=1, where k is the number of options which can be combined.
6. Start from the lowest-cost k options, eliminate “left[t,p]”, until all left[t,p]=0
7. Compare the final total cost with a lower bound. If the error < 10%, stop; otherwise, k=k+1 and return to step 4.b
8. Test the extending work policy (every cell should work longer than 1500 hours per year). If satisfied, put out the result; otherwise, k=k+1 and return to step 4.b

3.2.1.8 Explanation:

<u>*Step 1:*</u>

- We transfer the daily capacity requirement dt,pto relative capacity requirement Ct,pin order to simplify the calculation.
- To clear again that for relative capacity Ct,p,one unit means the output of a 40min pace cell working for the whole day (10 hours).

- Then, the relative capacity for one 40min pace cell for one day is 1, for a 30min pace cell is 1.33 and for a 20min is 2. The formula to calculate the relative capacity.

$$C = \frac{dt}{qare}$$

Where c is the relative capacity, d is the daily capacity requirement, t is the working pace 40min, q is the quality, a is the availability, r is the reliability and e is the efficiency.

Step 2:

Since different paces have different working cost-efficiency, we need to determine which one is the most cost-efficient. The formula to calculate the cost-efficiency is

$$\text{Cost} - \text{efficiency} = \frac{300 + h_{r,p} * 40 * 10 + m_{r,p} * 3000/30}{th_r}$$

Where hr,p is the human resource needed for product p at pace r, mr,p is the machine resource required for product p at pace r, thris the throughput of a cell at pace r.

For example, for WorkPal 1, the cost-efficiency of 20min pace is

- (300+5*40*10+1*3000/30)/2=1200, pace is 30min
- (300+4*40*10+1*3000/30)/1.33=1503.76, pace is 40 min
- (300+3*40*10+1*3000/30)/1=1600. 1200<1503.76<1600

So, the most cost-efficient pace for WorkPal 1 is 20min.

We will do the same thing for remaining WorkPal & MyPal keeping in mind following assumptions:

- If the number of working cells Np,r,t can be non-integer, we can merely use the most cost-efficient pace for each product, then the cost will be minimized.
- But Np,r,tmust be integer, thus, we can divide Ct,p by the relative capacity Rpof the most cost-efficient pace rp, the integer quotient is “base[t,p]” and the remainder is “left[t,p]”.
- The base[t,p] are already integer, then we just need to find a way to transfer left[t,p] to integer, that is, solving this left part of demand for product p at time t, or “eliminating” left[t,p].

Step 3

As mentioned in the statement, we have 5 options to eliminate left[t,p]:

- extending work
- changing pace
- changeover within group
- changeover from outside group and
- adding another work cell.

Each one has different marginal cost and different conditions.

Intuitively, we need to compare the marginal costs for those options.

- changing pace
- changeover within group and
- changeover from outside group

Notice that

- Changeover from outside group have the lowest cost because they just need to pay the regular salary to workers, but they still have conditions
- For changing pace, there exists at least one cell whose pace is slower than 20min and setup time for changing pace must be satisfied;
- For changeover within group and changeover from outside group, one extra working cell must exist, and the setup time must be considered.
- Extending work incurs additional fee for workers, and extending the hours of one cell should be less than 5/7 hours per day.
- Adding another cell has no conditions, but the cost depends on base[t,p] and the maximum cells required in this month, year and 5-year horizon. For example, if for a product p at time t, base[t,p]+1>Max month, then additional maintenance fee of machines will be caused.

Step 4

We need to know "the combination of options". For example, if a certain left[t,p]=0.7 and there is a cell at pace 30min.

We can combine option 1 and 2 to eliminate this left[t,p]: use option 2 change pace from 30 min to 20 min, then the relative capacity will be improved from 1.33 to 2, increasing 2-1.33=0.67, then left[t,p]=0.7-0.67=0.03; then use option 1 extend 0.03*10/2=0.15 hour, then left[t,p] becomes 0.

In this example, two options are combined to eliminate the left[t,p]. To simplify the calculation, we first see if using only one option could get a near optimal solution, if so, that is fine; if not, try to combine 2 options, 3 options, …, until we can get a near optimal solution.

As to find a lower bound of total cost, notice that for base[t,p], they are already producing at the most cost-efficient way, any total cost of a feasible solution will be the sum of "cost of base" and "cost of left", thus, the cost of base[t,p] can be served as a lower bound

Step 5

Examine if work policy is satisfied. If we pass the test, then the solution we found is a feasible solution.

3.2.2 Calculating the Production Planning

By this algorithm, we can find the production planning of the forecast daily dynamic capacity resource requirement with 99% service level.

Step 1

Calculate the relative capacity requirement:

	WorkPal1	WorkPal2	WorkPal3	WorkPal4	WorkPal5	WorkPal6	WorkPal7	WorkPal8	WorkPal9	WorkPal10
1	7.497726	1.238127	0.9349231	0.9241311	1.280612	2.117910	6.312523	6.979507	8.074874	1.821722
2	7.500327	1.252740	0.9377420	0.9269619	1.297410	2.125350	6.327869	6.981935	8.128999	1.826242
3	7.502942	1.267320	0.9406311	0.9298346	1.314083	2.132853	6.343325	6.984372	8.147622	1.830816
4	7.505575	1.281871	0.9435901	0.9327491	1.330894	2.140417	6.358888	6.986819	8.142624	1.835445
5	7.508229	1.296394	0.9466189	0.9357053	1.347443	2.148042	6.374558	6.989279	8.175224	1.840128
6	7.510909	1.310892	0.9497174	0.9387031	1.385120	2.155727	6.390334	6.991754	8.154215	1.844865
7	7.513619	1.325368	0.9528854	0.9417423	1.401510	2.163472	6.406216	6.994247	8.215160	1.849655
8	7.516362	1.339822	0.9561226	0.9448230	1.417794	2.171277	6.422202	6.996760	8.237294	1.854500
9	7.519142	1.354257	0.9594290	0.9479449	1.434233	2.179140	6.438292	6.999294	8.258039	1.859398
10	7.521964	1.368674	0.9628041	0.9511079	1.450426	2.187062	6.454484	7.001853	8.257396	1.864350
11	7.524831	1.383077	0.9662479	0.9543119	1.486691	2.195042	6.470779	7.004439	8.275690	1.869355
12	7.527747	1.397465	0.9697601	0.9575567	1.502792	2.203080	6.487174	7.007053	8.305409	1.874412
13	7.530717	1.411840	0.9733404	0.9608422	1.518800	2.211175	6.503670	7.009700	8.348416	1.879523
14	7.533743	1.426205	0.9769887	0.9641683	1.534975	2.219326	6.520266	7.012380	8.342052	1.884687
15	7.536831	1.440561	0.9807046	0.9675348	1.550917	2.227534	6.536960	7.015095	8.376968	1.889903

Figure 50 Calculating the relative capacity requirement

Step 2

Notice that in the first step, we just get one feasible solution. Next, we need to maximize the efficiency. In this step, we need to determine the most efficient working pace for each product group.

The result is shown below.

	w1-4	w5-7	w8-10	w11-13	w14-15	w16-17	w18-20	w21-24	w25-28	w29-32	w33-36	w37-40
20min	1239.5	1049.5	844.5	1044.5	854.5	649.5	454.5	654.5	449.5	649.5	254.5	464.5
30min	1563.158	976.6917	969.1729	1269.925	976.6917	969.1729	675.9398	976.6917	668.4211	969.1729	375.188	690.9774
40min	1679	1279	1279	1279	1289	889	889	889	879	889	489	909

Figure 51 One Feasible Solution

From the table above we can see that except for the WorkPal product group 5-7, 20 min pace is the most cost-efficient one. For group 5-7, the most cost-efficient pace is 30 min.

Then we use the most efficient working pace for each group as much as possible. We got (example for WorkPal 1-15 and day 1-22):

	WorkPal1	WorkPal2	WorkPal3	WorkPal4	WorkPal5	WorkPal6	WorkPal7	WorkPal8	WorkPal9	WorkPal10	WorkPal11	WorkPal12	WorkPal13	WorkPal14	WorkPal15
1	16.64726	0	0	2.627580	0	5.623583	9.190920	12.46651	11.35096	3.651495	12.47867	11.66608	5.251420	7.067349	7.443252
2	17.01382	0	0	2.652827	0	5.487996	8.805667	12.22900	12.49831	3.717886	10.97038	10.46076	5.082170	7.406784	7.917339
3	16.46025	0	0	2.537812	0	5.358955	9.705215	13.05094	12.04292	3.958202	11.44634	11.10129	4.986792	7.463824	7.858429
4	16.87168	0	0	2.672464	0	5.570283	9.361105	12.51514	11.62774	3.767445	11.02555	11.11812	5.180354	7.187975	7.459149
5	16.61454	0	0	2.578021	0	5.925614	10.088599	13.22206	11.62681	3.836641	12.24116	11.48374	5.287888	6.955139	7.968768
6	17.60105	0	0	2.701452	0	5.671272	10.189588	11.88863	11.65393	4.005891	11.63990	10.87687	5.125184	7.295509	7.841597
7	17.76001	0	0	2.687425	0	6.340791	9.236739	12.05040	12.51514	3.887136	11.03397	10.91428	5.056923	7.366575	7.811674
8	18.69509	0	0	2.555579	0	6.042499	9.305935	13.04439	11.76520	3.824485	11.84842	10.57671	5.112093	7.333848	7.654581
9	18.80730	0	0	2.535942	0	5.151366	9.101152	12.06349	12.06349	4.050775	12.49737	10.42897	5.108353	7.416135	8.079108
10	17.34764	0	0	2.432148	0	5.365500	8.770133	12.13643	12.22059	3.798303	11.81850	10.68331	4.948454	7.266522	7.670477
11	16.66784	0	0	2.449915	0	5.424410	9.186245	11.45569	11.84749	3.774926	11.42670	10.77121	5.135470	7.000958	7.619983
12	17.04467	0	0	2.489188	0	5.833976	9.238610	12.30942	11.75024	3.946046	11.21070	10.23541	5.128924	7.635879	7.707880
13	17.51221	0	0	2.597658	0	5.082170	9.806204	12.09061	12.71244	3.844122	12.38329	10.76840	5.172873	7.307665	7.658321
14	15.80382	0	0	2.805246	0	5.825560	8.897305	12.59275	11.84188	3.778666	11.17329	10.87594	5.085911	7.404914	7.859364
15	17.52063	0	0	2.481707	0	5.274797	8.946864	11.49870	11.29392	3.799238	11.54546	11.13309	4.895154	7.173014	7.739673
16	17.53279	0	0	2.744465	0	5.155107	8.951539	11.46691	12.10464	4.270519	11.54826	10.75344	5.229913	7.322627	7.787362
17	17.47294	0	0	2.725764	0	5.530075	9.856699	12.49176	12.03731	3.853473	11.45849	11.47720	5.086846	7.518994	7.738738
18	18.71941	0	0	2.649087	0	6.155644	8.807537	13.26320	12.52729	3.930149	11.86806	11.35751	5.559062	7.225378	7.965963
19	16.15915	0	0	2.486383	0	5.677818	9.412535	12.83587	11.18077	4.115296	11.42483	10.69266	5.128924	7.193585	8.007107
20	18.00407	0	0	2.655633	0	5.328097	9.589265	11.91668	12.01580	3.667391	11.84281	11.35096	5.318746	7.079505	8.111836
21	17.69175	0	0	2.619165	0	5.886341	9.098347	12.20282	11.57257	3.940435	11.98775	10.94233	5.315006	7.526475	7.660191
22	17.71793	0	0	2.439629	0	5.155107	9.008579	13.71859	12.45155	3.830096	11.50338	11.16207	5.189705	6.987867	8.057601

Figure 52 For WorkPal 1-15 and Day 1-22

Step 3

Compare several choices to eliminate the left[t,p].The cost of step 2 is much lower than the step 1, while we are still able to continue to reduce the cost.

Divide the resource requirement table by 2(for product group 5-7, divide by 1.5), we can get an integer table, or base table(base); and a remainder table(left). The base[t,p] table has reached the optimal (as below)

	WorkPal1	WorkPal2	WorkPal3	WorkPal4	WorkPal5	WorkPal6	WorkPal7	WorkPal8	WorkPal9	WorkPal10	WorkPal11	WorkPal12	WorkPal13	WorkPal14	WorkPal15
1	8	0	0	1	0	3	6	6	5	1	6	5	2	3	3
2	8	0	0	1	0	3	5	6	6	1	5	5	2	3	3
3	8	0	0	1	0	3	6	6	6	1	5	5	2	3	3
4	8	0	0	1	0	3	6	6	5	1	5	5	2	3	3
5	8	0	0	1	0	3	6	6	5	1	6	5	2	3	3
6	8	0	0	1	0	3	6	5	5	2	5	5	2	3	3
7	8	0	0	1	0	4	6	6	6	1	5	5	2	3	3
8	9	0	0	1	0	4	6	6	5	1	5	5	2	3	3
9	9	0	0	1	0	3	6	6	6	2	6	5	2	3	4
10	8	0	0	1	0	3	5	6	6	1	5	5	2	3	3
11	8	0	0	1	0	3	6	5	5	1	5	5	2	3	3
12	8	0	0	1	0	3	6	6	5	1	5	5	2	3	3
13	8	0	0	1	0	3	6	6	6	1	6	5	2	3	3
14	7	0	0	1	0	3	5	6	5	1	5	5	2	3	3
15	8	0	0	1	0	3	5	5	5	1	5	5	2	3	3
16	8	0	0	1	0	3	5	5	6	2	5	5	2	3	3
17	8	0	0	1	0	3	6	6	6	1	5	5	2	3	3
18	9	0	0	1	0	4	5	6	6	1	5	5	2	3	3
19	8	0	0	1	0	3	6	6	5	2	5	5	2	3	4
20	9	0	0	1	0	3	6	5	6	1	5	5	2	3	4
21	8	0	0	1	0	3	6	6	5	1	5	5	2	3	3
22	8	0	0	1	0	3	6	6	6	1	5	5	2	3	4

Figure 53 Compare several choices to eliminate the left[t,p] part a

Now focus on the left[t,p] table(as shown below).

	WorkPal1	WorkPal2	WorkPal3	WorkPal4	WorkPal5	WorkPal6	WorkPal7	WorkPal8	WorkPal9	WorkPal10	WorkPal11	WorkPal12	WorkPal13	WorkPal14	WorkPal15
1	0.647263716	0	0	0.6275802	0	1.123582766	0.190920354	0.4665123781	1.3509596278	1.651494962	0.47866844	1.66608224	1.25142016	1.06734928	1.443252215
2	1.013815836	0	0	0.6528275	0	0.987995886	1.305666597	0.2290015663	0.4983051640	1.717885780	0.97038128	0.46076162	1.08217033	1.40678402	1.917338757
3	0.460247329	0	0	0.5378124	0	0.858954578	0.705215420	1.0509385885	0.0429202609	1.958201837	1.44633799	1.10129275	0.98679197	1.46382402	1.858428595
4	0.871683381	0	0	0.6724642	0	1.070283096	0.361105267	0.5151366388	1.6277438811	1.767445122	1.02555111	1.11812423	1.18035393	1.18797485	1.459148608
5	0.614535849	0	0	0.5780209	0	1.425614232	1.088599013	1.2220585829	1.6268087991	1.836641186	0.24115763	1.48374126	1.28788835	0.95513944	1.968768263
6	1.601047292	0	0	0.7014517	0	1.171271945	1.189587863	1.8886317414	1.6539261753	0.005891016	1.63989995	0.87687309	1.12518409	1.29550927	1.841597120
7	1.760011221	0	0	0.6874255	0	0.340790612	0.236739369	0.0504009164	0.5151366388	1.887135610	1.03396685	0.91427636	1.05692311	1.36657550	1.811674498
8	0.695093158	0	0	0.5555789	0	0.042499474	0.305935433	1.0443930149	1.7652009257	1.824485121	1.84842322	0.57671178	1.11209295	1.33384763	1.654580733
9	0.807302990	0	0	0.5359422	0	0.651366388	0.101152488	0.0634920635	0.0634920635	0.050774949	0.49737008	0.42896884	1.10835262	1.41613484	0.079107932
10	1.347640087	0	0	0.4321481	0	0.865500152	1.270133483	0.1364284545	0.2205858288	1.798302826	1.81850060	0.68331113	0.94845361	1.26652173	1.670477126
11	0.667835519	0	0	0.4499147	0	0.924410314	0.186244945	1.4556888047	1.8474881361	1.774925778	1.42670126	0.77120883	1.13547000	1.00095846	1.619982701
12	1.044673540	0	0	0.4891881	0	1.333976202	0.238609533	0.3094186128	1.7502396147	1.946045772	1.21069734	0.23540688	1.12892442	1.63587909	1.707880403
13	1.512214508	0	0	0.5976576	0	0.582170325	0.806204269	0.0906094397	0.7124389275	1.844121841	0.38329009	0.76840358	1.17287327	1.30766533	1.658321060
14	1.803819810	0	0	0.8052458	0	1.325560465	1.397304626	0.5927484396	1.8418776445	1.778666106	1.17329406	0.87593800	1.08591065	1.40491386	1.859363677
15	1.520630245	0	0	0.4817075	0	0.774797204	1.446863969	1.4987025738	1.2939196297	1.799237908	1.54545667	1.13308554	0.89515394	1.17301354	1.739673189
16	1.532786310	0	0	0.7444655	0	0.655106716	1.451539379	1.4669097880	0.1046356687	0.270519204	1.54826192	0.75344227	1.22991327	1.32262665	1.787362368
17	1.472941066	0	0	0.7257638	0	1.030074573	0.856698693	0.4917595904	0.0373097693	1.853472661	1.45849405	1.47719569	1.08684573	1.51899385	1.738738107
18	0.719405288	0	0	0.6490871	0	0.155644388	1.307536760	1.2632021881	0.5272927040	1.930149379	1.86805994	1.35750520	1.55906211	1.22537812	1.965963018
19	0.159150946	0	0	0.4863829	0	1.177817519	0.412534773	0.8358697431	1.1807747154	0.115295603	1.42483110	0.69266194	1.12892442	1.19358534	0.007106623
20	0.004067606	0	0	0.6556327	0	0.828096874	0.589265259	1.9166841995	0.0158028847	1.667391355	1.84281273	1.35095963	1.31874606	1.07950534	0.111835800
21	1.691750240	0	0	0.6191645	0	1.386340791	0.098347243	0.2028192720	1.5725740468	1.940435281	1.98775043	0.94232882	1.31500573	1.52647451	1.660191224
22	1.717932534	0	0	0.4396288	0	0.655106716	0.008579377	1.7185870912	0.4515510672	1.830095612	1.50337798	1.16207308	1.18970475	0.98786731	0.057601047

Figure 54 Compare several choices to eliminate the left[t,p] part b

We have the following choices: extend the working time, change paces, changeover cell within product group, changeover cell from outside product group, and add another working cell. Then we need to determine the priority of these options.

The marginal cost for extending working cost is left[i,j]*10*40*1.5*hj, where c is the value of left[i,j], i is the time, j is the product. Hj is the human resource needed.

For changeover pace/within group/out group, the marginal cost is c*10*40*hj, but there are additional conditions: time slot must be satisfied, and additional working cell should be set first.

The marginal cost for set another working cell is …

$$250 + left[i,j] * 10 * 40 * hj + Ymonth * mj * 3000 + Yyear * 40000 + Ytotal * 200000$$

Where…

- mj is the number of machines the cell needs,
- Ymonth is a binary variable equal to 1 if base[i,j]+1,
  the minimum number of cells it needs is larger than the maximum number of cells used in this month,
- Similarly, Yyear is a binary variable equal to 1 if base[i,j]+1 is larger than the maximum number of cells used in this year,
- Ytotal equal to 1 if base[i,j]+1is larger than the maximum number of cells used in the total table.

Thus, based on the formula above, we can find the threshold
left * [i,j] = (250 + Ymonth * mj * 3000 + Yyear * 40000 + Ytotal * 200000) / (10 * 40 * 0.5 hj)

If the left value is lower than the threshold c, extending working time is cheaper for the company. The threshold for each product group is attached below:

	w1-4	w5-7	w8-10	w11-13	w14-15	w16-17	w18-20	w21-24	w25-28	w29-32	w33-36	w37-40
daily	0.138889	0.625	0.25	0.15625	0.25	0.3125	1.25	0.3125	1.25	0.3125	#DIV/0!	1.25
month	6.805556	15.625	6.25	5.78125	6.25	7.8125	16.25	7.8125	16.25	7.8125	#DIV/0!	16.25

Figure 55 Threshold for each product group

Notice that for group w33-36, the human resource is 0, no worker needed. That is, cells in group 33-36 can work 24 hours a day without additional extending working fee.

And notice that all left values are less than 2, and the threshold for Ymonth=1 are all larger 2, that is to say, if base[i,j]+1 > maximum of this month, then extending working is cheaper.

Also notice that according to the policy, a cell cannot be extended to work over 5 hour a week, or 0.5 unit of capacity per week, or 1/14 unit of capacity per day. Thus, the extending working time should be less than min(left*[i,j],base[i,j]/14).

To sum up, the priority for working option is change pace> extend working > changeover within group/ outside group > add another cell.

<u>Step 4</u>

In the first iteration, I assume that only one option can be implemented at one time. For example, if left[1,5]=0.7, which means the remainder of product 5 at time 1 is 0.7 unit of capacity. It is possible that we change the pace from 30min to 20min, then 0.7-(2-1.33)=0.03, and extend working time to product 0.03 unit.

In this way, two policies are combined. But in the first iteration, we assume that only 1 policy can be implemented.

If the result of the first iteration is no good enough, we can continue to the next iteration, allowing two policies to be combined, and so on, 3,4,5 policies can be combined in iteration 3,4,5, respectively.

First, considering changing pace. Since only in group w5-7, the most cost-efficient pace is 30min, change pace can improve throughput and left[i,j] can be reduced.

In other groups, if we change the pace, left[i,j] would increase. Thus, only consider group w5-7. If the left[i,j] is lower than 2-1.33-change pace time slot (here is 1 hour or 0.1 unit of capacity)=0.57, left[i,j] can be eliminated and record the time.

Then, after time i, if left[i',j] < 0.67, set left[i',j]=0 but we don't need to record time because the pace has already been changed. The following table is the result of changing pace. The first column is the type of WorkPal, the second column is the time to change pace.

	changepace	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13
1	0	7	6	7	6	7	7	6	6	7	6	7	6
2	0	1	7	11	18	19	24	34	36	37	44	51	52

	V14	V15	V16	V17	V18	V19	V20	V21	V22	V23	V24	V25	V26
1	6	7	7	6	7	6	7	7	6	7	6	7	
2	61	66	79	92	97	100	101	106	110	110	122	123	

Figure 56 Changing pace record

Totally there are 400 times of changing pace.

Next, consider extending working hours. If the left[i,j] is less than min(threshold, base[i,j]/14), then record the time and set left[i,j] as 0.

The following table is the result of extending work for each WorkPal product at each time (example for WorkPal 1-14, ranging from day 1 - 22). 0 means no need to extend the work right now.

	WorkPal1	WorkPal2	WorkPal3	WorkPal4	WorkPal5	WorkPal6	WorkPal7	WorkPal8	WorkPal9	WorkPal10	WorkPal11	WorkPal12	WorkPal13	WorkPal14	WorkPal15
1	0.00000000	0	0	0	0	0	0	0.000000000	0.000000000	0.00000000	0.0000000	0.0000000	0.0000000	0.0000000	0.00000000
2	0.00000000	0	0	0	0	0	0	1.145007831	0.000000000	0.00000000	0.0000000	0.0000000	0.0000000	0.0000000	0.00000000
3	0.00000000	0	0	0	0	0	0	0.000000000	0.214601304	0.00000000	0.0000000	0.0000000	0.0000000	0.0000000	0.00000000
4	0.00000000	0	0	0	0	0	0	0.000000000	0.000000000	0.00000000	0.0000000	0.0000000	0.0000000	0.0000000	0.00000000
5	0.00000000	0	0	0	0	0	0	0.000000000	0.000000000	0.00000000	1.2057882	0.0000000	0.0000000	0.0000000	0.00000000
6	0.00000000	0	0	0	0	0	0	0.000000000	0.000000000	0.02945508	0.0000000	0.0000000	0.0000000	0.0000000	0.00000000
7	0.00000000	0	0	0	0	0	0	0.252004582	0.000000000	0.00000000	0.0000000	0.0000000	0.0000000	0.0000000	0.00000000
8	0.00000000	0	0	0	0	0	0	0.000000000	0.000000000	0.00000000	0.0000000	0.0000000	0.0000000	0.0000000	0.00000000
9	0.00000000	0	0	0	0	0	0	0.317460317	0.317460317	0.25387475	0.0000000	0.0000000	0.0000000	0.0000000	0.39553966
10	0.00000000	0	0	0	0	0	0	0.682142273	1.102929144	0.00000000	0.0000000	0.0000000	0.0000000	0.0000000	0.00000000
11	0.00000000	0	0	0	0	0	0	0.000000000	0.000000000	0.00000000	0.0000000	0.0000000	0.0000000	0.0000000	0.00000000
12	0.00000000	0	0	0	0	0	0	1.547093064	0.000000000	0.00000000	0.0000000	1.1770344	0.0000000	0.0000000	0.00000000
13	0.00000000	0	0	0	0	0	0	0.453047198	0.000000000	0.00000000	1.9164504	0.0000000	0.0000000	0.0000000	0.00000000
14	0.00000000	0	0	0	0	0	0	0.000000000	0.000000000	0.00000000	0.0000000	0.0000000	0.0000000	0.0000000	0.00000000
15	0.00000000	0	0	0	0	0	0	0.000000000	0.000000000	0.00000000	0.0000000	0.0000000	0.0000000	0.0000000	0.00000000
16	0.00000000	0	0	0	0	0	0	0.000000000	0.523178344	0.00000000	0.0000000	0.0000000	0.0000000	0.0000000	0.00000000
17	0.00000000	0	0	0	0	0	0	0.000000000	0.186548846	0.00000000	0.0000000	0.0000000	0.0000000	0.0000000	0.00000000
18	0.00000000	0	0	0	0	0	0	0.000000000	0.000000000	0.00000000	0.0000000	0.0000000	0.0000000	0.0000000	0.00000000
19	0.79575473	0	0	0	0	0	0	0.000000000	0.000000000	0.57647801	0.0000000	0.0000000	0.0000000	0.0000000	0.03553311
20	0.02033803	0	0	0	0	0	0	0.000000000	0.079014424	0.00000000	0.0000000	0.0000000	0.0000000	0.0000000	0.55917900
21	0.00000000	0	0	0	0	0	0	1.014096360	0.000000000	0.00000000	0.0000000	0.0000000	0.0000000	0.0000000	0.00000000
22	0.00000000	0	0	0	0	0	0	0.000000000	0.000000000	0.00000000	0.0000000	0.0000000	0.0000000	0.0000000	0.28800524

Figure 57 Extending hours record

Totally we need to extend *10020.42 h*ours in the five years.

Then consider change within groups, for each time i and product j, if there exists another left[i,j'] where j' is in the same group with j that left[i,j]+left[i,j']+ change over time slot (here is 0.1)<= 2, that means we can introduce another cell to work on these two products.

Similarly, 3 or 4 products can be worked by a cell if such condition is satisfied.

B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
wtingrp																					
Group1	1	8	11	19	1	11	19	1	19	1	19	1	19	19	1	12	19	1	11	19	1
Group2	4	9	13	20	4	12	20	4	20	4	20	4	20	20	4	13	20	4	12	20	4
Group3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Group4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Time	1	1	1	1	2	2	2	3	3	4	4	5	5	7	8	8	8	9	9	9	10

Figure 58 changeover within group record

The table above shows the record of changeover cells within group. The first 4 rows denote the types of WorkPal need to be combined, and the last column means the time. Totally there are 4856 times of changeover within group.

Changeover outside group. It is a little complicated because the changeover time is one day. We have to compare left[i,j]+left[i+1,j']<2 where j' and j are not in the same group, and base[i,j]>base[i+1,j] and left[i+1,j]=0 which means there is extra cell in product j.

B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
woutgrp																					
Group1	11	12	1	11	1	8	1	1	16	9	18	1	16	18	1	18	16	19	18	8	1
Group2	6	13	14	20	4	4	4	4	13	4	9	4	7	10	4	10	4	4	6	6	4
Time	1	8	9	9	18	19	32	45	45	46	50	51	52	52	54	56	60	68	70	72	73

Figure 59 changeover from outside group record

The table above is the result of changeover outside WorkPal group. The first column is the original type of WorkPal, the second column denotes the selected WorkPal group, and the last column is the time of changeover.

Totally there are 1641 times of changeover from outside of WorkPal group.

Step 5

If there is still some left[i,j] larger than 0, let base[i,j]+1 and set left[i,j]=0. Then we can get the result if the average working time for each cell is longer than 1500 hours per year, or 150 units of capacity per year.

The test shows that we have passed the working policy test, every worker is able to work more than 1500 hours per year.

Then we need to examine our result accuracy.

First, we need to find a lower bound. Go back to the original base[i,j] and left[i,j].

- For base[i,j], it has already been the most cost-efficiency.
- For any feasible solution, left[i,j] need to be considered, which means additional cost would be larger than if we merely consider base[i,j].

Thus, base[i,j] can be used as a lower bound. The result shows that the error is about 6.9%. It is good enough to use this method.

3.2.3 Simulation Validation

Now we got the capacity plan, i.e., allocation of working cells to each type of product at each day. Then we can calculate the upper bounds for each product at each day.

Here we know that Upper bound = Maximum capacity in regular hours (in 20min pace) + Maximum capacity in extending hours (in 20min pace) + Changeover.

Notice that Changeover depends on the demands of other products, thus, we can judge if the demand is larger than the sum of maximum output in regular and extending hours, if so, see if we can changeover cells.

We will use the validation steps as shown below:

1. Calculate the maximum output for each product at each day, record it as Max1;
2. Compare Max1 with simulated OTS demand, set OverCap[i,j]=Max1[i,j]-demand[i,j], where i is the index of time and j is the index of product;
3. For those OverCap[i,j]<0, see if sum(OverCap[i, j']) - setup time*60/20>0. If not, "NotSatisfied" +1, where setup time is the setup time needed for changeover (in hours), and "setup time*60/20" is the capacity loss of changeover;
4. Repeat 100 scenarios, count the total Not Satisfied

Based on the step 1 above, we can get Max1 table below:

	WorkPal1	WorkPal2	WorkPal3	WorkPal4	WorkPal5	WorkPal6	WorkPal7	WorkPal8	WorkPal9	WorkPal10	WorkPal11	WorkPal12	WorkPal13	WorkPal14	WorkPal15
1	280	0	0	32	0	125	187	218	156	63	218	187	63	125	125
2	280	0	0	32	0	94	187	187	218	63	187	156	94	125	125
3	280	0	0	32	0	125	218	218	187	63	187	187	94	125	125
4	280	0	0	32	0	125	187	218	187	63	187	187	94	125	125
5	280	0	0	32	0	125	218	218	187	63	187	187	94	125	125
6	280	0	0	63	0	125	218	187	187	63	187	187	94	125	125
7	280	0	0	63	0	125	187	187	218	63	187	187	94	125	125
8	311	0	0	32	0	125	187	218	187	63	187	187	63	125	125
9	311	0	0	32	0	125	187	187	187	63	218	156	63	125	125
10	280	0	0	32	0	125	187	187	187	63	187	187	63	94	125
11	280	0	0	32	0	125	187	187	187	63	187	187	94	125	125
12	280	0	0	32	0	125	187	187	187	63	187	156	94	125	125
13	280	0	0	63	0	125	187	187	218	63	187	187	94	125	125
14	249	0	0	63	0	125	187	218	187	63	187	187	94	125	125
15	280	0	0	63	0	125	187	187	187	63	187	187	94	125	125
16	280	0	0	63	0	125	187	187	187	63	187	187	94	125	125
17	280	0	0	63	0	125	218	218	187	63	187	187	94	125	125
18	311	0	0	32	0	125	187	218	187	63	187	187	94	125	125
19	249	0	0	32	0	125	187	218	187	63	187	187	63	125	125
20	280	0	0	32	0	125	218	187	187	63	187	187	94	125	125
21	280	0	0	63	0	125	187	187	187	63	187	187	94	125	125
22	280	0	0	63	0	125	187	218	218	63	187	187	94	125	125

Figure 60 Max 1 Table

From the simulator in task 1&2, we can easily generate daily demand for WorkPal product.

Row Labels	Sum of WorkPal40	Sum of WorkPal39	Sum of WorkPal38	Sum of WorkPal37	Sum of WorkPal7	Sum of WorkPal8	Sum of WorkPal9	Sum of WorkPal4	Sum of WorkPal3	Sum of WorkPal10	Sum of WorkPal11	Sum of WorkPal12
1-Jan	3	0	0	0	131	69	425	51	0	125	454	425
2-Jan	6	4	0	0	149	25	430	57	0	125	486	488
3-Jan	0	7	3	0	119	102	372	47	0	113	471	473
4-Jan	1	4	0	3	154	46	407	49	0	116	421	436
5-Jan	2	9	0	0	142	52	384	46	0	109	496	513
6-Jan	0	0	0	0	138	97	392	60	0	132	523	455
7-Jan	7	4	1	7	176	42	382	46	0	119	490	446
8-Jan	0	0	2	9	142	115	381	50	0	127	488	466
9-Jan	0	0	0	2	91	87	412	58	0	116	489	478
10-Jan	0	6	0	0	133	63	408	45	0	113	504	478
11-Jan	5	6	3	0	202	90	408	53	0	123	495	469
12-Jan	3	3	1	8	155	63	374	52	0	135	475	435
13-Jan	3	0	0	1	156	68	407	58	0	122	471	438
14-Jan	1	0	3	1	144	77	351	41	0	120	515	488
15-Jan	1	6	0	11	143	51	385	58	0	128	501	415
16-Jan	3	4	0	6	129	62	419	49	0	122	495	502
17-Jan	5	4	0	6	157	108	406	44	0	113	510	475
18-Jan	2	3	0	0	127	132	371	37	0	113	449	498
19-Jan	0	11	0	5	141	142	372	46	0	123	487	459
20-Jan	0	7	1	0	148	72	408	61	0	120	496	503
21-Jan	6	0	6	4	178	60	385	52	0	122	537	457
22-Jan	0	1	0	0	158	139	382	42	0	125	491	480
23-Jan	2	0	8	0	109	59	426	63	0	118	480	452
24-Jan	1	0	11	0	152	69	389	47	0	122	461	495
25-Jan	2	0	6	1	219	42	390	41	0	119	516	501
26-Jan	5	1	0	0	161	116	397	45	0	98	500	478

Demand_Log_WorkPals | Detrended_Log | WorkPal_Simulator | Pivot_Table_WorkPal_Simulator

Figure 61 Example of simulator

Then, as mentioned in task 2, we need to transfer this daily demand table to OTS table. Here we created 100 scenarios, counted in each scenario how many days in which the daily demand cannot be satisfied.

Finally, we can get:

Total		Scenario1	Scenario2	Scenario3	Scenario4	Scenario5	Scenario6	Scenario7	Scenario8	Scenario9	Scenario10	Scenario11	Scenario12	Scenario13	Scenario1
182600	Days	1826	1826	1826	1826	1826	1826	1826	1826	1826	1826	1826	1826	1826	1826
1713	NotSatisfied	7	22	14	31	2	0	24	17	13	21	20	34	5	13

Figure 62 Table of simulation validation result

The final number of days in which demand is not satisfied is 1713 days, the ratio is 0.94%, so the ratio of satisfaction is 100%-0.94%=99.06%, close to 99%.

3.2.4 Sensitivity Analysis

3.2.4.1 Service Level 95% to 99.9%

The first sensitivity analysis is changing the service level from 95% to 99.9%. It is easy. Replace the original data with 95%, 96%, 97%, 98%, 99% and 99.9% service level.

The summary for the sensitivity analysis results are shown below
(details are attached in the Appendix)

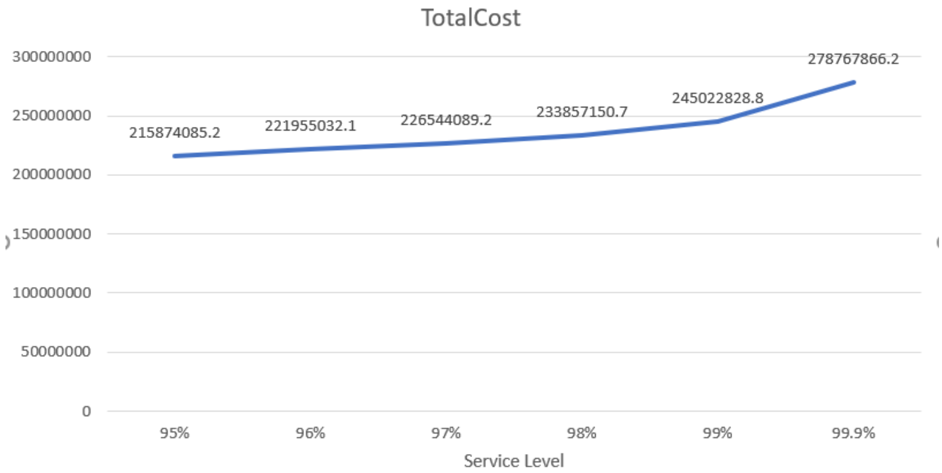


Figure 63 Sensitivity Analysis for Total Cost

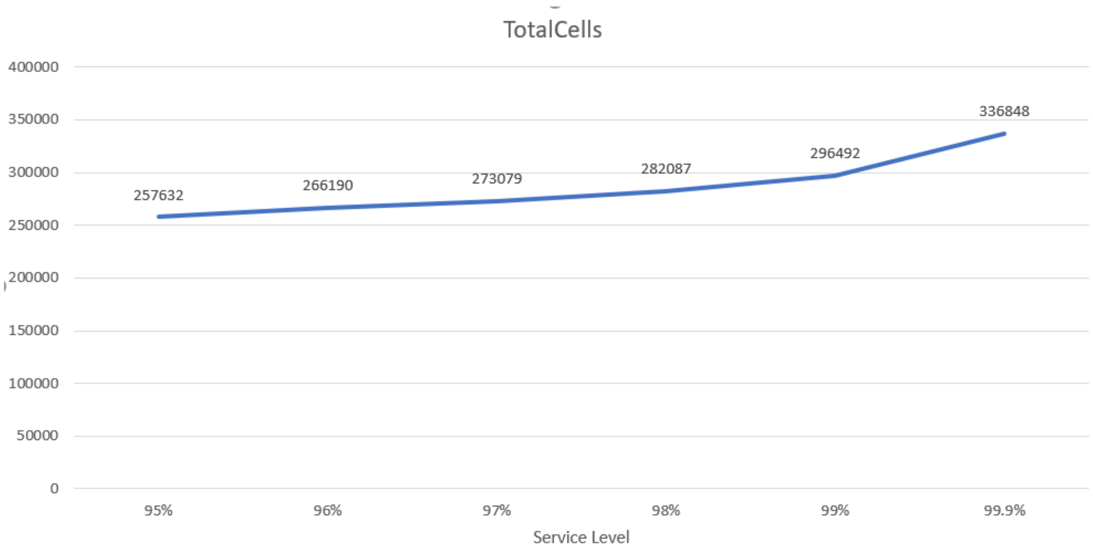


Figure 64 Sensitivity Analysis for Work Cells Required

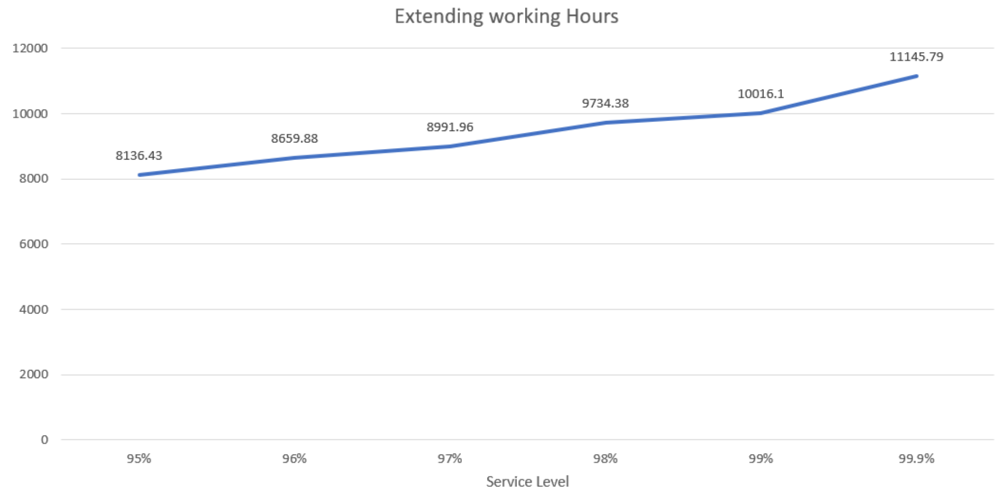


Figure 65 Sensitivity Analysis for Extending Hours

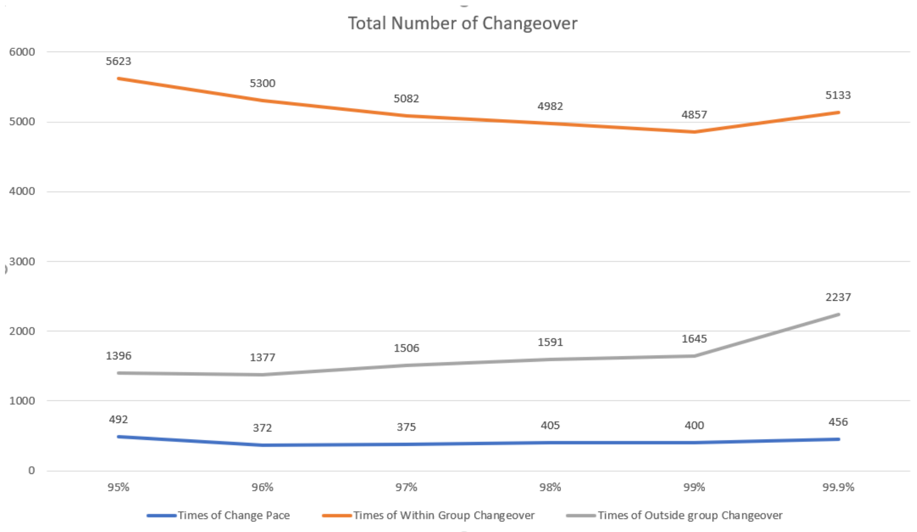


Figure 66 Sensitivity Analysis Changeover

3.2.4.2 Shortening the Setup Time for Changeover (Adding Another Cost)

For the second sensitivity analysis, the changeover time is shortened, while each changeover would incur an extra investment of 100,000 $ per cell.

Then in the third step, the priority for each option will change and will be as follows:

Extending working time> add another cell if Ymonth=0 > add another cell if Ymonth=1 but Yyear=0> changeover pace/within group/outside group > add another cell if Ytotal=1.

In the first policy, we must extend 11319.47 hours in the next five years, instead of about 10020 hours.

Then, add another working cell if Yyear=0. After that, changeover. For changing pace, in this scenario no pace is changed in the next five years. It makes sense because too much cost has generated.

About changeover cells within group, only 279 changeover happens.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1		wtingrp															
2	1	Group1	8	9	18	19	1	11	19	1	19	1	19	1	19	19	1
3	2	Group2	10	10	19	20	4	12	20	4	20	4	20	4	20	20	4
4	3	Group3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	4	Group4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	5	Time	789	1624	1625	1627	1648	1650	1656	1665	1672	1674	1675	1676	1680	1682	1682

Figure 67 Table of changeover within group

From the above we can see that most of changing over within group happens at the end of 5 years. It makes sense because when it close to the end, demand level is high and more cells are needed, so changeover becomes frequent.

And for changing over from outside of WorkPal group, the result table is attached below.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1		woutgrp															
2	1	Group1	1	11	7	1	1	8	7	1	16	9	18	21	16	18	21
3	2	Group2	6	8	10	6	10	4	11	10	13	4	9	4	7	10	4
4	3	Time	742	742	750	763	766	767	782	785	786	791	794	796	803	810	814

Figure 68 Table of changeover from outside group

Totally there are 1118 times of changing over happening in the next five years.

The last policy is adding another cell if the capacity requirement cannot be satisfied.
After that, calculate the total cost, it is 249,318,918 dollars.

The error is strictly less than 8.4%. We can see that the cost has increased about 3,889,102.7 dollars.

Finally, test if constraint of minimum working hours policy is satisfied. We passed the test.

And we also need to guarantee that this resource plan yields the working policy: every worker should work at least 1500 hours annually. That is to say, the annual average working time for each cell should be longer than 1500*2 hours. (There is a shift for workers)

$$A = \frac{dt}{Nqer} \geq \frac{1500 * 2 * 60}{365}$$

Where A is the actual daily working time for each cell. Notice that we need to change the time unit to minutes instead of hours.

4 Task 4

In Task 4, CoPal is to serve the customer by satisfying the demand on two critical factors:

- The quantity of a certain type of MyPal.
- The OTD time.

In Task 2, we have explained our strategy of choosing the targeted lead time but didn't distinguish the difference between OTS and OTD. Here, we need to take it into consideration.

The lead time of OTS is the time spent from receiving the order to finishing the shipment; whereas the lead time of OTD is from receiving the order to product arriving at the customer, which in our study, quals the production time plus the travel time.

In Task 4, we used the PULL strategy for the whole planning process. That is, we started our planning from the end of the supply chain, i.e. the regional customer's demand and pull the shipment from the RFC and then the flow among RFCs, CDC, factory (or factories) and finally the production and resource allocation at the factory (or factories).

The following picture demonstrates the planning process.

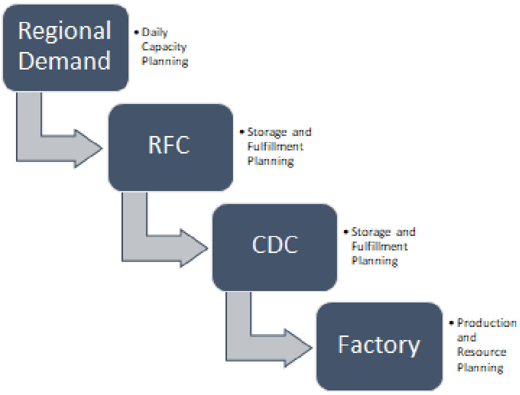


Figure 69 Illustration of the Planning Process

Here is the visual explanation of our planning strategy.

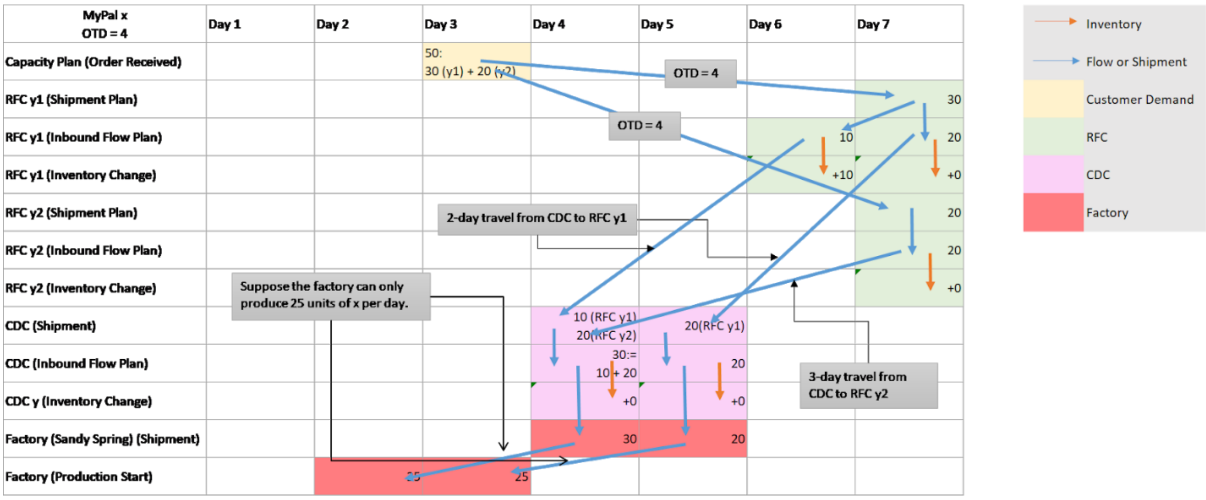


Figure 70 Visual Explanation of Planning Strategy

Suppose that according to the daily capacity plan, on day 3, there are 30 units of MyPal x required at megaregion y1 and 20 at y2, both with OTD equal 4 days.

Then RFCs y1 and y2 must ship 30 and 20 MyPal x's on day 7 respectively.

Then here comes the decision on when and how many units to receive. Say RFC y1 decides to receive 10 units from CDC on day 6 and 20 on day 7; while y2 is to receive 20 from CDC on day 7.
This decision induces the change of the inventory level at the end of day 6 and 7, shown in the picture.

Suppose that it takes 2 days to ship the MyPal x from CDC to y1 and 3 days to y2. Then CDC should send 30 MyPal x's on day 4, 10 for y1 and 20 for y2 and 20 on day 5 for y1.

Again, similarly, fulfillment and storage decisions are required again at CDC.
Say that CDC is to receive 30 units from the factory on day 4 and 20 on day 5. Then the factory is to deliver those units on those days.

Now, we need to decide when and how many units to produce at the factory. And this decision becomes the input of the resource design.

Hence, in this section, we are to start with the storage and fulfillment planning (4.1) and then the resource and production planning (4.2).

4.1 Storage and Fulfillment Planning

4.1.1 Assumptions

The daily plan of the storage and fulfillment is based on the aggregate warehouse throughput and storage capacity model. To use this model in the context of our case, we made the following assumptions and we categorized them into 4 classes.

4.1.1.1 Class 1: Distance Assumptions

- CDC is adjacent to the factory at Sandy Spring which means the distance between CDC and this factory is negligible.
- The distances used in the model are the distances of road travel among the most populated cities (shown in table below) in each megaregion from Google map. Here is the distance table in mile.

Megaregions	Cities	Sandy Spring	Phoenix	Seattle	Miami	Denver	Chicago	New Orleans	New York	San Francisco	Atlanta	Los Angeles	Dallas
	Sandy Spring	0	1856	2653	679	1398	710	484	868	2483	16	2183	792
Arizon Sun Corridor	Phoenix	0	0	1415	2362	822	1753	1520	2407	753	1846	372	1064
Cascadia	Seattle	0	0	0	3320	1316	2042	2612	2861	808	2669	1137	2107
Florida	Miami	0	0	0	0	2065	1382	863	1286	3114	663	2733	1313
Front Range	Denver	0	0	0	0	0	1006	1300	1777	1250	1402	1017	795
Great Lakes	Chicago	0	0	0	0	0	0	927	790	2127	719	2015	967
Gulf Coast	New Orleans	0	0	0	0	0	0	0	1307	2237	469	1893	506
Northeast	New York	0	0	0	0	0	0	0	0	2902	868	2790	1548
Northern California	San Francisco	0	0	0	0	0	0	0	0	0	2482	383	1732
Piedmont Atlantic	Atlanta	0	0	0	0	0	0	0	0	0	0	2184	782
Southern California	Los Angeles	0	0	0	0	0	0	0	0	0	0	0	1436
Texas Triangle	Dallas	0	0	0	0	0	0	0	0	0	0	0	0

Figure 71 Distances between Megaregion's Most Populated Cities

RFC1	Phoenix
RFC2	Seattle
RFC3	Miami
RFC4	Denver
RFC5	Chicago
RFC6	New Orleans
RFC7	New York
RFC8	San Francisco
RFC9	Atlanta
RFC10	Los Angeles
RFC11	Dallas

Table 6 RFC Location

- Based on assumption 2 and taking break times into consideration, the travel times among each region are the drive times corresponding to the distance * 1.5
- The distance between the regional factory and the RFC, and the RFC and the regional customers are negligible.

Here is the table of the travel time in hours

Megaregions	Cities	Sandy Spring	Phoenix	Seattle	Miami	Denver	Chicago	New Orleans	New York	San Francisco	Atlanta	Los Angeles	Dallas
	Sandy Spring	0	40.5	58.5	15	30	15.75	10.5	19.95	54	0.75	48	17.25
Arizon Sun Corridor	Phoenix	0	0	32.25	51	18.75	39	33	54	16.5	39	8.25	22.5
Cascadia	Seattle	0	0	0	73.5	28.5	46.5	58.5	63	19.5	58.5	25.5	48
Florida	Miami	0	0	0	0	45	30.45	18.3	28.5	67.5	13.95	58.5	28.95
Front Range	Denver	0	0	0	0	0	21	29.25	39	27	30.45	21.75	18
Great Lakes	Chicago	0	0	0	0	0	0	19.95	18	46.5	15.9	43.5	21
Gulf Coast	New Orleans	0	0	0	0	0	0	0	29.25	49.5	9.9	40.5	11.25
Northeast	New York	0	0	0	0	0	0	0	0	64.5	19.8	61.5	35.25
Northern California	San Francisco	0	0	0	0	0	0	0	0	0	54	8.7	40.5
Piedmont Atlantic	Atlanta	0	0	0	0	0	0	0	0	0	0	46.5	16.95
Southern California	Los Angeles	0	0	0	0	0	0	0	0	0	0	0	30.75
Texas Triangle	Dallas	0	0	0	0	0	0	0	0	0	0	0	0

Figure 72 Travel Time Between Megaregion Cities

4.1.1.2 Class 2: Capacity Assumption

- All the facilities operate 7 days a week.
- There is no upper bound of inventory.
- The lower bound of inventory (ex. safety stock) is calculated following this formula:

  *z-score at service level (99%) * the standard deviation of the related daily demand / the reliability*

  where, the reliability at all the places, i.e., the factories, the CDC, the RFCs, is 0.9.

- There is no lower bound nor upper bound of the volume of the input and output of flows.
- There is no lower bound nor upper bound of the number of the input and output shipments.

4.1.1.3 Class 3: Shipment Assumptions

- The size dimension (length, width, and height) of the packaged product can be converted to the volume dimension. The greatest number of packaged products is 240 per truck. Here is the calculation.

*The inner dimension of a 53-foot semi-trailer truck is 16m*2.59m*2.79m. We place the longest side along the longest side. Then we can have [16/0.8] = 20 units in this dimension. Similarly, we can put 4 units along the width and 3 units along the height. Totally, that is 20*4*3 = 240 units per truck*

- Each package weighs 18 kg, which is the mean of the weight range, 12-24 kg. And after calculation, the overall weight of packages of a full truck won't exceed the legally maximum load. Therefore, we don't need to consider the weight dimension in our model.

- The CDC and RFCs are in control of the vehicles for outbound flow. Therefore, when considering the cost of shipment, we also take the cost for the unloaded (empty) truck. Specifically, the cost of an empty 53-foot semi-trailer truck and LTL truck is the same as the full-loaded 53-foot truck.

4.1.1.4 Class 6: Planning Point (Day 0) Status

- The inventory everywhere at the beginning of day 1 equals the inventory level at the end of the five-year planning horizon, that is day 1826.

4.1.2 Models

We'll explain the model in 2 parts: *Variable Definition and General Model*

4.1.2.1 Variable Definition

p: the product MyPal p, $p = 1,2, \ldots ,25$

t: day t, $t = 1,2, \ldots ,1826$

v_A: the factory at place A

$c1, c2$: RFC $c1$ or RFC $c2$, $c1, c2 = 1,2, \ldots ,11$

$F_{p,A,t}^{I,B}$: the inbound flow of MyPal p from place A to place B on day t

$F_{p,A,t}^{O,B}$: the outbound flow of MyPal p from place B to place A on day t

If there is no A in the subscription, then it means this flow will serve the respective customers directly.

$S_{A,t}^{B}$: the number of shipments from place B to place A on day t

D_A^B: the distance between place A and place B

$I_{p,t}^{A}$: the inventory level of MyPal p at place A at the end of day t

$I_{p,0}^{A}$: the initial inventory level of MyPal p at place A on day 1

$R_{p,t}^{Ad}$: the demand requirement of MyPal p at place Ad on day t

c_{item}^{A}: the unit cost of the item at place A

4.1.2.2 General Model

This is the general network to describe the supply chain including the factory, central distribution center and regional fulfillment centers.

Objective:

Minimize Total Cost = Total Flow Handling Cost + Total Shipment Cost + Total Inventory Cost

Constraints:

1. Inventory Balance Everywhere
2. Linking Outbound Flow and Inbound Flow
3. Linking Outbound Flow and Respective Demand
4. Safety Stock Requirement (Lower Bound of Inventory) Everywhere
5. Linking Outbound Shipment and Flow

Then, using the defined variables, here is the mathematical model.

$$\min \sum_{A}\sum_{B}\sum_{p=1}^{25}\sum_{t=1}^{1826} c_{flow\ handling}^{A} F_{p,B,t}^{I,A} + \sum_{A}\sum_{B'}\sum_{p=1}^{25}\sum_{t=1}^{1826} c_{flow\ handling}^{A} F_{p,B',t}^{O,A} + \sum_{A}\sum_{B}\sum_{t=1}^{1826} 2c_{shipment}^{A} D_{B}^{A} S_{B',t}^{A} + \sum_{A}\sum_{p=1}^{25}\sum_{t=1}^{1826} c_{inventory}^{A} I_{p,t}^{A}$$

$s.t.$

Constraint 1

$$I_{p,t-1}^{A} + \sum_{B} F_{p,B,t}^{I,A} - \sum_{B'} F_{p,B',t}^{O,A} + I_{p,t}^{A} = 0, \forall A, \forall p = 1,2,\dots,25, \forall t = 1,2,\dots,1826$$

$$I_{p,0}^{A} = 0, \forall A, \forall p = 1,2,\dots,25$$

Constraint 2

$$F_{p,B',t}^{O,A} = F_{p,A,t+travel\ time\ between\ A\ and\ B'}^{I,B'} \forall A, B', \forall p = 1,2,\dots,25, \forall t = 1,2,\dots,1826$$

Constraint 3

$$\sum_{B'} F_{p,t}^{O,Ad} = R_{p,t}^{Ad}, \qquad \forall Ad, \forall p = 1,2,\dots,25, \forall t = 1,2,\dots,1826$$

Constraint 4

$$I_{p,t-1}^{A} \geq i_{p,t-1}^{A}, \forall A, \forall p = 1,2,\dots,25, \forall t = 1,2,\dots,1826$$

$$i_{p,t}^{A} = \frac{z_{99\%} \times \sigma_{demand\ of\ p\ on\ day\ t\ at\ the\ places\ that\ A\ serves}}{0.9}, \forall A, \forall p = 1,2,\dots,25, \forall t = 1,2,\dots,1826$$

Constraint 5

If the 53-foot semi-trailer truck is used, then

$$\sum_{p=1}^{25} F_{p,B',t}^{O,A} \leq 240 \times S_{B',t}^{A}, \forall A, \forall B', \forall t = 1,2,\dots,1826$$

If the LTL is used, then

$$S_{B',t}^{A} = \left\lceil \frac{1}{240} \sum_{p=1}^{25} F_{p,B',t}^{O,A} \right\rceil$$

4.1.3 Specific Model for each Combination of the Options

The specific models are developed by adjusting the general model to the context of the combinations. Before going into the details of these models, we want to first highlight the critical modification due to the options.

For one thing, for the simplest combination, **Option i1a**, shown in the following Figure 80, on each day, the activities among these places construct a network. Based on the assumptions, the objective is as follows.

Minimize Total Cost = Total Flow Handling Cost+ Total Shipment Cost + Total Inventory

Cost over the following 5 years, where

- *Total Flowing Handling Cost =*
  1. *handling cost of flow of MyPals from factory to CDC +*
  2. *handling cost of outbound flow of MyPals from CDC to RFCs +*
  3. *handling cost of inbound flow of MyPals from CDC to RFCs +*
  4. *handling cost of flow of MyPals from RFCs to regional customers*
- *Total Shipment Cost = shipment cost of MyPals from CDC to RFCs*
- *Total Inventory Cost =*
  1. *inventory of MyPals at CDC +*
  2. *inventory of MyPals at RFCs*

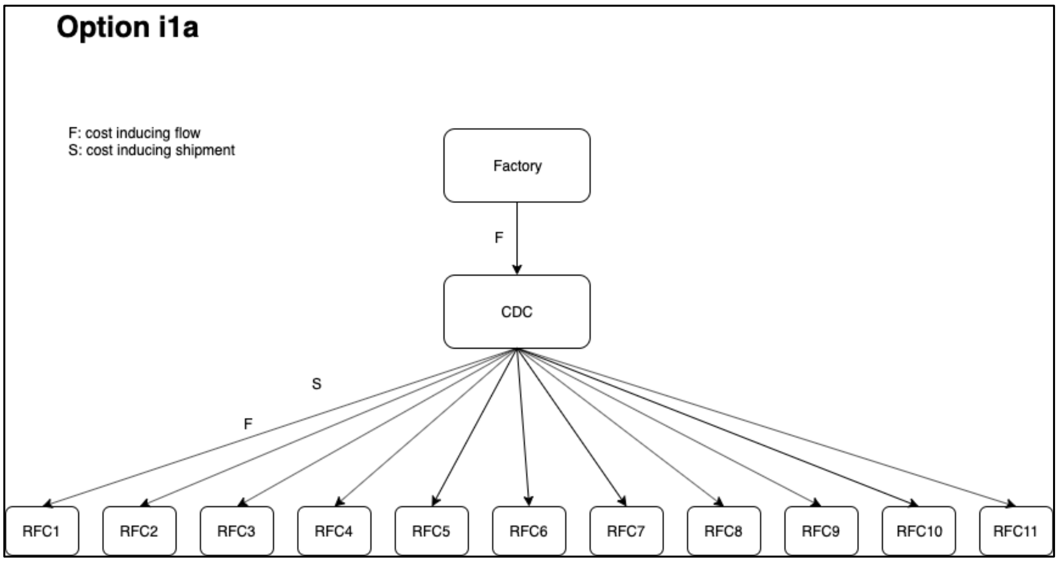


Figure 73 Option i1a

Then the constraints are:

1. Inventory Balance at CDC
2. Inventory Balance at RFC
3. Linking Outbound Flow and Inbound Flow from CDC to RFC
   The outbound flow of MyPal p from CDC to an RFC on day t =
   the inbound flow of MyPal p from CDC to the RFC on day (t + travel time between CDC and c1)

4. Linking Demand and Flow from RFC to its Customer
   The outbound flow of MyPal p from RFC to its Customer on day t= The Demand of MyPal p at this region on day (t - OTD)
5. Safety Stock at CDC
6. Safety Stock at RFC
7. Linking Outbound Shipment and Flow from CDC to RFC
   *The volume of outbound flow of MyPals from CDC to RFC on day t <= 240 * The number of shipments from CDC to RFC on day t*

For another thing, for the most complex combination, **Option i2b**, there are three significant changes.

First, the creation of CFC. We define the CFC as the combination of the original CDC at Sandy Spring and the RFC at piedmont Atlantic.

Second, we categorized the demand into 2 types based on the travel time between CFC and RFCs:
1. Fast-delivery-target
2. Slow-delivery-target

That is, the slow-delivery-target demand are those demand with OTD requirements greater than the travel time.

Then CFC ships the slow-delivery-target orders to the respective RFCs and RFCs immediately transport these orders to the customers. The RFCs only create storage plans for the fast-delivery-target demand which follows the same logic in the simplest case.

Third, we expanded the network by adding virtual nodes that represent a temporary RFC and are denoted as c1, which are to ship products to its neighbors, denoted as c2, as shown in Figure 81. But there is no inventory in c1.

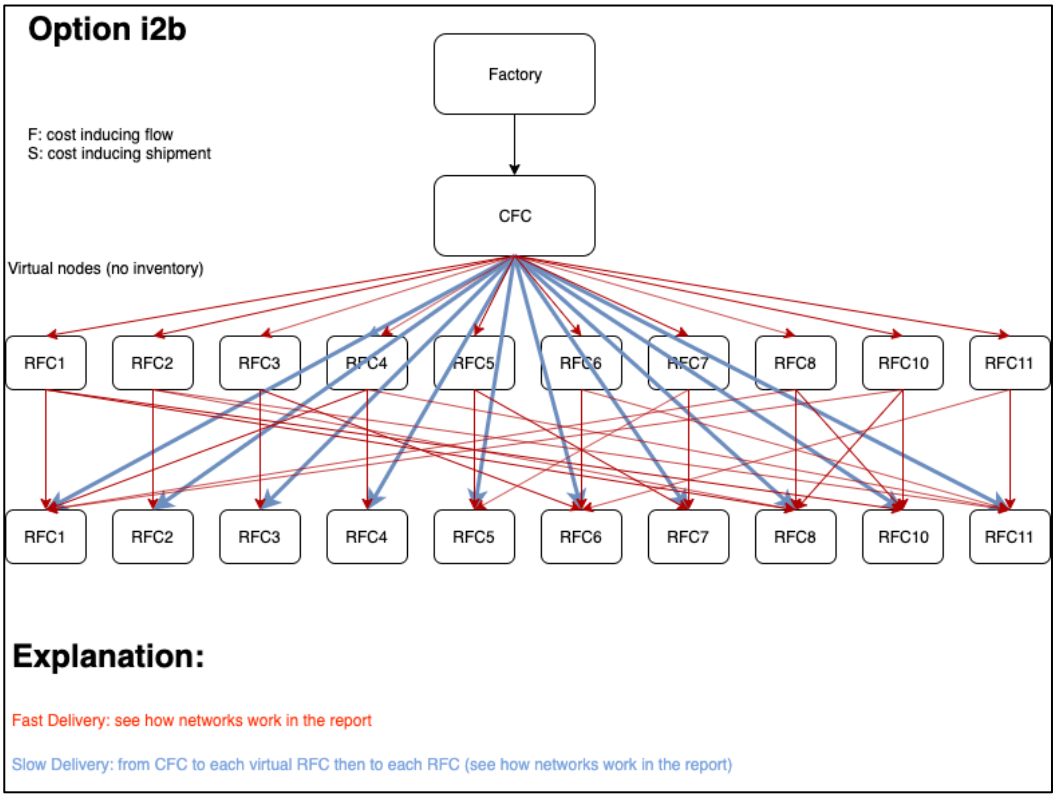


Figure 74 Option i2b

However, in this combination, due to the creation of CFC, the distance between the CFC and the RFC at Piedmont Atlanta becomes 0.

Besides, we defined the neighbors of an RFC as the first 2 closest other RFCs (shown in table #) and itself.

RFCs	Neighboring RFC1	Neighboring RFC2
1	8	10
2	8	10
3	9	6
4	11	1
5	7	9
6	9	11
7	9	5
8	10	1
9	3	6
10	1	8
11	6	9

Figure 75 Two Closest Neighbor of an RFC

Based on these adjustments, we have the following model for **Option i2b**.

Minimize Total Cost = Total Flow Handling Cost+ Total Shipment Cost + Total Inventory Cost over the following 5 years

where,

1. *Total Flowing Handling Cost =*
    a. *handling cost of flow of MyPals from factory to CFC +*
    b. *handling cost of outbound flow of MyPals from CFC to c1 +*
    c. *handling cost of inbound flow of MyPals from CFC to c1 +*
    d. *handling cost of outbound flow of MyPals from CFC to c2 +*
    e. *handling cost of inbound flow of MyPals from CFC to c2 +*
    f. *handling cost of outbound flow of MyPals from c1 to c2 +*
    g. *handling cost of inbound flow of MyPals from c1 to c2 +*
    h. *handling cost of flow of MyPals from c2 to regional customers*

2. *Total Shipment Cost =*
    a. *shipment cost of MyPals from CFC to c1 +*
    b. *shipment cost of MyPals from CFC to c2 +*
    c. *shipment cost of MyPals from c1 to c2*

3. *Total Inventory Cost =*
    a. *inventory of MyPals at CFC +*
    b. *inventory of MyPals at c2*

Then the constraints are:

1. Inventory Balance at CFC
2. Inventory Balance at c2
3. Linking Outbound Flow and Inbound Flow from CFC to c1
   The outbound flow of MyPal p from CFC to c1 on day t =
   the inbound flow of MyPal p from CFC to c1 on day (t + travel time between CFC and c1)
4. Linking Outbound Flow and Inbound Flow from CFC to c2
   The outbound flow of MyPal p from CFC to c2 on day t =
   the inbound flow of MyPal p from CFC to c2 on day (t + travel time between CFC and c2)
5. Linking Outbound Flow and Inbound Flow from c1 to c2
   The outbound flow of MyPal p from c1 to c2 on day t =
   the inbound flow of MyPal p from c1 to c2 on day (t + travel time between c1 and c2)
6. Linking Demand and Flow from CFC to c2
   The outbound flow of MyPal p from CFC to its c2 on day t= The slow-delivery-target demand of MyPal p at this region on day (t+travel time between CFC and c2)
7. Linking Demand and Flow from c2 to its Customer
   The outbound flow of MyPal p from RFC to its Customer on day t= The fast-delivery-target demand of MyPal p at this region on day t
8. Safety Stock at CFC
9. Safety Stock at c2

10. Linking Outbound Shipment and Flow from CDC to c1
    The number of shipments from CDC to c1 on day t =
    the smallest integer not less than the volume of outbound flow of MyPals from CDC to c1 on day t divided by 240
11. Linking Outbound Shipment and Flow from CDC to c2
    The number of shipments from CDC to c2 on day t =
    the smallest integer not less than the volume of outbound flow of MyPals from CDC to c2 on day t divided by 240
12. Linking Outbound Shipment and Flow from c1 to c2
    The number of shipments from c1 to c2 on day t =
    the smallest integer not less than the volume of outbound flow of MyPals from c1 to c2 on day t divided by 240

4.1.4 Mathematical Model

Here, we are to list the mathematical models for the 12 combinations.

4.1.4.1 Options i1a

$$\min \frac{1.5}{7}\sum_{p,t} F^{I,CDC}_{p,v_{CDC},t} + \frac{1.5}{7}\sum_{p,t,c1} F^{O,CDC}_{p,c1,t} + 2*2\sum_{t,c1} D^{O,CDC}_{c1} S^{CDC}_{c1,t} + \frac{2}{7}\sum_{p,t} I^{CDC}_{p,t} + \frac{2}{7}\sum_{p,t,c1} F^{O,CDC}_{p,c1,t+\delta t(CDC,c1)} + \frac{2}{7}\sum_{p,t,c1} F^{O,c1}_{p,t} + \frac{2.5}{7}\sum_{p,t,c1} I^{c1}_{p,t}$$

$s.t.$

$$I^{CDC}_{p,t-1} + F^{I,CDC}_{p,v_{CDC},t} - \sum_{c1} F^{O,CDC}_{p,c1,t} + I^{CDC}_{p,t} = 0, \forall p,t$$

$$I^{CDC}_{p,0} = I^{CDC}_{p,1826}, \forall p$$

$$I^{CDC}_{p,t} \geq i^{CDC}_{p,t}, \forall p,t$$

$$I^{c1}_{p,t-1} + \left[F^{O,CDC}_{p,c1,t-\delta t(CDC,c1)}\right]_+ - F^{O,c1}_{p,t} + I^{c1}_{p,t} = 0, \forall c1,p,t$$

$$I^{c1}_{p,0} = I^{c1}_{p,1826}, \forall c1,p$$

$$I^{c1}_{p,t} \geq i^{c1}_{p,t}, \forall c1,p,t$$

$$F^{O,c1}_{p,t} = R^{c1}_{p,t}, \forall c1,p,t$$

$$\sum_{p} F^{O,CDC}_{p,c1,t} \leq 240 S^{CDC}_{c1,t}, \qquad \forall c1,p,t$$

4.1.4.2 Options i1b

$$\min \frac{1.5}{7}\sum_{p,t} F^{I,CDC}_{p,v_{CDC},t} + \frac{1.5}{7}\sum_{p,t,c1} F^{O,CDC}_{p,c1,t} + 2*2\sum_{t,c1} D^{O,CDC}_{c1} S^{CDC}_{c1,t} + \frac{2}{7}\sum_{p,t} I^{CDC}_{p,t} + \frac{2}{7}\sum_{p,t,c1} F^{O,CDC}_{p,c1,t+\delta t(CDC,c1)} + \frac{2}{7}\sum_{\substack{p,t,c1,\\ c2\in c1's\ Neighbor\backslash c1}} F^{O,c1}_{p,c2,t} + 2 * 2\sum_{\substack{t,c1\\ c2\in c1's\ Neighbor\backslash c1}} D^{O,c1}_{c2} S^{c1}_{c2,t} + \frac{2}{7}\sum_{\substack{p,t,c2,\\ c1\in c2's\ Neighbor\backslash c2}} F^{O,c1}_{p,c2,t+\delta t(c2,c1)} + \frac{2}{7}\sum_{p,t,c2} F^{O,c2}_{p,t} + \frac{2.5}{7}\sum_{p,t,c1} I^{c2}_{p,t}$$

$s.t.$

$$I^{CDC}_{p,t-1} + F^{I,CDC}_{p,v_{CDC},t} - \sum_{c1} F^{O,CDC}_{p,c1,t} + I^{CDC}_{p,t} = 0, \forall p,t$$

$$I^{CDC}_{p,0} = I^{CDC}_{p,1826}, \forall p$$

$$I^{CDC}_{p,t} \geq i^{CDC}_{p,t}, \forall p,t$$

$$[F^{O,CDC}_{p,c1,t-\delta t(CDC,c1)}]_{+} - \sum_{c2\in c1's\ Neighbor} F^{O,c1}_{p,c2,t} = 0, \forall c1,c2,p,t$$

$$I^{c2}_{p,t-1} + \sum_{c1\in c2's\ Neighbor} \left[F^{O,c1}_{p,c1,t-\delta t(c2,c1)}\right]_{+} - F^{O,c2}_{p,t} + I^{c2}_{p,t} = 0, \forall c2,p,t$$

$$I^{c2}_{p,0} = I^{c2}_{p,1826}, \forall c2,p$$

$$I^{c2}_{p,t} \geq i^{c2}_{p,t}, \forall c2,p,t$$

$$F^{O,c2}_{p,t} = R^{c2}_{p,t}, \forall c2,p,t$$

$$\sum_{p} F^{O,CDC}_{p,c1,t} \leq 240 S^{CDC}_{c1,t}, \qquad \forall c1,p,t$$

$$\sum_{p} F^{O,CDC}_{p,c2,t} \leq 240 S^{CDC}_{c2,t}, \qquad \forall c2,p,t$$

$$\sum_{p} F^{O,c1}_{p,c2,t} \leq 240 S^{c1}_{c2,t}, \qquad \forall c1, c2 \in c1's\ Neigbhor, p,t$$

4.1.4.3 Options i1c

$$\min \frac{1.5}{7}\sum_{p,t} F^{I,CDC}_{p,v_{CDC},t} + \frac{1.5}{7}\sum_{p,t,c1} F^{O,CDC}_{p,c1,t} + (2 + 0.27 * 0.6 * 0.8 * 0.8)\sum_{t,c1} D^{O,CDC}_{c1} S^{CDC}_{c1,t} + \frac{2}{7}\sum_{p,t} I^{CDC}_{p,t} + \frac{2}{7}\sum_{p,t,c1} F^{O,CDC}_{p,c1,t+\delta t(CDC,c1)} + \frac{2}{7}\sum_{p,t,c1} F^{O,c1}_{p,t} + \frac{2.5}{7}\sum_{p,t,c1} I^{c1}_{p,t}$$

$s.t.$

$$I^{CDC}_{p,t-1} + F^{I,CDC}_{p,v_{CDC},t} - \sum_{c1} F^{O,CDC}_{p,c1,t} + I^{CDC}_{p,t} = 0, \forall p,t$$

$$I^{CDC}_{p,0} = I^{CDC}_{p,1826}, \forall p$$

$$I^{CDC}_{p,t} \geq i^{CDC}_{p,t}, \forall p,t$$

$$I^{c1}_{p,t-1} + \left[F^{O,CDC}_{p,c1,t-\delta t(CDC,c1)}\right]_{+} - F^{O,c1}_{p,t} + I^{c1}_{p,t} = 0, \forall c1,p,t$$

$$I^{c1}_{p,0} = I^{c1}_{p,1826}, \forall c1,p$$

$$I^{c1}_{p,t} \geq i^{c1}_{p,t}, \forall c1,p,t$$

$$F^{O,c1}_{p,t} = R^{c1}_{p,t}, \forall c1,p,t$$

$$S^{CDC}_{c1,t} = \left\lceil \frac{1}{240}\sum_{p=1}^{25} F^{O,CDC}_{p,c1,t} \right\rceil, \forall c1,p,t$$

4.1.4.4 Options i2a

$$\min \frac{1.5}{7}\sum_{p,t} F^{I,CFC}_{p,v_{CFC},t} + \frac{1.5}{7}\Big(\sum_{p,t,c1} F^{O,CFC}_{p,c1,t} + \sum_{p,t,c1} F'^{O,CFC}_{p,c1,t}\Big) + 2 * 2\sum_{t,c1} D^{O,CFC}_{c1} S^{CFC}_{c1,t} + \frac{2}{7}\sum_{p,t} I^{CFC}_{p,t} + \frac{2}{7}\Big(\sum_{p,t,c1} F^{O,CFC}_{p,c1,t+\delta t(CFC,c1)} + \sum_{p,t,c1} F'^{O,CFC}_{p,c1,t+\delta t(CFC,c1)}\Big) + \frac{2}{7}\sum_{p,t,c1} F^{O,c1}_{p,t} + \frac{2.5}{7}\sum_{p,t,c1} I^{c1}_{p,t}$$

$s.t.$

$$I^{CFC}_{p,t-1} + F^{I,CFC}_{p,v_{CFC},t} - \sum_{c1} F^{O,CFC}_{p,c1,t} + \sum_{c1} F'^{O,CFC}_{p,c1,t} + I^{CFC}_{p,t} = 0, \forall p,t$$

$$I^{CFC}_{p,0} = I^{CFC}_{p,1826}, \forall p$$

$$I^{CFC}_{p,t} \geq i^{CFC}_{p,t}, \forall p,t$$

$$I_{p,t-1}^{c1} + \left[F_{p,c1,t-\delta t(CFC,c1)}^{O,CFC}\right]_+ + \left[F'^{O,CFC}_{p,c1,t-\delta t(CFC,c1)}\right]_+ - F_{p,t}^{O,c1} + I_{p,t}^{c1} = 0, \forall c1, p, t$$

$$I_{p,0}^{c1} = I_{p,1826}^{c1}, \forall c1, p$$

$$I_{p,t}^{c1} \geq i_{p,t}^{c1}, \forall c1, p, t$$

$$\left[F'^{O,CFC}_{p,c1,t-\delta t(CFC,c1)}\right]_+ = R_{p,t}^{slow,c1} \ \forall c1, p, t$$

$$F_{p,t}^{O,c1} = R_{p,t}^{c1}, \forall c1, p, t$$

$$\sum_p F_{p,c1,t}^{O,CFC} + \sum_p F'^{O,CFC}_{p,c1,t} \leq 240 S_{c1,t}^{CFC}, \qquad \forall c1, p, t$$

4.1.4.5 Options i2b

$$\begin{aligned}
\min \ & \frac{1.5}{7}\sum_{p,t} F_{p,v_{CDC},t}^{I,CFC} + \frac{1.5}{7}\sum_{p,t,c1} F_{p,c1,t}^{O,CFC} + \frac{1.5}{7}\sum_{p,t,c2} F_{p,c2,t}^{O,CFC} + 2*2\sum_{t,c1} D_{c1}^{O,CFC} S_{c1,t}^{CFC} + 2 \\
& * 2\sum_{t,c2} D_{c2}^{O,CFC} S_{c2,t}^{CFC} + \frac{2}{7}\sum_{p,t} I_{p,t}^{CFC} + \frac{2}{7}\sum_{p,t,c1} F_{p,c1,t+\delta t(CDC,c1)}^{O,CFC} \\
& + \frac{2}{7} \sum_{\substack{p,t,c1, \\ c2 \in c1's\ Neighbor \backslash c1}} F_{p,c2,t}^{O,c1} + 2*2 \sum_{\substack{t,c1 \\ c2 \in c1's\ Neighbor \backslash c1}} D_{c2}^{O,c1} S_{c2,t}^{c1} \\
& + \frac{2}{7} \sum_{\substack{p,t,c2, \\ c1 \in c2's\ Neighbor \backslash c2}} F_{p,c2,t+\delta t(c2,c1)}^{O,c1} + \frac{2}{7}\sum_{p,t,c2} F_{p,t}^{O,c2} + \frac{2.5}{7}\sum_{p,t,c2} I_{p,t}^{c2}
\end{aligned}$$

$s.t.$

$$I_{p,t-1}^{CFC} + F_{p,v_{CFC},t}^{I,CFC} - \sum_{c1} F_{p,c1,t}^{O,CFC} - \sum_{c2} F_{p,c2,t}^{O,CFC} + I_{p,t}^{CFC} = 0, \forall p, t$$

$$I_{p,0}^{CFC} = I_{p,1826}^{CFC}, \forall p$$

$$I_{p,t}^{CFC} \geq i_{p,t}^{CFC}, \forall p, t$$

$$[F_{p,c1,t-\delta t(CFC,c1)}^{O,CFC}]_+ - \sum_{c2 \in c1's\ Neighbor} F_{p,c2,t}^{O,c1} = 0, \forall c1, c2, p, t$$

$$I_{p,t-1}^{c2} + \left[F_{p,c2,t-\delta t(CFC,c2)}^{O,CFC}\right]_+ + \sum_{c1 \in c2's\ Neighbor} \left[F_{p,c1,t-\delta t(c2,c1)}^{O,c1}\right]_+ - F_{p,t}^{O,c2} + I_{p,t}^{c2} = 0, \forall c2, p, t$$

$$I_{p,0}^{c2} = I_{p,1826}^{c2}, \forall c2, p$$

$$I_{p,t}^{c2} \geq i_{p,t}^{c2}, \forall c2, p, t$$

$$\left[F_{p,c2,t-\delta t(CFC,c2)}^{O,CFC}\right]_{+} = R_{p,t}^{slow,c2}, \forall c2, p, t$$

$$F_{p,t}^{O,c2} = R_{p,t}^{c2}, \forall c2, p, t$$

$$\sum_{p} F_{p,c1,t}^{O,CFC} \leq 240 S_{c1,t}^{CFC}, \qquad \forall c1, p, t$$

$$\sum_{p} F_{p,c2,t}^{O,CFC} \leq 240 S_{c2,t}^{CFC}, \qquad \forall c2, p, t$$

$$\sum_{p} F_{p,c2,t}^{O,c1} \leq 240 S_{c2,t}^{c1}, \qquad \forall c1, c2 \in c1's\ Neigbhor, p, t$$

4.1.4.6 Options i2c

$$\min \frac{1.5}{7} \sum_{p,t} F_{p,v_{CFC},t}^{I,CFC} + \frac{1.5}{7} \Big(\sum_{p,t,c1} F_{p,c1,t}^{O,CFC} + \sum_{p,t,c1} F'^{O,CFC}_{p,c1,t} \Big) + (2 + 0.027 * 0.6 * 0.8 * 0.8) \sum_{t,c1} D_{c1}^{O,CFC} S_{c1,t}^{CFC} + \frac{2}{7} \sum_{p,t} I_{p,t}^{CFC} + \frac{2}{7} \Big(\sum_{p,t,c1} F_{p,c1,t+\delta t(CFC,c1)}^{O,CFC} + \sum_{p,t,c1} F'^{O,CFC}_{p,c1,t+\delta t(CFC,c1)} \Big) + \frac{2}{7} \sum_{p,t,c1} F_{p,t}^{O,c1} + \frac{2.5}{7} \sum_{p,t,c1} I_{p,t}^{c1}$$

$s.t.$

$$I_{p,t-1}^{CFC} + F_{p,v_{CFC},t}^{I,CFC} - \sum_{c1} F_{p,c1,t}^{O,CFC} + \sum_{c1} F'^{O,CFC}_{p,c1,t} + I_{p,t}^{CFC} = 0, \forall p, t$$

$$I_{p,0}^{CFC} = I_{p,1826}^{CFC}, \forall p$$

$$I_{p,t}^{CFC} \geq i_{p,t}^{CFC}, \forall p, t$$

$$I_{p,t-1}^{c1} + \left[F_{p,c1,t-\delta t(CFC,c1)}^{O,CFC}\right]_{+} + \left[F'^{O,CFC}_{p,c1,t-\delta t(CFC,c1)}\right]_{+} - F_{p,t}^{O,c1} + I_{p,t}^{c1} = 0, \forall c1, p, t$$

$$I_{p,0}^{c1} = I_{p,1826}^{c1}, \forall c1, p$$

$$I_{p,t}^{c1} \geq i_{p,t}^{c1}, \forall c1, p, t$$

$$\left[F'^{O,CFC}_{p,c1,t-\delta t(CFC,c1)}\right]_{+} = R_{p,t}^{slow,c1}\ \forall c1, p, t$$

$$F_{p,t}^{O,c1} = R_{p,t}^{c1}, \forall c1, p, t$$

$$\sum_{p} F_{p,c1,t}^{O,CFC} + \sum_{p} F'^{O,CFC}_{p,c1,t} \leq 240 S_{c1,t}^{CFC}, \qquad \forall c1, p, t$$

$$S_{c1,t}^{CFC} = \left\lceil \frac{1}{240} \sum_{p=1}^{25} (F_{p,c1,t}^{O,CFC} + F'^{O,CFC}_{p,c1,t}) \right\rceil, \forall c1, p, t$$

4.1.4.7 Options ii1a

$$\min \sum_{c1} \left(\frac{2}{7} \sum_{p,t} F_{p,v_{c1},t}^{I,c1} + \frac{2}{7} \sum_{p,t} F_{p,t}^{O,c1} + \frac{2.5}{7} \sum_{p,t} I_{p,t}^{c1}\right)$$

$s.t.$

$$I_{p,t-1}^{c1} + F_{p,v_{c1},t}^{I,c1} - F_{p,t}^{O,c1} + I_{p,t}^{c1} = 0, \forall c1, p, t$$

$$I_{p,0}^{c1} = I_{p,1826}^{c1}, \forall c1, p$$

$$I_{p,t}^{c1} \geq i_{p,t}^{c1}, \forall c1, p, t$$

$$F_{p,t}^{O,c1} = R_{p,t}^{c1}, \forall c1, p, t$$

4.1.4.8 Options ii1b

$$\min \sum_{c1} \left(\frac{2}{7} \sum_{p,t} F_{p,v_{c1},t}^{I,c1} + \frac{2}{7} \sum_{\substack{p,t \\ c2 \in c1's\ Neighbor \backslash c1}} F_{p,c2,t}^{O,c1} + 2 * 2 \sum_{\substack{t \\ c2 \in c1's\ Neighbor \backslash c1}} D_{c2}^{O,c1} S_{c2,t}^{c1}\right) + \sum_{c2} \left(\frac{2}{7} \sum_{\substack{p,t \\ c1 \in c2's\ Neighbor \backslash c2}} F_{p,c2,t+\delta t(c2,c1)}^{O,c1} + \frac{2}{7} \sum_{p,t} F_{p,t}^{O,c2} + \frac{2.5}{7} \sum_{p,t} I_{p,t}^{c2}\right)$$

$s.t.$

$$F_{p,v_{c1},t}^{I,c1} - \sum_{\substack{p,t \\ c2 \in c1's\ Neighbor}} F_{p,c2,t}^{O,c1} = 0, \forall c1, p, t$$

$$I_{p,t-1}^{c2}+\sum_{c1\in c2's\,Neighbor}\left[F_{p,c1,t-\delta t(c2,c1)}^{O,c1}\right]_{+}-F_{p,t}^{O,c2}+I_{p,t}^{c2}=0,\forall c2,p,t$$

$$I_{p,0}^{c2}=I_{p,1826}^{c2},\forall c2,p$$

$$I_{p,t}^{c2}\geq i_{p,t}^{c2},\forall c2,p,t$$

$$F_{p,t}^{O,c2}=R_{p,t}^{c2},\forall c2,p,t$$

$$\sum_{p}F_{p,c2,t}^{O,c1}\leq 240S_{c2,t}^{c1}\ ,\forall c1,c2\in c1's\,Neigbhor,p,t$$

4.1.4.9 Options ii1c

Because we have assumed that:

a) Any distances within one megaregion are negligible;
b) There are no limitations on either the volume of flows or number of shipments per time period,

The transportation methods don't affect the total cost in this context.
Therefore, the model of Options ii1a is the same as that of Options ii1c.

$$\min\ \sum_{c1}\left(\frac{2}{7}\sum_{p,t}F_{p,v_{c1},t}^{I,c1}+\frac{2}{7}\sum_{p,t}F_{p,t}^{O,c1}+\frac{2.5}{7}\sum_{p,t}I_{p,t}^{c1}\right)$$

$s.t.$

$$I_{p,t-1}^{c1}+F_{p,v_{c1},t}^{I,c1}-F_{p,t}^{O,c1}+I_{p,t}^{c1}=0,\forall c1,p,t$$

$$I_{p,0}^{c1}=I_{p,1826}^{c1},\forall c1,p$$

$$I_{p,t}^{c1}\geq i_{p,t}^{c1},\forall c1,p,t$$

$$F_{p,t}^{O,c1}=R_{p,t}^{c1},\forall c1,p,t$$

4.1.4.10Options ii2a

$$\min\ \frac{2}{7}\sum_{p,t}F_{p,v_{CFC},t}^{I,CFC}+\frac{2}{7}\sum_{p,t,c1}F_{p,c1,t}^{O,CFC}+2*2\sum_{t,c1}D_{c1}^{O,CFC}S_{c1,t}^{CFC}+\frac{2.5}{7}\sum_{p,t}I_{p,t}^{CFC}$$
$$+\sum_{c1}\left(\frac{2}{7}F_{p,c1,t+\delta t(CFC,c1)}^{O,CFC}+\frac{2}{7}\sum_{p,t}F_{p,v_{c1},t}^{I,c1}+\frac{2}{7}\sum_{p,t}F_{p,t}^{O,c1}+\frac{2.5}{7}\sum_{p,t}I_{p,t}^{c1}\right)$$

$s.t.$

$$I_{p,t-1}^{CFC} + F_{p,v_{CFC},t}^{I,CFC} - \sum_{c1} F_{p,c1,t}^{O,CFC} + I_{p,t}^{CFC} = 0, \forall p,t$$

$$I_{p,0}^{CFC} = I_{p,1826}^{CFC}, \forall p$$

$$I_{p,t}^{CFC} \geq i_{p,t}^{CFC}, \forall p,t$$

$$I_{p,t-1}^{c1} + \left[F_{p,c1,t-\delta t(CFC,c1)}^{O,CFC}\right]_{+} + F_{p,v_{c1},t}^{I,c1} - F_{p,t}^{O,c1} + I_{p,t}^{c1} = 0, \forall c1,p,t$$

$$I_{p,0}^{c1} = I_{p,1826}^{c1}, \forall c1,p$$

$$I_{p,t}^{c1} \geq i_{p,t}^{c1}, \forall c1,p,t$$

$$\left[F_{p,c1,t-\delta t(CFC,c1)}^{O,CFC}\right]_{+} = R_{p,t}^{slow,c1} \ \forall c1,p,t$$

$$F_{p,t}^{O,c1} = R_{p,t}^{c1}, \forall c1,p,t$$

$$\sum_{p} F_{p,c1,t}^{O,CFC} \leq 240 S_{c1,t}^{CFC}, \qquad \forall c1,p,t$$

4.1.4.11Options ii2b

$$\begin{aligned}\min\ & \frac{2}{7}\sum_{p,t} F_{p,v_{CFC},t}^{I,CFC} + \frac{2}{7}\sum_{p,t,c2} F_{p,c2,t}^{O,CFC} + 2*2\sum_{t,c2} D_{c2}^{O,CFC} S_{c2,t}^{CFC} + \frac{2.5}{7}\sum_{p,t} I_{p,t}^{CFC} \\ & + \sum_{c1}\Big(\frac{2}{7}\sum_{p,t} F_{p,v_{c1},t}^{I,c1} + \frac{2}{7}\sum_{\substack{p,t \\ c2\in c1's\ Neighbor\backslash c1}} F_{p,c2,t}^{O,c1} + 2 \\ & * 2\sum_{\substack{t \\ c2c2\in c1's\ Neighbor\backslash c1}} D_{c2}^{O,c1} S_{c2,t}^{c1}\Big) \\ & + \sum_{c2}\Big(\frac{2}{7} F_{p,c2,t+\delta t(CFC,c2)}^{O,CFC} + \frac{2}{7}\sum_{c1\in c2's\ Neighbor\backslash c2} F_{p,c2,t+\delta t(c1,c2)}^{O,c1} + \frac{2}{7}\sum_{p,t} F_{p,t}^{O,c2} \\ & + \frac{2.5}{7}\sum_{p,t} I_{p,t}^{c2}\Big)\end{aligned}$$

$s.t.$

$$I_{p,t-1}^{CFC} + F_{p,v_{CFC},t}^{I,CFC} - \sum_{c2} F_{p,c2,t}^{O,CFC} + I_{p,t}^{CFC} = 0, \forall p,t$$

$$I_{p,0}^{CFC} = I_{p,1826}^{CFC}, \forall p$$

$$I_{p,t}^{CFC} \geq i_{p,t}^{CFC}, \forall p,t$$

$$F_{p,v_{c1},t}^{I,c1} - \sum_{c2 \in c1's\ Neighbor} F_{p,c2,t}^{O,c1} = 0, \forall c1, c2, p, t$$

$$I_{p,t-1}^{c2} + \left[F_{p,c2,t-\delta t(CFC,c2)}^{O,CFC}\right]_+ + \sum_{c1 \in c2's\ Neighbor} \left[F_{p,c1,t-\delta t(c2,c1)}^{O,c1}\right]_+ - F_{p,t}^{O,c2} + I_{p,t}^{c2} = 0, \forall c2, p, t$$

$$I_{p,0}^{c2} = I_{p,1826}^{c2}, \forall c2, p$$

$$I_{p,t}^{c2} \geq i_{p,t}^{c2}, \forall c2, p, t$$

$$\left[F_{p,c2,t-\delta t(CFC,c2)}^{O,CFC}\right]_+ = R_{p,t}^{slow,c2}, \forall c2, p, t$$

$$F_{p,t}^{O,c2} = R_{p,t}^{c2}, \forall c2, p, t$$

$$\sum_{p} F_{p,c2,t}^{O,CFC} \leq 240 S_{c2,t}^{CFC}, \qquad \forall c2, p, t$$

$$\sum_{p} F_{p,c2,t}^{O,c1} \leq 240 S_{c2,t}^{c1}, \qquad \forall c1, c2 \in c1's\ Neigbhor, p, t$$

4.1.4.12Options ii2c

$$\min\ \frac{2}{7}\sum_{p,t} F_{p,v_{CFC},t}^{I,CFC} + \frac{2}{7}\sum_{p,t,c1} F_{p,c2,t}^{O,CFC} + 2*2\sum_{t,c1} D_{c1}^{O,CFC} S_{c1,t}^{CFC} + \frac{2.5}{7}\sum_{p,t} I_{p,t}^{CFC} + \sum_{c1}\left(\frac{2}{7} F_{p,c1,t+\delta t(CFC,c1)}^{O,CFC} + \frac{2}{7}\sum_{p,t} F_{p,v_{c1},t}^{I,c1} + \frac{2}{7}\sum_{p,t} F_{p,t}^{O,c1} + \frac{2.5}{7}\sum_{p,t} I_{p,t}^{c1}\right)$$

$s.t.$

$$I_{p,t-1}^{CFC} + F_{p,v_{CFC},t}^{I,CFC} - \sum_{c1} F_{p,c1,t}^{O,CFC} + I_{p,t}^{CFC} = 0, \forall p,t$$

$$I_{p,0}^{CFC} = I_{p,1826}^{CFC}, \forall p$$

$$I_{p,t}^{CFC} \geq i_{p,t}^{CFC}, \forall p,t$$

$$I_{p,t-1}^{c1} + \left[F_{p,c1,t-\delta t(CFC,c1)}^{O,CFC}\right]_+ + F_{p,v_{c1},t}^{I,c1} - F_{p,t}^{O,c1} + I_{p,t}^{c1} = 0, \forall c1,p,t$$

$$I_{p,0}^{c1} = I_{p,1826}^{c1}, \forall c1,p$$

$$I_{p,t}^{c1} \geq i_{p,t}^{c1}, \forall c1,p,t$$

$$\left[F_{p,c1,t-\delta t(CFC,c1)}^{O,CFC}\right]_+ = R_{p,t}^{slow,c1} \ \forall c1,p,t$$

$$F_{p,t}^{O,c1} = R_{p,t}^{c1}, \forall c1,p,t$$

$$S_{c1,t}^{CFC} = \left\lceil \frac{1}{240} \sum_{p=1}^{25} F_{p,c1,t}^{O,CFC} \right\rceil, \forall c1,p,t$$

4.1.5 Overall Solution Methodology

These are the steps we followed to solve each model.

- We coded our model in Python.
- We figured out an intuitive initial solution for the combination as well as the initial cost.
- We used the Python to solve the model, getting the optimal solution and cost.
- We compared the initial solution with the optimal solution and calculated the reduction in percentage on cost.

Specifically, the initial solution is got in this way:

Inventories everywhere equal to the safety stocks except that for the inventories at the end of day 1 and day 1826, they equal the maximum safety stocks for day 1 and day 1826.

The daily flow equals to the daily demand.

4.1.5.1 Solution to Option i1a

We realized the model of Option i1a in Python code, which is in the attachment. However, running and solving an optimization model for 1,115,686 decision variables is time consuming.

Instead of a 5-year planning for all the MyPals, we realized two feasible solutions in Excel according to two basic ideas:

- Use the storage only for uncertainty and satisfy the clients by ordering from another place as long as the time allows in order to minimize the inventory level.

- Use the storage both for uncertainty and customer satisfaction in order to minimize the inbound and outbound flows.

The decision process is the same as the example shown in the beginning of this section.

The total cost of solution 1 is $79,166.27 and solution 2, $63,716.46. Therefore, solution 2 is better than solution 1 and we used solution 2 for the validation.

In both solutions, the inventory cost takes the most proportion and the flow cost hasn't been affected too much by the change of the solution, while there is a good reduction in the inventory cost and the shipping cost in solution 2.

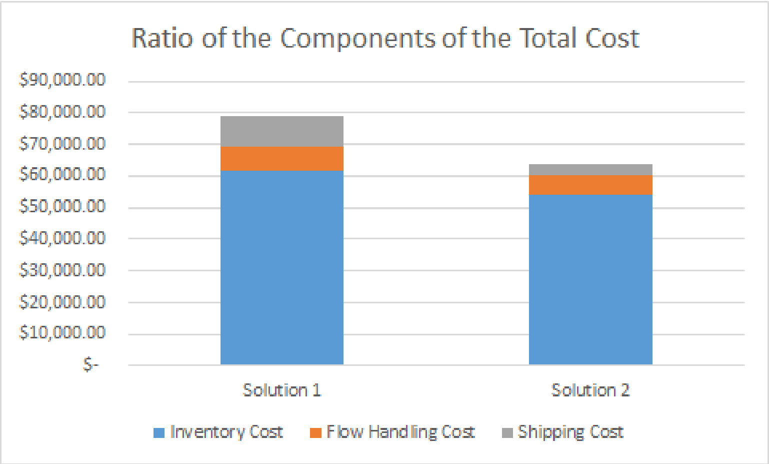


Figure 76 Ratio of the Components of the Total Cost

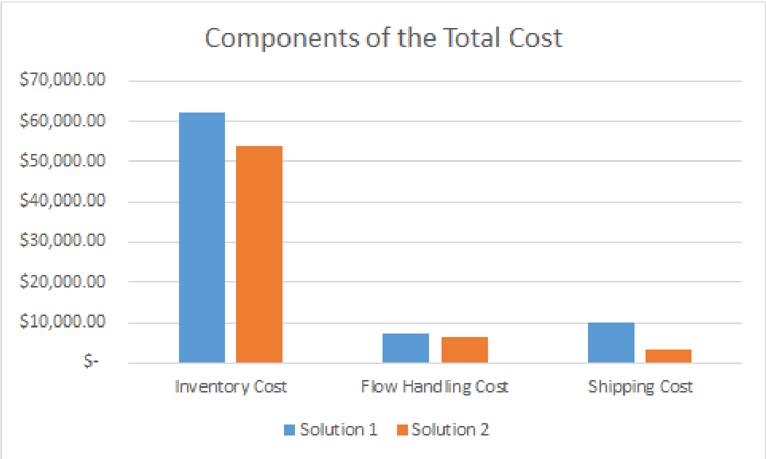


Figure 77 Components of the Total Cost

4.2 Resource & Production Planning

4.2.1 Assumptions

The production resource planning is similar in task 3. But notice that here, we have to change a few parameters.

Following the same assumptions in task 3,

- the working efficiency *e* is 86.5% (e is a random variable in [85%, 88%])
- the reliability *r* is 95% (r is a random variable in [90%, 100%]).
- the installment fee for each cell is 300,000 dollars
- The annual maintenance fee is 50,000 dollars
- daily operation fee is 300 dollars.
- the quality changes from 2% in the first year, to 1% in the second year, and 0.5% in the last three years.
- the setup time for changeover is 0, so for MyPal the changeover is seamless.

4.2.2 Solution

4.2.2.1 Example Solution For 5-year Horizon

Though we are clear that OTS and OTD are different, and that in task 4, the input of production planning, i.e. the requirement from CDC for the factory at Sandy Spring (production Option i) or the ones from RFCs for the respective regional factory (production Option ii) , since it is hard to solve the model built in part 1 over the 5 year planning horizon, we still used the OTD daily capacity planning we got in task 2 to illustrate how we are going to work out the resource and production plan once we get the true capacity requirement for the factory (or factories).

Here are the working steps and results in detail. (Next Page)

Step 1

The relative capacity requirement is attached below:

	MyPal1	MyPal2	MyPal3	MyPal4	MyPal5	MyPal6	MyPal7	MyPal8	MyPal9	MyPal10	MyPal11	MyPal12	MyPal13	MyPal14	MyPal15	MyPal16	MyPal17	M
1	537.25147	179.41882	139.90054	284.87900	153.55482	244.18354	241.58911	0	0	0	0	0	0	0	0	0	0	
2	710.51949	215.75574	192.31729	364.07948	218.58445	356.46507	369.73027	0	0	0	0	0	0	0	0	0	0	
3	599.88286	189.06805	161.98796	272.45902	184.24343	286.51066	299.93398	0	0	0	0	0	0	0	0	0	0	
4	156.49611	44.21293	37.59688	87.14933	45.32471	69.23585	78.70295	0	0	0	0	0	0	0	0	0	0	
5	200.50705	62.86070	51.85549	102.19024	62.26052	89.87042	94.89372	0	0	0	0	0	0	0	0	0	0	
6	46.61447	101.73742	76.78569	125.23629	95.66360	130.61556	119.70388	0	0	0	0	0	0	0	0	0	0	
7	455.78024	128.42428	123.38857	217.96937	133.73897	233.45730	214.30372	0	0	0	0	0	0	0	0	0	0	
8	533.02952	152.50927	151.69468	273.22228	174.25397	243.13385	256.84277	0	0	0	0	0	0	0	0	0	0	
9	688.11500	227.41163	187.18307	357.90715	228.95306	340.40096	329.97688	0	0	0	0	0	0	0	0	0	0	
10	537.25892	191.91083	171.88719	306.06574	200.02111	293.66894	273.11632	0	0	0	0	0	0	0	0	0	0	
11	149.61433	46.22787	35.91307	72.30959	41.05640	65.36242	66.37486	0	0	0	0	0	0	0	0	0	0	
12	197.62702	59.24473	45.57223	97.26877	67.86330	100.07264	102.60250	0	0	0	0	0	0	0	0	0	0	
13	39.48517	88.33314	74.36593	139.81775	92.62794	115.80396	112.86929	0	0	0	0	0	0	0	0	0	0	
14	422.80764	144.50577	123.21307	218.88909	139.62735	242.45585	221.82955	0	0	0	0	0	0	0	0	0	0	
15	530.37052	167.96409	144.38988	249.70850	166.54518	250.69610	236.25372	0	0	0	0	0	0	0	0	0	0	
16	727.65729	214.62409	187.15492	380.00451	205.12470	376.38274	394.56279	0	0	0	0	0	0	0	0	0	0	
17	538.71342	183.75170	147.91231	290.76738	173.11156	310.70740	309.87957	0	0	0	0	0	0	0	0	0	0	
18	146.04554	45.63846	39.01331	82.11694	43.07134	70.97430	65.19685	0	0	0	0	0	0	0	0	0	0	
19	186.24679	61.25967	51.18411	94.43510	62.00307	111.48101	96.65949	0	0	0	0	0	0	0	0	0	0	
20	50.29502	96.71495	73.76741	142.73421	91.04512	114.46121	115.11355	0	0	0	0	0	0	0	0	0	0	
21	463.65459	141.68203	119.02754	221.40984	132.27702	239.18011	207.48651	0	0	0	0	0	0	0	0	0	0	
22	548.19957	166.41025	126.53268	244.59332	150.33372	266.52014	273.22642	0	0	0	0	0	0	0	0	0	0	

Figure 78 Relative daily capacity requirement of MyPal production

Step 2

Get the base table and left table:

	MyPal1	MyPal2	MyPal3	MyPal4	MyPal5	MyPal6	MyPal7	MyPal8	MyPal9	MyPal10	MyPal11	MyPal12	MyPal13	MyPal14	MyPal15	MyPal16	MyPal17	M
1	268	89	69	142	102	162	161	0	0	0	0	0	0	0	0	0	0	
2	355	107	96	182	145	237	246	0	0	0	0	0	0	0	0	0	0	
3	299	94	80	136	122	191	199	0	0	0	0	0	0	0	0	0	0	
4	78	22	18	43	30	46	52	0	0	0	0	0	0	0	0	0	0	
5	100	31	25	51	41	59	63	0	0	0	0	0	0	0	0	0	0	
6	23	50	38	62	63	87	79	0	0	0	0	0	0	0	0	0	0	
7	227	64	61	108	89	155	142	0	0	0	0	0	0	0	0	0	0	
8	266	76	75	136	116	162	171	0	0	0	0	0	0	0	0	0	0	
9	344	113	93	178	152	226	219	0	0	0	0	0	0	0	0	0	0	
10	268	95	85	153	133	195	182	0	0	0	0	0	0	0	0	0	0	
11	74	23	17	36	27	43	44	0	0	0	0	0	0	0	0	0	0	
12	98	29	22	48	45	66	68	0	0	0	0	0	0	0	0	0	0	
13	19	44	37	69	61	77	75	0	0	0	0	0	0	0	0	0	0	
14	211	72	61	109	93	161	147	0	0	0	0	0	0	0	0	0	0	
15	265	83	72	124	111	167	157	0	0	0	0	0	0	0	0	0	0	
16	363	107	93	190	136	250	263	0	0	0	0	0	0	0	0	0	0	
17	269	91	73	145	115	207	206	0	0	0	0	0	0	0	0	0	0	
18	73	22	19	41	28	47	43	0	0	0	0	0	0	0	0	0	0	
19	93	30	25	47	41	74	64	0	0	0	0	0	0	0	0	0	0	
20	25	48	36	71	60	76	76	0	0	0	0	0	0	0	0	0	0	
21	231	70	59	110	88	159	138	0	0	0	0	0	0	0	0	0	0	
22	274	83	63	122	100	177	182	0	0	0	0	0	0	0	0	0	0	

Figure 79 Base table of MyPal production

	MyPal1	MyPal2	MyPal3	MyPal4	MyPal5	MyPal6	MyPal7	MyPal8	MyPal9	MyPal10	MyPal11	MyPal12	MyPal13	MyPal14	MyPal15	MyPal16	MyPal17
1	1.251468887	1.41881955	1.900535815	0.8790017985	0.55482016	1.18353895	8.910902e-02	0	0	0	0	0	0	0	0	0	
2	0.519486164	1.75573947	0.317291991	0.0794802862	1.08444625	0.96506853	7.302712e-01	0	0	0	0	0	0	0	0	0	
3	1.882861572	1.06804584	1.987959163	0.4590170720	1.24343269	0.01066146	1.433980e+00	0	0	0	0	0	0	0	0	0	
4	0.496112287	0.21292703	1.596882379	1.1493349393	0.32470731	0.23584767	7.029506e-01	0	0	0	0	0	0	0	0	0	
5	0.507047967	0.86070254	1.855485121	0.1902402580	0.76052331	1.37042337	3.937165e-01	0	0	0	0	0	0	0	0	0	
6	0.614471770	1.73741538	0.785688416	1.2362947004	1.16360161	0.11555623	1.203884e+00	0	0	0	0	0	0	0	0	0	
7	1.780243342	0.42428118	1.388570518	1.9693660245	0.23897171	0.95730139	1.303720e+00	0	0	0	0	0	0	0	0	0	
8	1.029518470	0.50926656	1.694678480	1.2222794807	0.25396687	0.13384618	3.427675e-01	0	0	0	0	0	0	0	0	0	
9	0.115002618	1.41163396	1.183069151	1.9071543433	0.95305978	1.40096111	1.476883e+00	0	0	0	0	0	0	0	0	0	
10	1.258919388	1.91082578	1.887191141	0.0657423907	0.52110975	1.16893700	1.163168e-01	0	0	0	0	0	0	0	0	0	
11	1.614333108	0.22787357	1.913069213	0.3095931406	0.55639822	0.86241512	3.748554e-01	0	0	0	0	0	0	0	0	0	
12	1.627015516	1.24472618	1.572229500	1.2687706053	0.36329987	1.07264238	6.025013e-01	0	0	0	0	0	0	0	0	0	
13	1.485170399	0.33313672	0.365931344	1.8177524737	1.12793648	0.30396077	3.692913e-01	0	0	0	0	0	0	0	0	0	
14	0.807638419	0.50577310	1.213069834	0.8890889486	0.12735079	0.95585061	1.329553e+00	0	0	0	0	0	0	0	0	0	
15	0.370517541	1.96408859	0.389876425	1.7084991587	0.04518211	0.19610442	7.537227e-01	0	0	0	0	0	0	0	0	0	
16	1.657293523	0.62409119	1.154922815	0.0045116921	1.12470276	1.38274050	6.279013e-02	0	0	0	0	0	0	0	0	0	
17	0.713422698	1.75169965	1.912307606	0.7673808799	0.61155676	0.20740435	8.795709e-01	0	0	0	0	0	0	0	0	0	
18	0.045543255	1.63845617	1.013305353	0.1169356090	1.07134475	0.47429784	6.968484e-01	0	0	0	0	0	0	0	0	0	
19	0.246789559	1.25967272	1.184112221	0.4350968255	0.50306712	0.48101468	6.594852e-01	0	0	0	0	0	0	0	0	0	
20	0.295019133	0.71495005	1.767407785	0.7342095950	1.04511899	0.46121497	1.113548e+00	0	0	0	0	0	0	0	0	0	
21	1.654594786	1.68203332	1.027544087	1.4098416976	0.27701790	0.68011379	4.865115e-01	0	0	0	0	0	0	0	0	0	
22	0.199565801	0.41024527	0.532681828	0.5933164869	0.33372035	1.02014015	2.264186e-01	0	0	0	0	0	0	0	0	0	

Figure 80 Left table of production

<u>*Step 3*</u>

After getting those tables, we need to determine the priority of each option.

Now because we changed the parameters, the new formula to judge the threshold of extending work is:

left*[i,j]=(300+Ymonth*mj*3000+Yyear*50000+Ytotal*300000)/(10*40*0.5hj)

Then we can get the threshold left*[i,j]:

	M1-4	M5	M6-7	M8-10	M11-14	M15-19	M20-25
daily	0.3	0.75	0.75	1.5	0.75	100	1.5
month	3.3	11.625	30.75	46.5	23.25	100	91.5

Figure 81 Threshold for MyPal products

Notice that same as task 3, if Ymonth=1, the thresholds of extending work(in the second row in the above table) are all larger than 2, which means for all products if base[i,j]+1 is larger than MaxMonth[i,j], extending work is cheaper, let alone MaxYear or MaxTotal.

Finally, the priority for each option is the same as task 3:
change pace> extend working > changeover within group/ outside group > add another cell

<u>*Step 4*</u>

Changing pace as shown in the table below, totally there are 461 changes (the first row is the product need to change pace, the second row is the time).

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	changepace																						
2	Group1	5	5	7	7	7	5	5	5	5	6	6	5	5	7	7	7	7	7	5	5	5	6
3	Time	8	9	12	15	16	22	27	28	29	34	35	44	51	61	62	64	75	76	84	86	89	91
4																							
5																							

Figure 82 Table of changing pace

For extending work, totally there are 27012.46 hours needed to be extended.

1	0.000000000	0.00000000	0.00000000	0.000000000	4.547520	1.37999208	0.00000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0.000000000	0.00000000	0.00000000	0.397401431	3.492077	3.49675590	0.00000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0.000000000	0.00000000	0.00000000	0.000000000	5.288968	3.83955985	0.00000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0.000000000	1.06463516	0.00000000	0.000000000	0.000000	0.00000000	5.28534290	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0.000000000	0.00000000	0.00000000	0.951201290	0.000000	0.00000000	0.00000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0.000000000	0.00000000	0.00000000	0.000000000	0.000000	4.62824234	0.00000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0.000000000	0.00000000	0.00000000	0.000000000	5.556178	0.00000000	2.28360648	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0.000000000	0.00000000	0.00000000	0.000000000	0.000000	0.00000000	0.00000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0.575013090	7.05816978	0.00000000	0.000000000	0.000000	3.01474522	0.00000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0.000000000	0.00000000	0.00000000	0.328711953	3.918118	0.00000000	0.00000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0.000000000	1.13936783	0.00000000	0.000000000	0.000000	0.00000000	2.81846156	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0.000000000	0.00000000	0.00000000	0.000000000	0.000000	0.54618332	4.53008495	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0.000000000	0.00000000	0.00000000	0.000000000	0.000000	0.00000000	0.00000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0.000000000	0.00000000	0.00000000	0.000000000	0.000000	3.42744819	0.00000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0.000000000	0.00000000	0.00000000	0.000000000	0.000000	5.23386784	1.90768920	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0.000000000	0.00000000	0.00000000	0.022558461	0.000000	2.87774813	4.23150473	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0.000000000	0.00000000	0.00000000	0.000000000	0.000000	5.31882969	0.00000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0.227716277	0.00000000	0.00000000	0.584678045	3.844697	0.00000000	0.00000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	1.233947793	0.00000000	0.00000000	0.000000000	0.000000	0.00000000	4.95853543	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	1.475095666	0.00000000	0.00000000	0.000000000	4.549767	3.46778173	0.00000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0.000000000	0.00000000	0.00000000	0.000000000	4.564044	0.00000000	0.00000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0.997829007	0.00000000	0.00000000	0.000000000	0.000000	3.91082821	0.00000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 83 Table of extending work

There are 1127 times of changeover within group (the first 4 rows are types of product need to changeover; the fifth row is the time):

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	wtingrp																						
2	Group1	1	2	1	1	1	2	1	1	1	1	2	1	2	2	2	2	2	1	1	3	3	3
3	Group2	3	4	4	2	3	3	2	2	2	3	3	4	4	4	3	3	3	2	3	4	4	4
4	Group3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	Group4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	Time	2	3	4	5	6	7	8	13	14	15	16	17	19	20	22	23	24	25	26	27	28	29
7																							
8																							
9																							

Figure 84 Table of changeover within group

There are 229 times of changeover from outside group (the cell changed from product in row 1 to product in row 2, the third row is the time):

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	woutgrp																						
2	Group1	1	5	1	3	1	1	1	1	5	5	1	2	2	2	4	1	1	5	1	5	5	5
3	Group2	5	1	5	5	5	5	5	5	2	2	5	5	5	5	5	5	5	1	5	2	2	2
4	Time	12	22	26	28	54	61	75	82	84	97	103	131	152	159	166	173	194	195	208	210	215	218
5																							
6																							

Figure 85 Table of changeover from outside group

<u>*Step 5*</u>

Test if wok policy (every worker should work at least 1500 hours per year).
And the error with lower bound is less than 6.14%

Then, we get the solution (base20 means the cells needed in 20min pace, base30 means the cells needed in 30min pace and base40 means cells in 40 min pace, and base means the sum of base20, base30 and base40):

	MyPal1	MyPal2	MyPal3	MyPal4	MyPal5	MyPal6	MyPal7	MyPal8	MyPal9	MyPal10	MyPal11	MyPal12	MyPal13	MyPal14	MyPal15	MyPal16	MyPal17
1	268	90	70	142	0	122	121	0	0	0	0	0	0	0	0	0	0
2	356	108	96	182	0	178	185	0	0	0	0	0	0	0	0	0	0
3	300	95	81	136	0	143	150	0	0	0	0	0	0	0	0	0	0
4	79	22	19	43	1	35	39	0	0	0	0	0	0	0	0	0	0
5	101	31	26	51	0	45	47	0	0	0	0	0	0	0	0	0	0
6	24	51	38	62	0	65	60	0	0	0	0	0	0	0	0	0	0
7	228	65	61	109	0	117	107	0	0	0	0	0	0	0	0	0	0
8	267	76	76	136	1	121	128	0	0	0	0	0	0	0	0	0	0
9	344	113	93	179	1	170	165	0	0	0	0	0	0	0	0	0	0
10	269	96	86	153	0	147	137	0	0	0	0	0	0	0	0	0	0
11	75	23	18	37	1	33	33	0	0	0	0	0	0	0	0	0	0
12	98	29	23	48	1	50	51	0	0	0	0	0	0	0	0	0	0
13	20	44	37	70	0	58	56	0	0	0	0	0	0	0	0	0	0
14	212	72	61	109	0	121	111	0	0	0	0	0	0	0	0	0	0
15	266	84	72	125	1	125	118	0	0	0	0	0	0	0	0	0	0
16	364	108	93	190	1	188	197	0	0	0	0	0	0	0	0	0	0
17	270	92	74	145	1	155	155	0	0	0	0	0	0	0	0	0	0
18	73	23	20	41	0	36	33	0	0	0	0	0	0	0	0	0	0
19	93	31	25	47	0	56	48	0	0	0	0	0	0	0	0	0	0
20	25	49	37	71	0	57	57	0	0	0	0	0	0	0	0	0	0
21	232	71	59	111	0	119	104	0	0	0	0	0	0	0	0	0	0
22	274	84	63	122	1	133	136	0	0	0	0	0	0	0	0	0	0

Figure 86 Table of base20 (the number of cells needed in 20min pace for each product at each time t)

Filter

	MyPal1	MyPal2	MyPal3	MyPal4	MyPal5	MyPal6	MyPal7	MyPal8	MyPal9	MyPal10	MyPal11	MyPal12	MyPal13	MyPal14	MyPal15	MyPal16	MyPal17
1	1	0	0	0	115	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	164	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	138	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	33	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	47	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	1	72	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	1	130	1	0	0	0	0	0	0	0	0	0	0	0
9	0	0	1	0	171	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	150	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0
12	0	1	0	1	50	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	69	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	1	0	105	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	124	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	153	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	129	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	32	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	1	0	46	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	68	0	1	0	0	0	0	0	0	0	0	0	0
21	0	0	1	0	99	1	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	112	0	1	0	0	0	0	0	0	0	0	0	0

Figure 87 Table of base30 (the number of cells needed in 30min pace for each product at each time t)

Filter

	MyPal1	MyPal2	MyPal3	MyPal4	MyPal5	MyPal6	MyPal7	MyPal8	MyPal9	MyPal10	MyPal11	MyPal12	MyPal13	MyPal14	MyPal15	MyPal16	MyPal17
1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
14	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 88 Table of base40 (the number of cells needed in 40min pace for each product at each time t)

	MyPal1	MyPal2	MyPal3	MyPal4	MyPal5	MyPal6	MyPal7	MyPal8	MyPal9	MyPal10	MyPal11	MyPal12	MyPal13	MyPal14	MyPal15	MyPal16	MyPal17	MyF
1	269	90	70	143	115	122	121	0	0	0	0	0	0	0	0	0	0	
2	356	108	96	182	164	178	185	0	0	0	0	0	0	0	0	0	0	
3	300	95	81	136	138	143	150	0	0	0	0	0	0	0	0	0	0	
4	79	22	19	43	34	35	39	0	0	0	0	0	0	0	0	0	0	
5	101	31	26	51	47	45	48	0	0	0	0	0	0	0	0	0	0	
6	24	51	38	63	72	65	60	0	0	0	0	0	0	0	0	0	0	
7	228	65	61	109	100	117	107	0	0	0	0	0	0	0	0	0	0	
8	267	76	76	137	131	122	129	0	0	0	0	0	0	0	0	0	0	
9	344	113	94	179	172	170	165	0	0	0	0	0	0	0	0	0	0	
10	269	96	86	153	150	147	137	0	0	0	0	0	0	0	0	0	0	
11	75	23	18	37	31	33	33	0	0	0	0	0	0	0	0	0	0	
12	98	30	23	49	51	50	51	0	0	0	0	0	0	0	0	0	0	
13	20	44	37	70	70	58	51	0	0	0	0	0	0	0	0	0	0	
14	212	72	62	110	105	121	111	0	0	0	0	0	0	0	0	0	0	
15	266	84	72	125	125	125	118	0	0	0	0	0	0	0	0	0	0	
16	364	108	93	190	154	188	197	0	0	0	0	0	0	0	0	0	0	
17	270	92	74	145	130	155	155	0	0	0	0	0	0	0	0	0	0	
18	73	23	20	41	32	36	33	0	0	0	0	0	0	0	0	0	0	
19	93	31	26	47	47	56	48	0	0	0	0	0	0	0	0	0	0	
20	25	49	37	71	68	57	58	0	0	0	0	0	0	0	0	0	0	
21	232	71	60	111	99	120	104	0	0	0	0	0	0	0	0	0	0	
22	274	84	63	122	113	133	137	0	0	0	0	0	0	0	0	0	0	

Figure 89 Table of base (the total number of cells needed for each product at each time t)

4.3 Validation

Based on the two feasible solutions we have, we generated 6 scenarios of demand during the first 9 days of MyPal 1 with requirement for OTD = 1 day.

Below are the inventory levels for first 7 days for CDC and RFCs. We are showing results of 3 trails. Since we don't hit 0 inventory level in any of the RFCs and CDC on a given day, we can say that we are protected aginsted the market demand.

For Trail 1

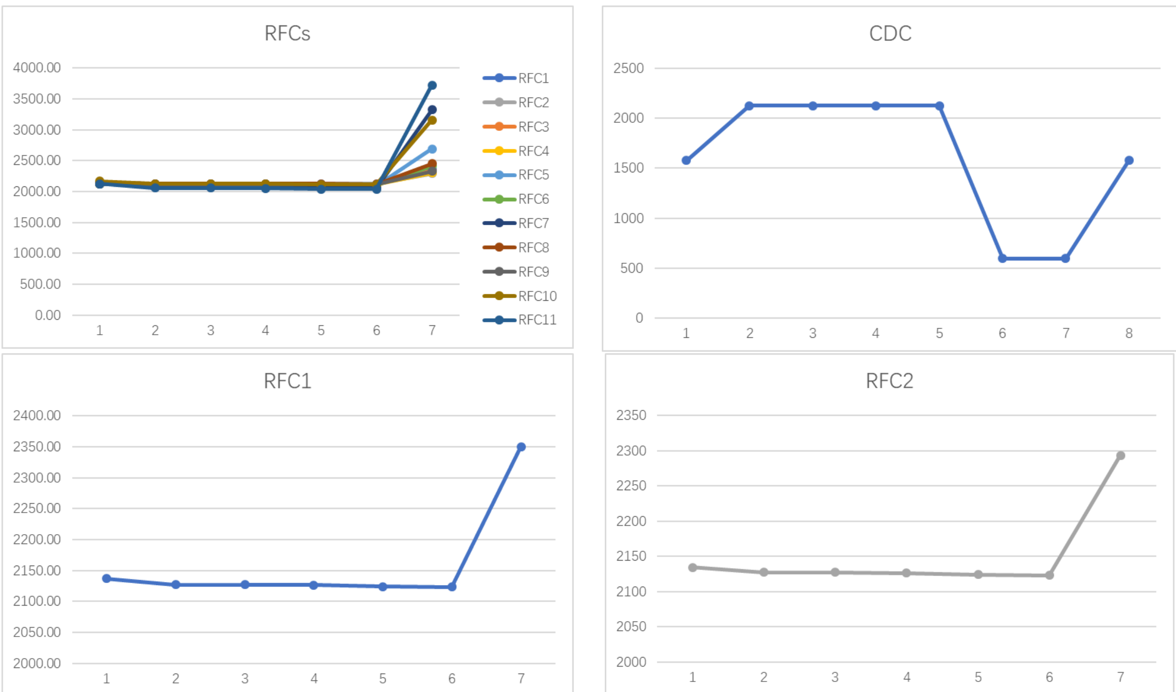


Figure 90 RFCs and CDC Stock Level for First 7 Days for Trail 1

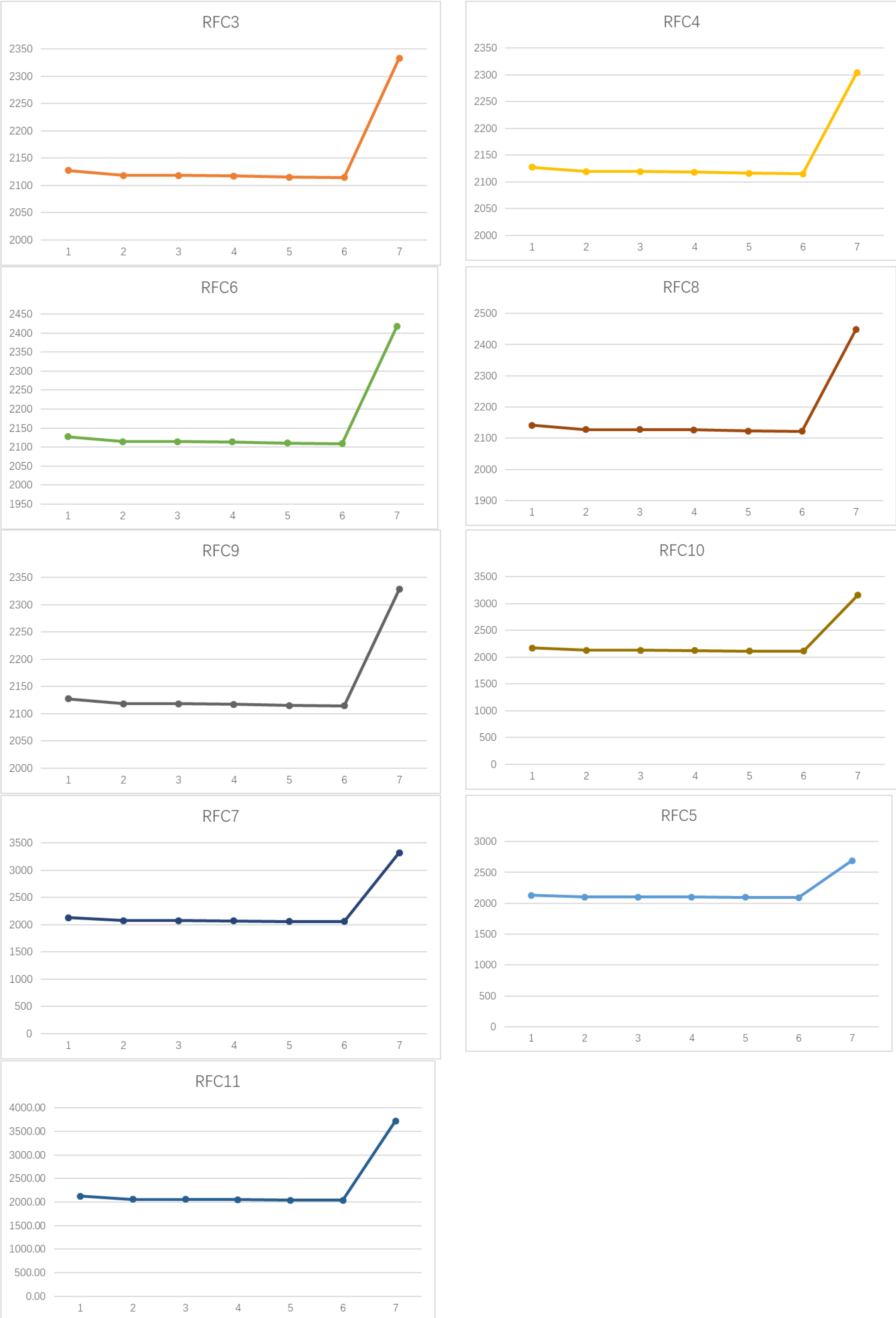


Figure 91 Individual RFC Stock for First 7 Days for Trail 1

For Trail 2

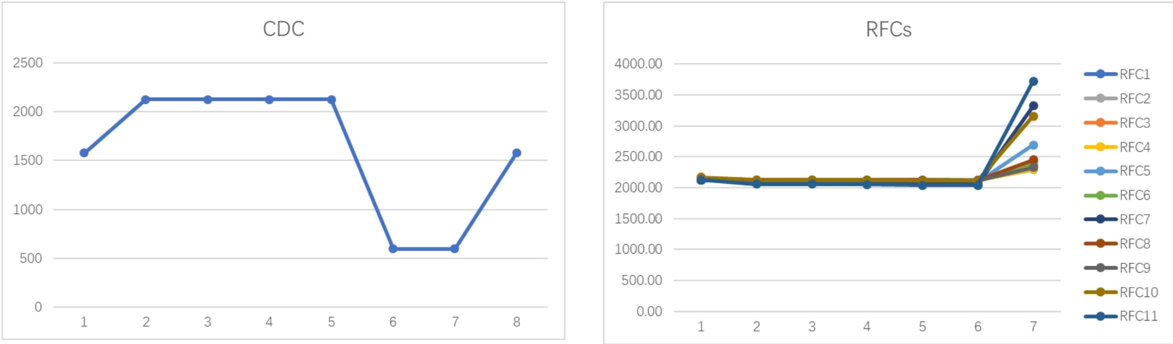


Figure 92 CDC & RFCs Stock for Trail 2 for First 7 Days

Figure 93 Individual RFCs Stock for Trail 2 for first 7 Days

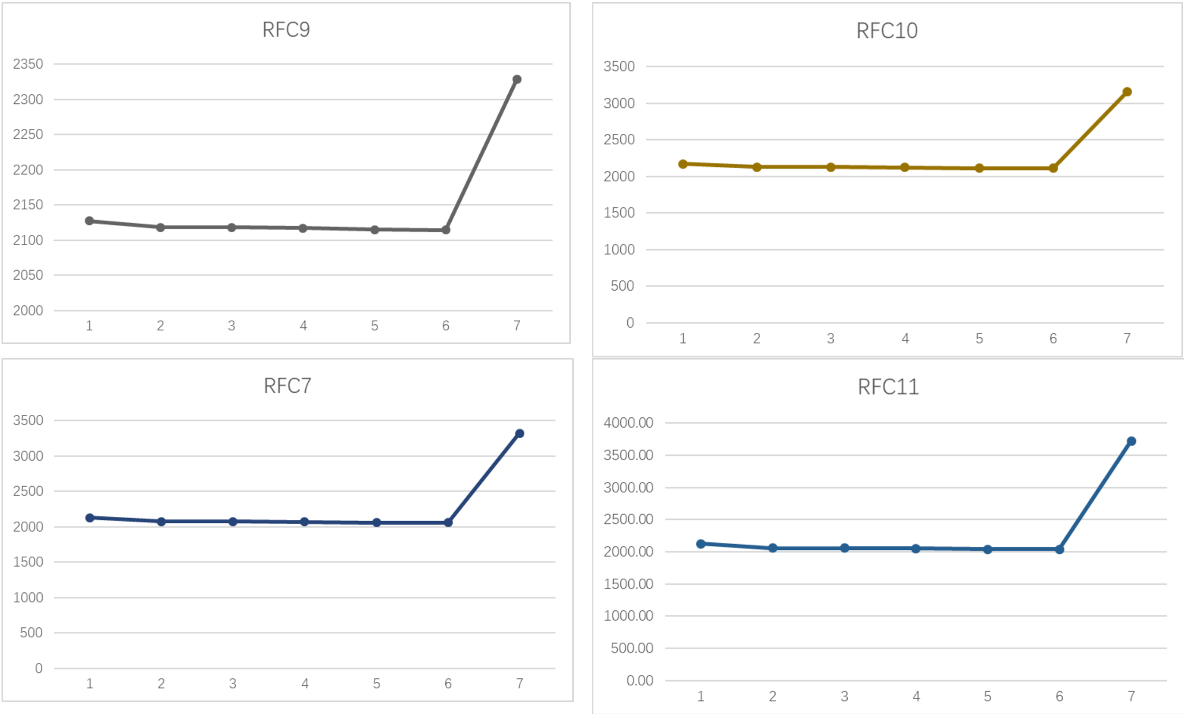


Figure 94 Individual RFC Stock for Trail 2 for First 7 Days

For Trail 3

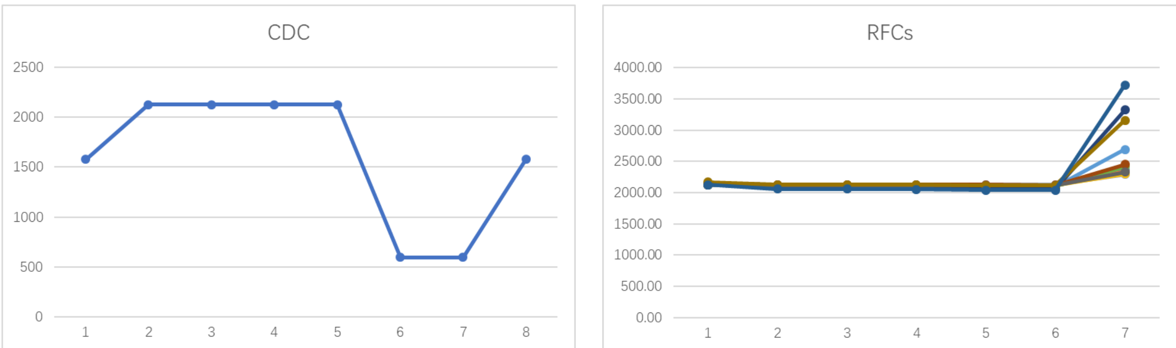


Figure 95 CDC and RFCs stock for Trial 3 for First 7 Days

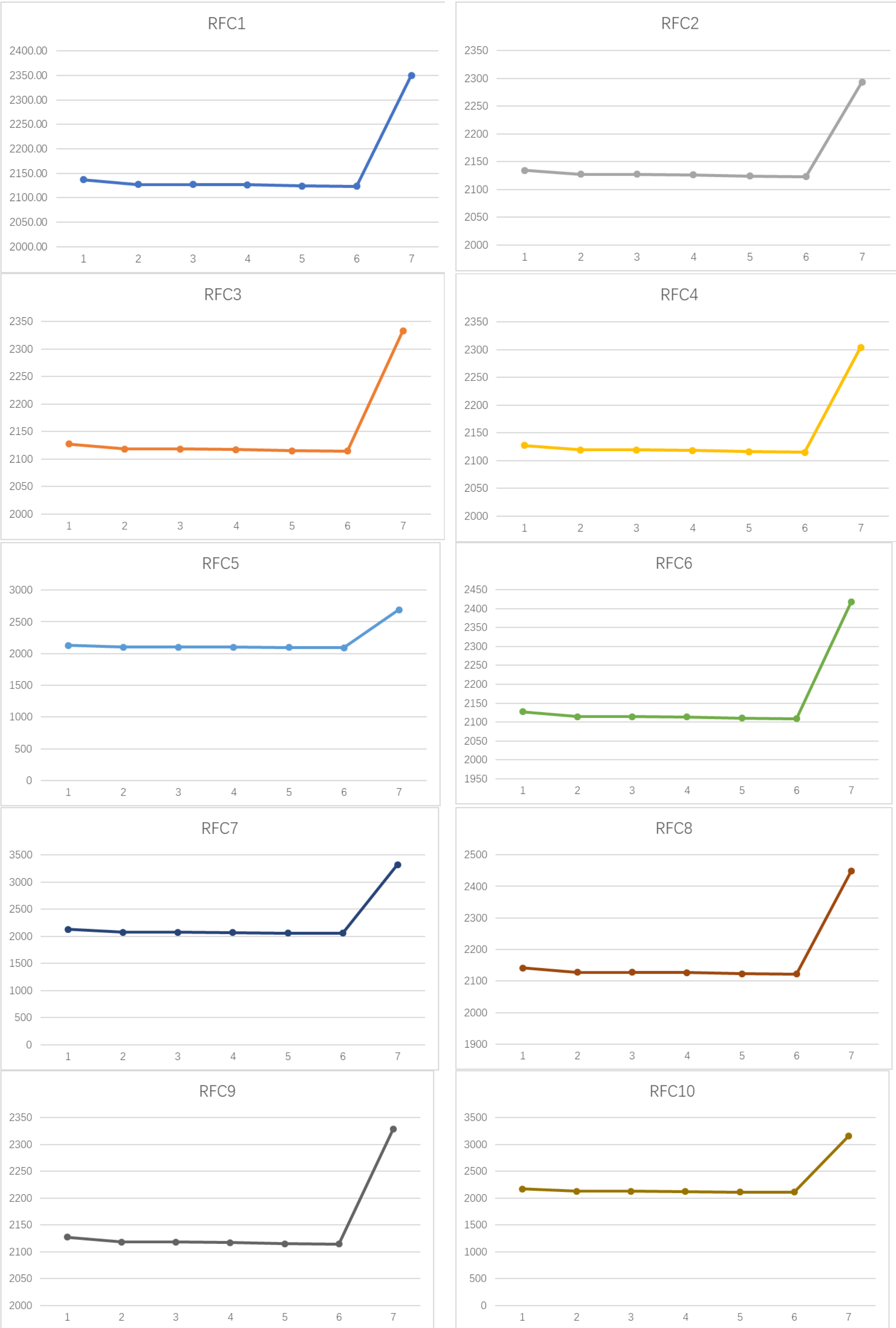


Figure 96 Individual RFC Stock for Trail 3 for First 7 Days

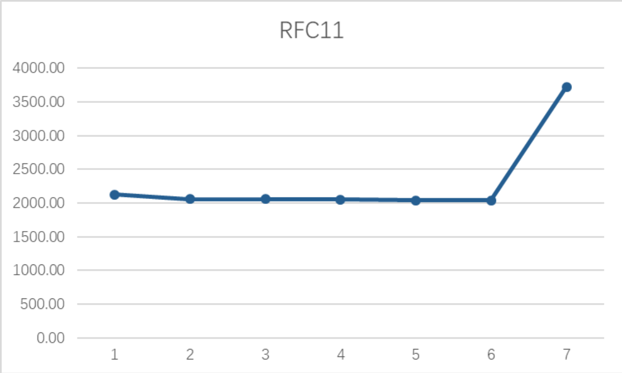


Figure 97 Stock Level for RFC11 for Trail 3 for First 7 Days

As we can see that in all the three trails, in all RFCs and in CDC, our stock never hits zero, so we are protected against these 3 trials and thus, we validate the results of Part 1 & Part 2.

Cost Comparison

Now, we will compare the total cost from the results of part 1 & part 2 and compare it with simulated costs. *X-axis shows various scenarios.*

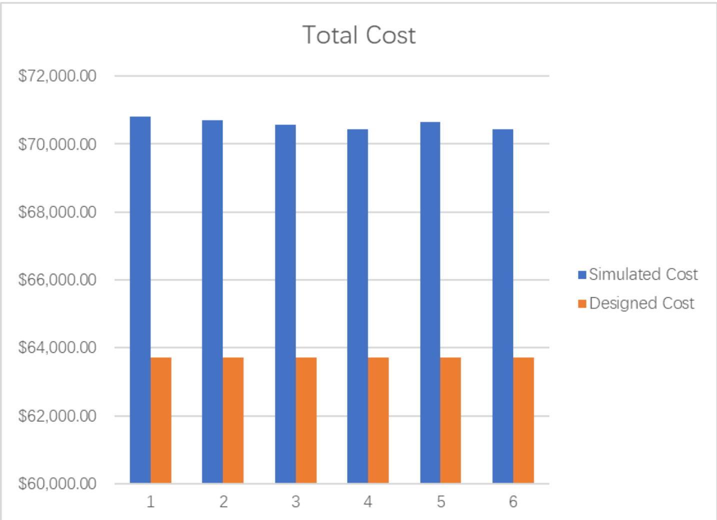


Figure 98 Total Cost Comparison B/T Simulated and Designed Cost

To facilitate further analysis, we will look into the individual cost components.

Figure 99 Comparison of the Inventory Cost

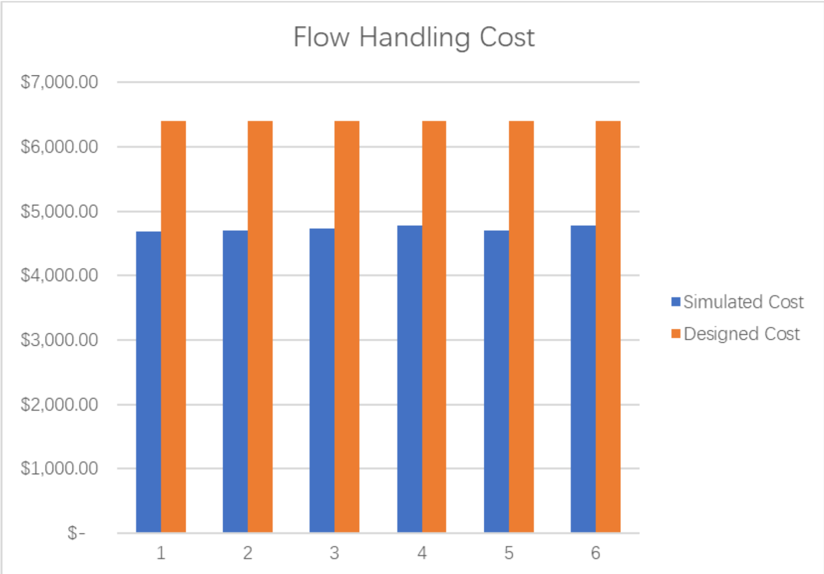


Figure 100 Comparison of the Flow Handling Cost

A *critical insight* from these 6 scenario runs is that we might have overbuild the capacity.

The reason for this is that we see an inventory buildup in the simulation scenarios and hence the inventory costs are higher in Figure 89.

On the other hand, since the actual demand in 6 scenarios turned out to be low, the flow handing cost is lower than the designed cost.

Below, we see the decomposition of the costs

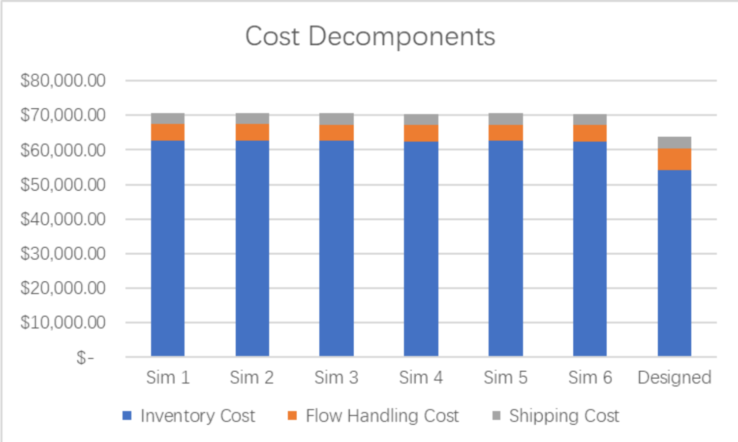


Figure 101 Cost Components for 6 Simulated Scenarios and Designed Capacity

From the figure above, we see that the total costs are pretty much the same across 6 simulation runs and about 5K dollars higher than the designed cost.

5 Task 5

In task 5, WorkPal products and MyPal products need to be taken into consideration together. It is possible that if MyPal and WorkPal are operated together, setting up a factory in a state or megaregion could be cheaper. Miami/Florida can serve as a good example.

5.1 Assumption

1. We only consider the production cost and transportation cost, and only consider demand in Miami/Florida megaregion/state, and all WorkPal demand in Florida state will be transported to Miami.
2. Shipment: Only full loaded trucks are used. For MyPal products, it is the same as in task 4, one truck can load 240 units of MyPal; for WorkPal products, we searched online and knew that the inner space of 53-feet truck is 16m*2.59m*2.79m. The size of WorkPal
3. Working cells in WorkPal can be transferred to MyPal at day 0, which means from day 1 we can use cells in WorkPal to process MyPal products.
4. The sum of delivery time from sandy spring to Miami and production time is one day. For those demand whose OTD is one day, we move this part of production to one day before order.

Then, from task1 and 2, we can get the OTS for WorkPal in Florida state (0.051 of total demand) and OTD for MyPal in Florida megaregion (0.035 of total demand).

Notice that when it goes down to state/megaregion level, the safety stock to guarantee 99% service level will chang, because the variance of WorkPal demand in Miami is 0.051 of the variance of total demand, the standard variance will be 0.051 of standard variance of total demand, and similarly, the standard variance of MyPal will be 0.035 of standard variance of total demand.

Then, the formula we used here is:

$$D_{l,s} = \frac{1}{l}\left(d * \frac{l}{b} + z_s * \sqrt{\sigma_b^2 * \frac{1}{b}}\right)$$

The meaning of notations is the same as in task 2

5.2 Independent Operations for MyPal & WorkPal

5.2.1 Product in Sandy Springs

OTS for WP

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	WorkPal1	WorkPal2	WorkPal3	WorkPal4	WorkPal5	WorkPal6	WorkPal7	WorkPal8	WorkPal9	WorkPal10	WorkPal11	WorkPal12	WorkPal13	WorkPal14	WorkPal15	WorkPal16	WorkPal17	WorkPal18	WorkPal19	WorkPal20	WorkPal21	WorkPal22	WorkPal23
2	9.07953	0	0	1.4331	0	3.06714	5.01279	6.79932	6.19089	1.99155	6.80595	6.36276	2.86416	3.85458	4.0596	2.93403	3.11457	2.03694	1.70748	3.68628	0	0	0
3	9.27945	0	0	1.44687	0	2.99319	4.80267	6.66978	6.81666	2.02776	5.98332	5.70537	2.77185	4.03971	4.31817	2.96973	3.31755	2.07162	1.58712	3.65466	0	0	0
4	8.97753	0	0	1.38414	0	2.92281	5.29329	7.11807	6.56829	2.15883	6.24291	6.05472	2.71983	4.07082	4.28604	3.16608	3.22167	2.09661	1.57284	3.65874	0	0	0
5	9.20193	0	0	1.45758	0	3.03807	5.10561	6.82584	6.34185	2.05479	6.01341	6.0639	2.8254	3.92037	4.06827	3.34713	3.1059	1.96452	1.61211	3.52818	0	0	0
6	9.06168	0	0	1.40607	0	3.23187	5.50239	7.2114	6.34134	2.09253	6.67641	6.26331	2.88405	3.79338	4.34622	3.09009	3.26196	1.97574	1.68147	3.55317	0	0	0
7	9.59973	0	0	1.47339	0	3.09315	5.55747	6.48414	6.35613	2.18484	6.34848	5.93232	2.79531	3.97902	4.27686	2.97534	3.23646	2.05428	1.74675	3.69546	0	0	0
8	9.68643	0	0	1.46574	0	3.45831	5.03778	6.57237	6.82584	2.12007	6.018	5.95272	2.75808	4.01778	4.26054	3.18189	3.23238	2.00532	1.60752	3.75513	0	0	0
9	10.19643	0	0	1.39383	0	3.29562	5.07552	7.1145	6.41682	2.0859	6.46221	5.76861	2.78817	3.99993	4.17486	3.24921	3.26196	1.99308	1.65189	3.55623	0	0	0
10	10.25763	0	0	1.38312	0	2.80959	4.96383	6.57951	6.57951	2.20932	6.81615	5.68803	2.78613	4.04481	4.4064	2.94117	3.20076	2.06958	1.72482	3.46953	0	0	0
11	9.46152	0	0	1.32651	0	2.92638	4.78329	6.61929	6.66519	2.07162	6.44589	5.82675	2.69892	3.96321	4.18353	3.23697	3.1518	2.21799	1.73655	3.76941	0	0	0
12	9.09075	0	0	1.3362	0	2.95851	5.01024	6.24801	6.4617	2.05887	6.2322	5.87469	2.80092	3.81837	4.15599	3.33285	3.18699	2.14047	1.63812	3.69699	0	0	0
13	9.29628	0	0	1.35762	0	3.18189	5.0388	6.71364	6.40866	2.1522	6.11439	5.58246	2.79735	4.16466	4.20393	3.31143	3.25227	2.03031	1.64985	3.75972	0	0	0
14	9.55128	0	0	1.41678	0	2.77185	5.34837	6.5943	6.93345	2.09661	6.75393	5.87316	2.82132	3.98565	4.1769	3.20841	3.25125	2.06703	1.65648	3.6159	0	0	0
15	8.61951	0	0	1.53	0	3.1773	4.85265	6.86817	6.45864	2.06091	6.09399	5.93181	2.77389	4.03869	4.28655	3.21861	3.18189	2.13843	1.63761	3.55011	0	0	0
16	9.55587	0	0	1.35354	0	2.87691	4.87968	6.27147	6.15978	2.07213	6.29697	6.07206	2.66985	3.91221	4.22127	3.17475	3.25074	2.0859	1.72686	3.56337	0	0	0
17	9.5625	0	0	1.49685	0	2.81163	4.88223	6.25413	6.60195	2.32917	6.2985	5.865	2.85243	3.99381	4.24728	3.18495	3.19209	2.04306	1.75083	3.70311	0	0	0
18	9.52986	0	0	1.48665	0	3.01614	5.37591	6.81309	6.56523	2.10171	6.24954	6.25974	2.7744	4.10091	4.22076	3.34866	3.24921	2.13486	1.70748	3.8556	0	0	0
19	10.20969	0	0	1.44483	0	3.35733	4.80369	7.23384	6.83247	2.14353	6.47292	6.19446	3.03195	3.94077	4.34469	3.25788	3.2844	1.86966	1.75236	3.65568	0	0	0
20	8.81331	0	0	1.35609	0	3.09672	5.13366	7.00077	6.09807	2.24451	6.23118	5.83185	2.79735	3.92343	4.36713	3.06102	3.23391	1.96605	1.55448	3.59295	0	0	0
21	9.81954	0	0	1.4484	0	2.90598	5.23005	6.49944	6.5535	2.00022	6.45915	6.19089	2.90088	3.86121	4.42425	3.13395	3.25482	2.15322	1.72686	3.6924	0	0	0
22	9.6492	0	0	1.42851	0	3.21045	4.9623	6.6555	6.31176	2.14914	6.5382	5.96802	2.89884	4.10499	4.17792	3.22269	3.23799	2.03898	1.73451	3.66027	0	0	0
23	9.66348	0	0	1.33059	0	2.81163	4.91334	7.48221	6.79116	2.08896	6.27402	6.08787	2.8305	3.81123	4.39467	3.19209	3.3456	2.20677	1.67994	3.66231	0	0	0
24	9.99549	0	0	1.41219	0	2.86824	4.67823	6.43212	6.49995	2.01144	6.7728	5.85327	2.83866	4.07439	4.26309	3.28644	3.2538	2.14965	1.52235	3.73218	0	0	0
25	9.57474	0	0	1.48002	0	2.9019	4.97352	7.36848	6.59481	2.01297	6.48669	5.68599	2.76573	4.13763	4.39059	3.17628	3.29103	2.14761	1.68912	3.71637	0	0	0
26	9.53598	0	0	1.24287	0	2.90496	5.00157	6.35001	6.71517	2.02317	6.61419	6.2067	2.90241	3.92802	4.35948	3.36192	3.18495	2.06754	1.73349	3.89946	0	0	0
27	9.93123	0	0	1.4586	0	3.11865	4.75014	6.71568	5.94099	2.24349	6.16947	6.05574	2.9427	4.16976	4.2228	3.20229	3.40986	2.18127	1.63455	3.89028	0	0	0
28	9.8634	0	0	1.40454	0	3.12324	5.46516	6.7218	6.11796	2.00022	5.89866	6.05319	2.83101	4.17996	4.34673	3.05796	3.25176	2.10069	1.64577	3.59856	0	0	0
29	9.78792	0	0	1.5045	0	2.96208	4.86387	7.33839	6.58257	1.85181	6.76872	5.76606	2.84988	3.98004	4.20138	3.17322	3.30939	2.12364	1.7748	3.62355	0	0	0

Figure 102 OTS for WP

Production resource planning for WorkPal: (We used the algorithm in task3.)

	WorkPal1	WorkPal2	WorkPal3	WorkPal4	WorkPal5	WorkPal6	WorkPal7	WorkPal8	WorkPal9	WorkPal10	WorkPal11	WorkPal12	WorkPal13	WorkPal14	WorkPal15
1	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
2	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
3	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
4	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
5	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
6	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
7	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
8	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
9	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
10	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
11	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
12	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
13	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
14	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
15	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
16	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
17	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
18	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
19	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
20	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
21	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
22	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0

Figure 103 Production resource planning for WorkPal

Totally 24 cells are used.

Since the demand is so low, no changing pace and changeover from outside group, only 37 times of changing within group: (the first 4 rows are those products needed to changeover, the last row is the time)

	wtingrp	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15	V16	V17	V18	V19	V20	V21	V22	V23	V24	V25	V26
1	1	1	8	11	14	16	18	1	8	11	14	16	18	1	8	11	14	16	18	1	8	11	14	16	18	1
2	2	4	9	12	15	17	19	4	9	12	15	17	19	4	9	12	15	17	19	4	9	12	15	17	19	4
3	3	0	10	13	0	0	20	0	10	13	0	0	20	0	10	13	0	0	20	0	10	13	0	0	20	0
4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	5	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3	3	3	3	4	4	4	4	4	4	5

Figure 104 Changeovers

Total production cost for WorkPal: $19,724,833, and the work policy test was passed.

5.2.1.1 Transportation fee:

Since we assume that only full loaded trucks are used, the total number of trucks needed for 5 years is ceiling(sum(demand)/117) = 2732, then the total cost for transportation is 2732*679(distance from Sandy Spring to Miami)*2 = 3710056

Then from assumption 1, we just consider production and transportation cost in task5, so the total cost=Total production cost + Transportation fee = $23434889

OTD for MyPal:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1		MyPal1	MyPal2	MyPal3	MyPal4	MyPal5	MyPal6	MyPal7	MyPal8	MyPal9	MyPal10	MyPal11	MyPal12	MyPal13	MyPal14	MyPal15	MyPal16	MyPal17	MyPal18	MyPal19	MyPal20	MyPal21	MyPal22
2	1/1/2019	227.1448	75.85655	59.1486	120.4441	64.9215	103.2385	102.1416	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1/2/2019	300.4008	91.21945	81.3099	153.9293	92.4154	150.71	156.3184	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1/3/2019	253.6247	79.93615	68.48695	115.1931	77.89635	121.134	126.8092	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	1/4/2019	66.16505	18.6928	15.8956	36.8459	19.16285	29.27225	33.27485	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	1/5/2019	84.77245	26.5769	21.924	43.20505	26.32315	37.99635	40.12015	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	1/6/2019	19.70815	43.0136	32.46425	52.9487	40.44565	55.223	50.60965	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	1/7/2019	192.6995	54.29655	52.1675	92.15535	56.54355	98.7035	90.60555	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	1/8/2019	225.3598	64.47945	64.13505	115.5158	73.6729	102.7947	108.5907	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	1/9/2019	290.9284	96.14745	79.1392	151.3197	96.79915	143.9183	139.5111	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	1/10/2019	227.1479	81.13805	72.67225	129.4017	84.567	124.1604	115.471	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	1/11/2019	63.2555	19.5447	15.1837	30.5718	17.35825	27.6346	28.06265	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	1/12/2019	83.5548	25.0481	19.2675	41.1243	28.69195	42.30975	43.37935	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	1/13/2019	16.69395	37.3464	31.4412	59.1136	39.1622	48.9608	47.72005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	1/14/2019	178.759	61.09565	52.0933	92.5442	59.0331	102.508	93.7874	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	1/15/2019	224.2356	71.0136	61.04665	105.5744	70.4137	105.9919	99.8858	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	1/16/2019	307.6465	90.741	79.1273	160.6623	86.72475	159.131	166.8174	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	1/17/2019	227.7629	77.68845	62.5359	122.9337	73.1899	131.3641	131.0141	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	1/18/2019	61.74665	19.2955	16.49445	34.71825	18.21015	30.00725	27.5646	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	1/19/2019	78.74335	25.9	21.64015	39.92625	26.2143	47.1331	40.8667	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	1/20/2019	21.26425	40.89015	31.18815	60.34665	38.493	48.3931	48.6689	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	1/21/2019	196.0287	59.9018	50.3237	93.60995	55.92545	101.1231	87.7233	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	1/22/2019	231.7735	70.35665	53.4968	103.4117	63.55965	112.6822	115.5175	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	1/23/2019	315.3833	94.2417	84.9114	144.8899	93.5746	152.04	154.1169	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	1/24/2019	217.0938	72.9232	67.0712	122.1399	78.79095	122.4297	111.7872	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	1/25/2019	64.48435	17.06285	15.57255	32.5633	17.8871	29.05035	29.8711	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	1/26/2019	90.6766	27.9615	20.4694	49.588	26.2843	36.53755	39.82825	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	1/27/2019	17.6505	39.7852	31.47235	61.9801	42.2464	47.9612	50.8046	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	1/28/2019	191.9911	58.30685	56.0567	92.6961	61.85655	97.9258	95.01625	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 105 OTD for MP

By assumption 5, we can move the production of one-day OTD demand to one day before order.

For example, during year 1, the demand of one-day OTD of MyPal is 10%.

We can have the following algorithm.

```
For i from 1 to 364, j from 1 to 25
    cp[i,j]=cp[i,j]+10%*cp[(i+1),j]
End
```

Then, we can get the capacity requirement for MyPal:

	MyPal1	MyPal2	MyPal3	MyPal4	MyPal5	MyPal6	MyPal7	MyPal8	MyPal9	MyPal10	MyPal11	MyPal12	MyPal13	MyPal14	MyPal15	MyPal16	MyPal17
1	18.8038014	6.2796587	4.8965188	9.9707651	5.3744187	8.5464239	8.4556188	0	0	0	0	0	0	0	0	0	0
2	24.8681820	7.5514509	6.7311052	12.7427818	7.6504556	12.4762774	12.9405595	0	0	0	0	0	0	0	0	0	0
3	20.9959002	6.6173816	5.6695786	9.5360656	6.4485201	10.0278732	10.4976893	0	0	0	0	0	0	0	0	0	0
4	5.4773639	1.5474524	1.3158909	3.0502267	1.5863648	2.4232547	2.7546033	0	0	0	0	0	0	0	0	0	0
5	7.0177467	2.2001246	1.8149420	3.5766584	2.1791183	3.1454648	3.3212801	0	0	0	0	0	0	0	0	0	0
6	1.6315065	3.5608095	2.6874991	4.3832703	3.3482261	4.5715445	4.1896359	0	0	0	0	0	0	0	0	0	0
7	15.9523085	4.4948498	4.3186000	7.6289278	4.6808640	8.1710055	7.5006302	0	0	0	0	0	0	0	0	0	0
8	18.6560331	5.3378243	5.3093137	9.5627798	6.0988888	8.5096846	8.9894969	0	0	0	0	0	0	0	0	0	0
9	24.0840251	7.9594072	6.5514074	12.5267504	8.0133571	11.9140336	11.5491909	0	0	0	0	0	0	0	0	0	0
10	18.8040622	6.7168789	6.0160517	10.7123010	7.0007388	10.2784128	9.5590711	0	0	0	0	0	0	0	0	0	0
11	5.2365017	1.6179756	1.2569574	2.5308358	1.4369739	2.2876845	2.3231199	0	0	0	0	0	0	0	0	0	0
12	6.9169455	2.0735654	1.5950280	3.4044070	2.3752155	3.5025425	3.5910875	0	0	0	0	0	0	0	0	0	0
13	1.3819810	3.0916598	2.6028076	4.8936213	3.2419778	4.0531386	3.9504252	0	0	0	0	0	0	0	0	0	0
14	14.7982673	5.0577021	4.3124574	7.6611181	4.8869573	8.4859548	7.7640344	0	0	0	0	0	0	0	0	0	0
15	18.5629681	5.8787431	5.0536457	8.7397975	5.8290814	8.7743637	8.2688803	0	0	0	0	0	0	0	0	0	0
16	25.4680053	7.5118432	6.5504223	13.3001579	7.1793646	13.1733959	13.8096977	0	0	0	0	0	0	0	0	0	0
17	18.8549698	6.4313095	5.1769308	10.1768583	6.0589045	10.8747592	10.8457850	0	0	0	0	0	0	0	0	0	0
18	5.1115940	1.5973460	1.3654657	2.8740927	1.5074971	2.4841004	2.2818897	0	0	0	0	0	0	0	0	0	0
19	6.5186376	2.1440885	1.7914439	3.3052284	2.1701073	3.9018355	3.3830820	0	0	0	0	0	0	0	0	0	0
20	1.7603257	3.3850233	2.5818593	4.9956973	3.1865792	4.0061425	4.0289742	0	0	0	0	0	0	0	0	0	0
21	16.2279108	4.9588712	4.1659640	7.7493445	4.6296956	8.3713040	7.2620279	0	0	0	0	0	0	0	0	0	0
22	19.1869848	5.8243586	4.4286439	8.5607661	5.2616802	9.3282049	9.5629247	0	0	0	0	0	0	0	0	0	0

Figure 106 Capacity Requirement for MP

Then, use the same algorithm in task 4, we can get the production resource planning:

	MyPal1	MyPal2	MyPal3	MyPal4	MyPal5	MyPal6	MyPal7	MyPal8	MyPal9	MyPal10	MyPal11	MyPal12	MyPal13	MyPal14	MyPal15	MyPal16	MyPal17
1	10	3	3	5	4	5	4	0	0	0	0	0	0	0	0	0	0
2	13	4	3	7	6	7	6	0	0	0	0	0	0	0	0	0	0
3	11	3	3	5	5	5	6	0	0	0	0	0	0	0	0	0	0
4	3	1	1	2	1	2	1	0	0	0	0	0	0	0	0	0	0
5	4	1	1	2	2	2	2	0	0	0	0	0	0	0	0	0	0
6	1	2	2	2	3	3	2	0	0	0	0	0	0	0	0	0	0
7	8	3	2	4	4	4	4	0	0	0	0	0	0	0	0	0	0
8	10	3	3	5	5	5	4	0	0	0	0	0	0	0	0	0	0
9	12	4	4	6	6	6	6	0	0	0	0	0	0	0	0	0	0
10	10	3	3	6	5	5	5	0	0	0	0	0	0	0	0	0	0
11	3	1	1	1	1	2	1	0	0	0	0	0	0	0	0	0	0
12	4	1	1	2	2	2	2	0	0	0	0	0	0	0	0	0	0
13	1	2	1	2	3	2	2	0	0	0	0	0	0	0	0	0	0
14	8	2	3	4	4	5	4	0	0	0	0	0	0	0	0	0	0
15	10	3	2	5	5	5	4	0	0	0	0	0	0	0	0	0	0
16	13	4	4	6	6	7	7	0	0	0	0	0	0	0	0	0	0
17	10	3	3	5	5	6	5	0	0	0	0	0	0	0	0	0	0
18	3	1	1	2	1	2	1	0	0	0	0	0	0	0	0	0	0
19	4	1	1	2	2	2	2	0	0	0	0	0	0	0	0	0	0
20	1	1	2	2	3	2	2	0	0	0	0	0	0	0	0	0	0
21	8	3	2	4	4	5	3	0	0	0	0	0	0	0	0	0	0
22	10	3	2	5	4	5	5	0	0	0	0	0	0	0	0	0	0

Figure 107 Production Resource Planning

Totally 283422 cells are needed.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	Changepace																						
2	group1	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
3	Time	2	0	1	9	35	42	44	49	56	61	63	68	70	72	75	77	82	89	91	98	112	120
4																							

Figure 108 Pace change Table

We will change the pace 476 times.

	MyPal1	MyPal2	MyPal3	MyPal4	MyPal5	MyPal6	MyPal7	MyPal8	MyPal9	MyPal10	MyPal11	MyPal12	MyPal13	MyPal14	MyPal15	MyPal16	MyPal17
1	0.00000000	0.00000000	0.00000000	0.0000000	0.000000	0.00000000	0.00000000	0	0	0	0	0	0	0	0	0	0
2	0.00000000	0.00000000	0.00000000	0.0000000	0.000000	0.00000000	0.00000000	0	0	0	0	0	0	0	0	0	0
3	0.00000000	0.00000000	0.00000000	0.0000000	0.000000	0.20957256	0.00000000	0	0	0	0	0	0	0	0	0	0
4	0.00000000	0.00000000	0.00000000	0.0000000	0.000000	0.00000000	0.00000000	0	0	0	0	0	0	0	0	0	0
5	0.00000000	0.00000000	0.00000000	0.0000000	0.000000	0.00000000	0.00000000	0	0	0	0	0	0	0	0	0	0
6	0.00000000	0.00000000	0.00000000	0.0000000	0.000000	0.00000000	0.00000000	0	0	0	0	0	0	0	0	0	0
7	0.00000000	0.00000000	0.00000000	0.0000000	0.000000	1.28575600	0.00000000	0	0	0	0	0	0	0	0	0	0
8	0.00000000	0.00000000	0.00000000	0.0000000	0.000000	0.00000000	0.00000000	0	0	0	0	0	0	0	0	0	0
9	0.42012546	0.00000000	0.00000000	0.0000000	0.000000	0.00000000	0.00000000	0	0	0	0	0	0	0	0	0	0
10	0.00000000	0.00000000	0.08025845	0.0000000	0.000000	2.09332929	0.00000000	0	0	0	0	0	0	0	0	0	0
11	0.00000000	0.00000000	0.00000000	0.0000000	0.000000	0.00000000	0.00000000	0	0	0	0	0	0	0	0	0	0
12	0.00000000	0.00000000	0.00000000	0.0000000	0.000000	0.00000000	0.00000000	0	0	0	0	0	0	0	0	0	0
13	0.00000000	0.00000000	0.00000000	0.0000000	0.000000	0.39953855	0.00000000	0	0	0	0	0	0	0	0	0	0
14	0.00000000	0.00000000	0.00000000	0.0000000	0.000000	0.00000000	0.00000000	0	0	0	0	0	0	0	0	0	0
15	0.00000000	0.00000000	0.00000000	0.0000000	0.000000	0.00000000	2.02165634	0	0	0	0	0	0	0	0	0	0
16	0.00000000	0.00000000	0.00000000	0.0000000	0.000000	0.00000000	0.00000000	0	0	0	0	0	0	0	0	0	0
17	0.00000000	0.00000000	0.00000000	0.8842917	0.000000	0.00000000	0.00000000	0	0	0	0	0	0	0	0	0	0
18	0.00000000	0.00000000	0.00000000	0.0000000	0.000000	0.00000000	0.00000000	0	0	0	0	0	0	0	0	0	0
19	0.00000000	0.00000000	0.00000000	0.0000000	0.000000	0.00000000	0.00000000	0	0	0	0	0	0	0	0	0	0
20	0.00000000	0.00000000	0.00000000	0.0000000	0.000000	0.04618439	0.21785090	0	0	0	0	0	0	0	0	0	0
21	1.13955409	0.00000000	0.00000000	0.0000000	0.000000	0.00000000	0.00000000	0	0	0	0	0	0	0	0	0	0
22	0.00000000	0.00000000	0.00000000	0.0000000	0.000000	0.00000000	0.00000000	0	0	0	0	0	0	0	0	0	0

Figure 109 12240 hours to extend

We will have to extend our operations for 12240 hours

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	WithinGroup																						
2	1	1	6	1	6	1	3	4	2	6	3	1	1	7	1	2	1	1	3	1	6	7	1
3	2	2	7	3	7	2	1	2	4	7	1	2	4	2	4	1	2	3	2	3	7	6	2
4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	Time	1	1	2	2	3	4	5	6	6	7	8	9	10	11	11	12	13	14	15	16	17	17
7																							
8																							

Figure 110 2113 times of changeover within group:

We will have to do changeover 2113 times

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	OutsideGroup																						
2	Group1	2	2	2	1	1	1	1	2	1	1	1	3	1	2	1	5	1	2	1	1	1	5
3	Group2	9	7	9	8	8	7	9	9	7	9	8	6	6	8	6	8	7	5	6	6	7	7
4	Time	743	750	768	775	777	778	782	789	790	801	803	813	820	824	827	831	834	851	862	869	876	883
5																							
6																							

Figure 111 125 times of changeover from outside group

125 times of changeover from outside group

Total production cost: $578,091,438, and the work policy test was passed.

Transportation cost: Similar as WorkPal, the transportation cost is ceiling(sum(demand)/240*679(distance from Sandy Spring to Miami)*2=$499252404

Total cost is $578091438+$499252404=$1077343842

5.2.1.2 Product in Miami

OTS for WorkPal is as below

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	WorkPal1	WorkPal2	WorkPal3	WorkPal4	WorkPal5	WorkPal6	WorkPal7	WorkPal8	WorkPal9	WorkPal10	WorkPal11	WorkPal12	WorkPal13	WorkPal14	WorkPal15	WorkPal16	WorkPal17	WorkPal18	WorkPal19	WorkPal20	WorkPal21	WorkPal22	WorkPal23
2	9.805892	0	0	1.547748	0	3.312511	5.413813	7.343266	6.686161	2.150874	7.350426	6.871781	3.093293	4.162946	4.384368	3.168752	3.363736	2.199895	1.844078	3.981182	0	0	0
3	10.02181	0	0	1.56262	0	3.232645	5.186884	7.203362	7.361993	2.189981	6.461986	6.1618	2.993598	4.362887	4.663624	3.207308	3.582954	2.23735	1.71409	3.947033	0	0	0
4	9.695732	0	0	1.494871	0	3.156635	5.716753	7.687516	7.093753	2.331536	6.742343	6.539098	2.937416	4.396486	4.628923	3.419366	3.479404	2.264339	1.698667	3.951439	0	0	0
5	9.938084	0	0	1.574186	0	3.281116	5.514059	7.371907	6.849198	2.219173	6.494483	6.549012	3.051432	4.234	4.393732	3.6149	3.354372	2.121682	1.741079	3.810434	0	0	0
6	9.786614	0	0	1.518556	0	3.49042	5.942581	7.788312	6.848647	2.259932	7.210523	6.764375	3.114774	4.09685	4.693918	3.337297	3.522917	2.133799	1.815988	3.837424	0	0	0
7	10.36771	0	0	1.591261	0	3.340602	6.002068	7.002871	6.86462	2.359627	6.856358	6.406906	3.018935	4.297342	4.619009	3.213367	3.495377	2.218622	1.88649	3.991097	0	0	0
8	10.46134	0	0	1.582999	0	3.734975	5.440802	7.09816	7.371907	2.289676	6.49944	6.428938	2.978726	4.339202	4.601383	3.436441	3.49097	2.165746	1.736122	4.05554	0	0	0
9	11.01214	0	0	1.505336	0	3.55927	5.481562	7.68366	6.930166	2.252772	6.979187	6.230099	3.011224	4.319924	4.508849	3.509147	3.522917	2.152526	1.784041	3.840728	0	0	0
10	11.07824	0	0	1.49377	0	3.034357	5.360936	7.105871	7.105871	2.386066	7.361442	6.143072	3.00902	4.368395	4.758912	3.176464	3.456821	2.235146	1.862806	3.747092	0	0	0
11	10.21844	0	0	1.432631	0	3.16049	5.165953	7.148833	7.198405	2.23735	6.961561	6.29289	2.914834	4.280267	4.518212	3.495928	3.403944	2.395429	1.875474	4.070963	0	0	0
12	9.81801	0	0	1.443096	0	3.195191	5.411059	6.747851	6.978636	2.22358	6.730776	6.344665	3.024994	4.12384	4.488469	3.599478	3.441949	2.311708	1.76917	3.992749	0	0	0
13	10.03998	0	0	1.46623	0	3.436441	5.441904	7.250731	6.921353	2.324376	6.603541	6.029057	3.021138	4.497833	4.540244	3.576344	3.512452	2.192735	1.781838	4.060498	0	0	0
14	10.31538	0	0	1.530122	0	2.993598	5.77624	7.121844	7.488126	2.264339	7.294244	6.343013	3.047026	4.304502	4.511052	3.465083	3.51135	2.232392	1.788998	3.905172	0	0	0
15	9.309071	0	0	1.6524	0	3.431484	5.240862	7.417624	6.975331	2.225783	6.581509	6.406355	2.995801	4.361785	4.629474	3.476099	3.436441	2.309504	1.768619	3.834119	0	0	0
16	10.32034	0	0	1.461823	0	3.107063	5.270054	6.773188	6.652562	2.2379	6.800728	6.557825	2.883438	4.225187	4.558972	3.42873	3.510799	2.252772	1.865009	3.84844	0	0	0
17	10.3275	0	0	1.616598	0	3.03656	5.272808	6.75446	7.130106	2.515504	6.80238	6.3342	3.080624	4.313315	4.587062	3.439746	3.447457	2.206505	1.890896	3.999359	0	0	0
18	10.29225	0	0	1.605582	0	3.257431	5.805983	7.358137	7.090448	2.269847	6.749503	6.760519	2.996352	4.428983	4.558421	3.616553	3.509147	2.305649	1.844078	4.164048	0	0	0
19	11.02647	0	0	1.560416	0	3.625916	5.187985	7.812547	7.379068	2.315012	6.990754	6.690017	3.274506	4.256032	4.692265	3.51851	3.547152	2.019233	1.892549	3.948134	0	0	0
20	9.518375	0	0	1.464577	0	3.344458	5.544353	7.560832	6.585916	2.424071	6.729674	6.298398	3.021138	4.237304	4.7165	3.305902	3.492623	2.123334	1.678838	3.880386	0	0	0
21	10.6051	0	0	1.564272	0	3.138458	5.648454	7.019395	7.07778	2.160238	6.975882	6.686161	3.13295	4.170107	4.77819	3.384666	3.515206	2.325478	1.865009	3.987792	0	0	0
22	10.42114	0	0	1.542791	0	3.467286	5.359284	7.18794	6.816701	2.321071	7.061256	6.445462	3.130747	4.433389	4.512154	3.480505	3.497029	2.202098	1.873271	3.953092	0	0	0
23	10.43656	0	0	1.437037	0	3.03656	5.306407	8.080787	7.334453	2.256077	6.775942	6.5749	3.05694	4.116128	4.746244	3.447457	3.613248	2.383312	1.814335	3.955295	0	0	0
24	10.79513	0	0	1.525165	0	3.097699	5.052488	6.94669	7.019946	2.172355	7.314624	6.321532	3.065753	4.400341	4.604137	3.549355	3.514104	2.321622	1.644138	4.030754	0	0	0
25	10.34072	0	0	1.598422	0	3.134052	5.371402	7.957958	7.122395	2.174008	7.005625	6.140869	2.986988	4.46864	4.741837	3.430382	3.554312	2.319419	1.82425	4.01368	0	0	0
26	10.29886	0	0	1.3423	0	3.137357	5.401696	6.858011	7.252384	2.185024	7.143325	6.703236	3.134603	4.242262	4.708238	3.630874	3.439746	2.232943	1.872169	4.211417	0	0	0
27	10.72573	0	0	1.575288	0	3.368142	5.130151	7.252934	6.416269	2.422969	6.663028	6.540199	3.178116	4.503341	4.560624	3.458473	3.682649	2.355772	1.765314	4.201502	0	0	0
28	10.65247	0	0	1.516903	0	3.373099	5.902373	7.259544	6.607397	2.160238	6.370553	6.537445	3.057491	4.514357	4.694468	3.302597	3.511901	2.268745	1.777432	3.886445	0	0	0
29	10.57095	0	0	1.62486	0	3.199046	5.25298	7.925461	7.109176	1.999955	7.310218	6.227345	3.07787	4.298443	4.53749	3.427078	3.574141	2.293531	1.916784	3.913434	0	0	0

Figure 112 OTS for WorkPal

Production resource planning is as below

	WorkPal1	WorkPal2	WorkPal3	WorkPal4	WorkPal5	WorkPal6	WorkPal7	WorkPal8	WorkPal9	WorkPal10	WorkPal11	WorkPal12	WorkPal13	WorkPal14	WorkPal15
1	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
2	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
3	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
4	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
5	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
6	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
7	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
8	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
9	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
10	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
11	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
12	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
13	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
14	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
15	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
16	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
17	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
18	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
19	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
20	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
21	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
22	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0

Figure 113 Production resource planning

Total cells required: 30

Since the demand is so low, merely 1 changing pace (happened at time 1, product 6) and no changeover from outside group, only 60 times of changing within group: (the first 4 rows are those products needed to changeover, the last row is the time)

	wtingrp	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15	V16	V17	V18	V19	V20	V21	V22	V23	V24	V25	V26
1	1	1	8	11	14	16	18	1	8	11	14	16	18	1	8	11	14	16	18	1	8	11	14	16	18	1
2	2	4	9	12	15	17	19	4	9	12	15	17	19	4	9	12	15	17	19	4	9	12	15	17	19	4
3	3	0	10	13	0	0	20	0	10	13	0	0	20	0	10	13	0	0	20	0	10	13	0	0	20	0
4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	5	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3	3	3	3	4	4	4	4	4	4	5

Figure 114 Pace Changeover

Total production cost: $25437289, and the work policy test was passed.

Notice that if production in Miami, we don't need to transport.

Thus, the total cost is the production cost. 25437289>23434889.

It makes sense because Miami is really close to Sandy Spring and demand in Miami is not large, so there is no need to build a factory in Miami.

OTD for MyPal:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1		MyPal1	MyPal2	MyPal3	MyPal4	MyPal5	MyPal6	MyPal7	MyPal8	MyPal9	MyPal10	MyPal11	MyPal12	MyPal13	MyPal14	MyPal15	MyPal16	MyPal17	MyPal18	MyPal19	MyPal20	MyPal21	MyPal22
2	1/1/2019	245.3163	81.92507	63.88049	130.0796	70.11522	111.4975	110.3129	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1/2/2019	324.4329	98.51701	87.81469	166.2436	99.80863	162.7668	168.8239	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1/3/2019	273.9147	86.33104	73.96591	124.4085	84.12806	130.8247	136.9539	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	1/4/2019	71.45825	20.18822	17.16725	39.79357	20.69588	31.61403	35.93684	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	1/5/2019	91.55425	28.70305	23.67792	46.66145	28.429	41.03606	43.32976	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	1/6/2019	21.2848	46.45469	35.06139	57.1846	43.6813	59.64084	54.65842	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	1/7/2019	208.1155	58.64027	56.3409	99.52778	61.06703	106.5998	97.85399	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	1/8/2019	243.3885	69.63781	69.26585	124.757	79.56673	111.0182	117.2779	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	1/9/2019	314.2027	103.8392	85.47034	163.4253	104.5431	155.4317	150.6719	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	1/10/2019	245.3197	87.62909	78.48603	139.7538	91.33236	134.0932	124.7086	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	1/11/2019	68.31594	21.10828	16.3984	33.01754	18.74691	29.84537	30.30766	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	1/12/2019	90.23918	27.05195	20.8089	44.41424	30.98731	45.69453	46.8497	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	1/13/2019	18.02947	40.33411	33.9565	63.84269	42.29518	52.87766	51.53765	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	1/14/2019	193.0597	65.9833	56.26076	99.94774	63.75575	110.7086	101.2904	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	1/15/2019	242.1744	76.69469	65.93038	114.0203	76.0468	114.4713	107.8767	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	1/16/2019	332.2582	98.00028	85.45748	173.5152	93.66273	171.8615	180.1627	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	1/17/2019	245.9839	83.90353	67.53877	132.7683	79.04509	141.8732	141.4952	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	1/18/2019	66.68638	20.83914	17.81401	37.49571	19.66696	32.40783	29.76977	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	1/19/2019	85.04282	27.972	23.37136	43.12035	28.31144	50.90375	44.13604	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	1/20/2019	22.96539	44.16136	33.6832	65.17438	41.57244	52.26455	52.56241	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	1/21/2019	211.711	64.69394	54.3496	101.0987	60.39949	109.2129	94.74116	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	1/22/2019	250.3154	75.98518	57.77654	111.6846	68.64442	121.6967	124.7589	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	1/23/2019	340.6139	101.781	91.70431	156.481	101.0606	164.2032	166.4463	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	1/24/2019	234.4613	78.75706	72.4369	131.911	85.09423	132.224	120.7302	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	1/25/2019	69.6431	18.42788	16.81835	35.16836	19.31807	31.37438	32.26079	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	1/26/2019	97.93073	30.19842	22.10695	53.55504	28.38704	39.46055	43.01451	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	1/27/2019	19.06254	42.96802	33.99014	66.93851	45.62611	51.7981	54.86897	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	1/28/2019	207.3504	62.9714	60.54124	100.1118	66.80507	105.7599	102.6176	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 115 OTD for MyPal

Similarly, as before, convert the OTD demand to capacity requirement planning:

	MyPal1	MyPal2	MyPal3	MyPal4	MyPal5	MyPal6	MyPal7	MyPal8	MyPal9	MyPal10	MyPal11	MyPal12	MyPal13	MyPal14	MyPal15	MyPal16	MyPal17
1	20.3081055	6.7820314	5.2882403	10.7684263	5.8043722	9.2301378	9.1320683	0	0	0	0	0	0	0	0	0	0
2	26.8576366	8.1555670	7.2695936	13.7622044	8.2624921	13.4743796	13.9758043	0	0	0	0	0	0	0	0	0	0
3	22.6755722	7.1467721	6.1231449	10.2989508	6.9644018	10.8301030	11.3375045	0	0	0	0	0	0	0	0	0	0
4	5.9155530	1.6712486	1.4211622	3.2942449	1.7132739	2.6171150	2.9749715	0	0	0	0	0	0	0	0	0	0
5	7.5791664	2.3761346	1.9601373	3.8627911	2.3534478	3.3971020	3.5869825	0	0	0	0	0	0	0	0	0	0
6	1.7620270	3.8456743	2.9024990	4.7339319	3.6160841	4.9372680	4.5248068	0	0	0	0	0	0	0	0	0	0
7	17.2284932	4.8544378	4.6640880	8.2392420	5.0553331	8.8246860	8.1006806	0	0	0	0	0	0	0	0	0	0
8	20.1485158	5.7648503	5.7340588	10.3278022	6.5867999	9.1904594	9.7086566	0	0	0	0	0	0	0	0	0	0
9	26.0107471	8.5961598	7.0755200	13.5288904	8.6544257	12.8671563	12.4731262	0	0	0	0	0	0	0	0	0	0
10	20.3083872	7.2542292	6.4973358	11.5692851	7.5607979	11.1006858	10.3237968	0	0	0	0	0	0	0	0	0	0
11	5.6554218	1.7474136	1.3575140	2.7333026	1.5519319	2.4706993	2.5089695	0	0	0	0	0	0	0	0	0	0
12	7.4703012	2.2394506	1.7226303	3.6767595	2.5652327	3.7827459	3.8783745	0	0	0	0	0	0	0	0	0	0
13	1.4925394	3.3389926	2.8110322	5.2851110	3.5013360	4.3773897	4.2664592	0	0	0	0	0	0	0	0	0	0
14	15.9821287	5.4623182	4.6574540	8.2740076	5.2779139	9.1648312	8.3851571	0	0	0	0	0	0	0	0	0	0
15	20.0480056	6.3490425	5.4579373	9.4389813	6.2954079	9.4763127	8.9303907	0	0	0	0	0	0	0	0	0	0
16	27.5054457	8.1127906	7.0744561	14.3641705	7.7537138	14.2272676	14.9144735	0	0	0	0	0	0	0	0	0	0
17	20.3633674	6.9458142	5.5910852	10.9910070	6.5436168	11.7447399	11.7134478	0	0	0	0	0	0	0	0	0	0
18	5.5205215	1.7251336	1.4747029	3.1040202	1.6280968	2.6828285	2.4644409	0	0	0	0	0	0	0	0	0	0
19	7.0401286	2.3156156	1.9347594	3.5696467	2.3437159	4.2139824	3.6537285	0	0	0	0	0	0	0	0	0	0
20	1.9011517	3.6558251	2.7884080	5.3953531	3.4415055	4.3266339	4.3512921	0	0	0	0	0	0	0	0	0	0
21	17.5261437	5.3555809	4.4992412	8.3692920	5.0000713	9.0410083	7.8429901	0	0	0	0	0	0	0	0	0	0
22	20.7219436	6.2903073	4.7829354	9.2456274	5.6826146	10.0744613	10.3279586	0	0	0	0	0	0	0	0	0	0

Figure 116 capacity requirement planning

Then, we get the number of cells needed:

	MyPal1	MyPal2	MyPal3	MyPal4	MyPal5	MyPal6	MyPal7	MyPal8	MyPal9	MyPal10	MyPal11	MyPal12	MyPal13	MyPal14	MyPal15	MyPal16	MyPal17
1	11	3	3	6	5	5	5	0	0	0	0	0	0	0	0	0	0
2	14	4	4	7	6	7	7	0	0	0	0	0	0	0	0	0	0
3	12	3	3	5	5	6	6	0	0	0	0	0	0	0	0	0	0
4	3	1	1	2	1	2	1	0	0	0	0	0	0	0	0	0	0
5	4	2	1	2	2	2	2	0	0	0	0	0	0	0	0	0	0
6	1	2	2	2	3	3	2	0	0	0	0	0	0	0	0	0	0
7	9	3	2	4	4	5	4	0	0	0	0	0	0	0	0	0	0
8	10	3	3	6	5	5	5	0	0	0	0	0	0	0	0	0	0
9	13	5	3	7	7	7	6	0	0	0	0	0	0	0	0	0	0
10	11	3	3	6	6	6	5	0	0	0	0	0	0	0	0	0	0
11	3	1	1	2	1	2	1	0	0	0	0	0	0	0	0	0	0
12	4	1	1	2	2	2	2	0	0	0	0	0	0	0	0	0	0
13	1	2	2	3	3	3	2	0	0	0	0	0	0	0	0	0	0
14	8	3	3	4	4	5	4	0	0	0	0	0	0	0	0	0	0
15	10	4	2	5	5	5	5	0	0	0	0	0	0	0	0	0	0
16	14	4	4	7	6	7	8	0	0	0	0	0	0	0	0	0	0
17	11	3	3	6	5	6	6	0	0	0	0	0	0	0	0	0	0
18	3	1	1	2	1	2	1	0	0	0	0	0	0	0	0	0	0
19	4	1	1	2	2	3	1	0	0	0	0	0	0	0	0	0	0
20	1	1	2	3	3	3	2	0	0	0	0	0	0	0	0	0	0
21	9	3	2	4	4	5	4	0	0	0	0	0	0	0	0	0	0
22	11	3	2	5	4	5	5	0	0	0	0	0	0	0	0	0	0

Figure 117 Number of Cells

Total 917 cells are needed.

We will have to pace change 438 times as shown in the table below.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	Changepace																						
2	group1	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
3	Time	2	0	2	22	23	28	35	37	61	64	65	68	75	77	78	79	82	85	89	97	99	100
4																							

Figure 118 Pacechange

We will have to extend 12990 hours as shown in the table below

	MyPal1	MyPal2	MyPal3	MyPal4	MyPal5	MyPal6	MyPal7	MyPal8	MyPal9	MyPal10	MyPal11	MyPal12	MyPal13	MyPal14	MyPal15	MyPal16	MyPal17
1	0.00000000	0.00000000	0.00000000	0.00000000	0.000000	0.0000000	0.00000000	0	0	0	0	0	0	0	0	0	0
2	0.00000000	0.77783476	0.00000000	0.00000000	0.000000	0.0000000	0.00000000	0	0	0	0	0	0	0	0	0	0
3	0.00000000	0.00000000	0.61572428	1.49475423	0.000000	0.0000000	0.00000000	0	0	0	0	0	0	0	0	0	0
4	0.00000000	0.00000000	0.00000000	0.00000000	0.000000	0.0000000	0.00000000	0	0	0	0	0	0	0	0	0	0
5	0.00000000	0.00000000	0.00000000	0.00000000	0.000000	0.0000000	0.00000000	0	0	0	0	0	0	0	0	0	0
6	0.00000000	0.00000000	0.00000000	0.00000000	0.000000	0.0000000	0.00000000	0	0	0	0	0	0	0	0	0	0
7	0.00000000	0.00000000	0.00000000	1.19621018	0.000000	0.0000000	0.75699702	0	0	0	0	0	0	0	0	0	0
8	0.74257899	0.00000000	0.00000000	0.00000000	0.000000	0.0000000	0.00000000	0	0	0	0	0	0	0	0	0	0
9	0.05373549	0.00000000	0.00000000	0.00000000	0.000000	0.0000000	0.00000000	0	0	0	0	0	0	0	0	0	0
10	0.00000000	0.00000000	0.00000000	0.00000000	0.000000	0.0000000	2.43456222	0	0	0	0	0	0	0	0	0	0
11	0.00000000	0.00000000	0.00000000	0.00000000	0.000000	0.0000000	0.00000000	0	0	0	0	0	0	0	0	0	0
12	0.00000000	0.00000000	0.00000000	0.00000000	0.000000	0.0000000	0.00000000	0	0	0	0	0	0	0	0	0	0
13	0.00000000	0.00000000	0.00000000	0.00000000	0.000000	0.0000000	0.00000000	0	0	0	0	0	0	0	0	0	0
14	0.00000000	0.00000000	0.00000000	1.37003781	0.000000	0.0000000	0.00000000	0	0	0	0	0	0	0	0	0	0
15	0.24002782	0.00000000	0.00000000	0.00000000	0.000000	0.0000000	0.00000000	0	0	0	0	0	0	0	0	0	0
16	0.00000000	0.56395324	0.00000000	1.82085271	0.000000	1.7087789	0.00000000	0	0	0	0	0	0	0	0	0	0
17	0.00000000	0.00000000	0.00000000	0.00000000	0.000000	0.0000000	0.00000000	0	0	0	0	0	0	0	0	0	0
18	0.00000000	0.00000000	0.00000000	0.00000000	0.000000	0.0000000	0.00000000	0	0	0	0	0	0	0	0	0	0
19	0.00000000	0.00000000	0.00000000	0.00000000	0.000000	0.0000000	0.00000000	0	0	0	0	0	0	0	0	0	0
20	0.00000000	0.00000000	0.00000000	0.00000000	0.000000	0.0000000	0.00000000	0	0	0	0	0	0	0	0	0	0
21	0.00000000	0.00000000	0.00000000	0.00000000	0.000000	0.0000000	0.00000000	0	0	0	0	0	0	0	0	0	0
22	0.00000000	0.00000000	0.00000000	0.00000000	0.000000	0.5598594	2.46585432	0	0	0	0	0	0	0	0	0	0

Figure 119 Extended Hours

We have to do change within group 2056 times as shown in the table below.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	WithinGroup																						
2	1	3	6	1	2	7	1	6	1	6	4	4	1	4	1	6	7	1	2	2	6	1	6
3	2	2	7	4	4	6	3	7	2	7	2	3	4	3	2	7	6	4	3	4	7	4	7
4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	Time	3	4	6	6	7	9	9	10	11	12	13	14	15	17	18	19	21	21	24	25	26	27
7																							
8																							

Figure 120 Change within Group

We have to change 125 times outside group as shown in the table below.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	OutsideGroup																						
2	Group1	2	2	2	1	1	1	1	2	1	1	1	3	1	2	1	5	1	2	1	1	1	5
3	Group2	9	7	9	8	8	7	9	9	7	9	8	6	6	8	6	8	7	5	6	6	7	7
4	Time	743	750	768	775	777	778	782	789	790	801	803	813	820	824	827	831	834	851	862	869	876	883
5																							
6																							

Figure 121 Change outside Group

Total production cost: $624095112, and work policy test passed.

Since we don't need to transport, the total cost is $624095112.

And 624095112<1077343842, thus, for MyPal, it is better to build a factory in Miami.

5.3 Combine WorkPal and MyPal

5.3.1 Product in Sandy Spring

Here we have two types of cells, one is WorkPal, the other one is MyPal. For WorkPal cells, the installment, maintenance and operation fee is a little bit lower, but the setup time for changeover is longer.

Therefore, we can use WorkPal cells for both WorkPal and MyPal products first, then like sensitivity analysis in task 3, when we consider the changeover, the marginal fee becomes:

*300+Y'year*50000+Y'total*300000-250-Y'year*40000-Y'total*200000=50+Y'year*10000+Y'total*100000*

where Y'year and Y'total means if changeover has happened in this year or these five years, respectively.

Then, when we determine the priority of each option, just like in task 3 sensitivity analysis, the priority would be:

changeover pace with WorkPal-type cells>Extending working time>within group/outside group with WorkPal-type cells> add another cell if Ymonth=0 > add another cell if Ymonth=1 but Yyear=0> changeover pace/within group/outside group with MyPal-type cells> add another cell if Ytotal=1

In summary, the capacity requirement is as below

	WorkPal1	WorkPal2	WorkPal3	WorkPal4	WorkPal5	WorkPal6	WorkPal7	WorkPal8	WorkPal9	WorkPal10	WorkPal11	WorkPal12	WorkPal13	WorkPal14	WorkPal15
1	0.7516338	0	0	0.1186368	0	0.2539081	0.4149755	0.5628704	0.5125026	0.1648672	0.5634193	0.5267305	0.2371047	0.3190950	0.3360673
2	0.7681839	0	0	0.1197767	0	0.2477863	0.3975811	0.5521467	0.5643059	0.1678647	0.4953192	0.4723096	0.2294630	0.3344207	0.3574725
3	0.7431899	0	0	0.1145837	0	0.2419600	0.4381962	0.5892576	0.5437450	0.1787152	0.5168090	0.5012300	0.2251566	0.3369961	0.3548127
4	0.7617665	0	0	0.1206633	0	0.2515016	0.4226595	0.5650658	0.5249995	0.1701024	0.4978102	0.5019899	0.2338961	0.3245413	0.3367850
5	0.7501562	0	0	0.1163992	0	0.2675450	0.4555062	0.5969838	0.5249573	0.1732266	0.5526955	0.5184977	0.2387513	0.3140287	0.3597946
6	0.7946977	0	0	0.1219721	0	0.2560613	0.4600659	0.5367788	0.5261817	0.1808684	0.5255484	0.4910973	0.2314051	0.3293966	0.3540528
7	0.8018750	0	0	0.1213389	0	0.2862905	0.4170443	0.5440828	0.5650658	0.1755065	0.4981901	0.4927861	0.2283231	0.3326053	0.3527017
8	0.8440945	0	0	0.1153859	0	0.2728224	0.4201685	0.5889621	0.5312058	0.1726778	0.5349633	0.4775448	0.2308140	0.3311276	0.3456089
9	0.8491609	0	0	0.1144993	0	0.2325872	0.4109224	0.5446738	0.5446738	0.1828949	0.5642637	0.4708741	0.2306452	0.3348429	0.3647765
10	0.7832562	0	0	0.1098129	0	0.2422555	0.3959767	0.5479669	0.5517667	0.1714956	0.5336123	0.4823578	0.2234256	0.3280878	0.3463266
11	0.7525627	0	0	0.1106151	0	0.2449153	0.4147644	0.5172311	0.5349211	0.1704401	0.5159223	0.4863265	0.2318695	0.3160974	0.3440467
12	0.7695771	0	0	0.1123883	0	0.2634075	0.4171287	0.5557776	0.5305303	0.1781663	0.5061696	0.4621347	0.2315740	0.3447645	0.3480154
13	0.7906869	0	0	0.1172858	0	0.2294630	0.4427559	0.5458982	0.5739742	0.1735644	0.5591129	0.4861998	0.2335583	0.3299454	0.3457777
14	0.7135518	0	0	0.1266585	0	0.2630275	0.4017186	0.5685701	0.5346678	0.1706090	0.5044809	0.4910551	0.2296319	0.3343363	0.3548549
15	0.7910668	0	0	0.1120506	0	0.2381602	0.4039562	0.5191732	0.5099272	0.1715378	0.5212842	0.5026654	0.2210191	0.3238658	0.3494508
16	0.7916157	0	0	0.1239142	0	0.2327561	0.4041673	0.5177378	0.5465315	0.1928165	0.5214109	0.4855243	0.2361337	0.3306209	0.3516040
17	0.7889137	0	0	0.1230699	0	0.2496861	0.4450358	0.5640104	0.5434917	0.1739866	0.5173578	0.5182022	0.2296741	0.3394870	0.3494086
18	0.8451923	0	0	0.1196079	0	0.2779310	0.3976655	0.5988414	0.5656147	0.1774486	0.5358499	0.5127981	0.2509950	0.3262301	0.3596680
19	0.7295953	0	0	0.1122617	0	0.2563568	0.4249815	0.5795471	0.5048186	0.1858080	0.5158379	0.4827800	0.2315740	0.3247946	0.3615256
20	0.8128943	0	0	0.1199034	0	0.2405667	0.4329610	0.5380454	0.5425206	0.1655849	0.5347100	0.5125026	0.2401445	0.3196439	0.3662542
21	0.7987930	0	0	0.1182568	0	0.2657718	0.4107958	0.5509645	0.5225086	0.1779130	0.5412540	0.4940526	0.2399757	0.3398248	0.3458622
22	0.7999752	0	0	0.1101507	0	0.2327561	0.4067427	0.6194023	0.5621949	0.1729311	0.5193843	0.5039742	0.2343182	0.3155064	0.3638055

Figure 122 Capacity Requirement

The working cells required is 876, 34 of them are MyPal-type working cells as shown below

	WorkPal1	WorkPal2	WorkPal3	WorkPal4	WorkPal5	WorkPal6	WorkPal7	WorkPal8	WorkPal9	WorkPal10	WorkPal11	WorkPal12	WorkPal13	WorkPal14	WorkPal15
1	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0
2	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0
3	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0
4	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0
5	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0
6	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0
7	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0
8	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0
9	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0
10	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0
11	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0
12	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0
13	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0
14	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0
15	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0
16	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0
17	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0
18	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0
19	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0
20	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0
21	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0
22	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0

Figure 123 Number of Cells

Total production cost is $471400836 and work policy test passed.

The transportation cost is not affected by the production; thus, the transportation cost is the sum of WorkPal and MyPal transportation cost in the former part: $3710056+$499252404=$502962460.

Then, the total cost would be $471400836+$502962460=$974363296.

5.3.2 Product in Miami

Similar as before, input the WorkPal and MyPal demand, we can get the capacity requirement as below.

	WorkPal1	WorkPal2	WorkPal3	WorkPal4	WorkPal5	WorkPal6	WorkPal7	WorkPal8	WorkPal9	WorkPal10	WorkPal11	WorkPal12	WorkPal13	WorkPal14	WorkPal15
1	0.8117645	0	0	0.1281278	0	0.2742207	0.4481735	0.6079001	0.5535028	0.1780565	0.6084928	0.5688690	0.2560731	0.3446226	0.3629526
2	0.8296386	0	0	0.1293589	0	0.2676092	0.4293876	0.5963184	0.6094504	0.1812939	0.5349448	0.5100944	0.2478200	0.3611743	0.3860703
3	0.8026451	0	0	0.1237504	0	0.2613168	0.4732519	0.6363982	0.5872446	0.1930124	0.5581537	0.5413283	0.2431691	0.3639558	0.3831977
4	0.8227078	0	0	0.1303164	0	0.2716217	0.4564722	0.6102711	0.5669995	0.1837106	0.5376350	0.5421491	0.2526077	0.3505046	0.3637278
5	0.8101686	0	0	0.1257111	0	0.2889486	0.4919467	0.6447425	0.5669539	0.1870848	0.5969112	0.5599775	0.2578514	0.3391510	0.3885782
6	0.8582735	0	0	0.1317299	0	0.2765462	0.4968712	0.5797211	0.5682762	0.1953378	0.5675923	0.5303851	0.2499175	0.3557483	0.3823770
7	0.8660250	0	0	0.1310460	0	0.3091937	0.4504078	0.5876094	0.6102711	0.1895470	0.5380454	0.5322089	0.2465889	0.3592137	0.3809179
8	0.9116221	0	0	0.1246168	0	0.2946482	0.4537820	0.6360790	0.5737023	0.1864920	0.5777604	0.5157484	0.2492792	0.3576178	0.3732576
9	0.9170938	0	0	0.1236592	0	0.2511942	0.4437962	0.5882477	0.5882477	0.1975265	0.6094048	0.5085441	0.2490968	0.3616303	0.3939586
10	0.8459167	0	0	0.1185980	0	0.2616360	0.4276549	0.5918043	0.5959080	0.1852153	0.5763013	0.5209465	0.2412997	0.3543348	0.3740327
11	0.8127677	0	0	0.1194643	0	0.2645086	0.4479456	0.5586096	0.5777148	0.1840753	0.5571961	0.5252326	0.2504191	0.3413852	0.3715705
12	0.8311433	0	0	0.1213794	0	0.2844801	0.4504990	0.6002398	0.5729727	0.1924196	0.5466632	0.4991055	0.2500999	0.3723456	0.3758566
13	0.8539418	0	0	0.1266686	0	0.2478200	0.4781764	0.5895700	0.6198921	0.1874495	0.6038419	0.5250958	0.2522430	0.3563411	0.3734400
14	0.7706360	0	0	0.1367912	0	0.2840697	0.4338561	0.6140557	0.5774412	0.1842577	0.5448393	0.5303395	0.2480024	0.3610832	0.3832433
15	0.8543522	0	0	0.1210146	0	0.2572130	0.4362727	0.5607071	0.5507213	0.1852609	0.5629870	0.5428786	0.2387006	0.3497751	0.3774069
16	0.8549450	0	0	0.1338274	0	0.2513766	0.4365007	0.5591568	0.5902540	0.2082418	0.5631237	0.5243662	0.2550244	0.3570706	0.3797324
17	0.8520267	0	0	0.1329154	0	0.2696610	0.4806387	0.6091312	0.5869710	0.1879055	0.5587464	0.5596584	0.2480480	0.3666460	0.3773613
18	0.9128076	0	0	0.1291765	0	0.3001655	0.4294788	0.6467488	0.6108639	0.1916445	0.5787179	0.5538219	0.2710745	0.3523285	0.3884414
19	0.7879629	0	0	0.1212426	0	0.2768654	0.4589801	0.6259109	0.5452041	0.2006727	0.5571049	0.5214024	0.2500999	0.3507782	0.3904477
20	0.8779259	0	0	0.1294957	0	0.2598121	0.4675979	0.5810890	0.5859223	0.1788317	0.5774868	0.5535028	0.2593561	0.3452154	0.3955545
21	0.8626965	0	0	0.1277174	0	0.2870335	0.4436594	0.5950417	0.5643093	0.1921460	0.5845544	0.5335768	0.2591737	0.3670108	0.3735312
22	0.8639732	0	0	0.1189627	0	0.2513766	0.4392821	0.6689545	0.6071705	0.1867656	0.5609351	0.5442922	0.2530637	0.3407469	0.3929099

Figure 124 Capacity Requirement Combined

And the number of working cells needed is 945, 37 of them are MyPal-type cells as shown below.

	WorkPal1	WorkPal2	WorkPal3	WorkPal4	WorkPal5	WorkPal6	WorkPal7	WorkPal8	WorkPal9	WorkPal10	WorkPal11	WorkPal12	WorkPal13	WorkPal14	WorkPal15	W
1	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0	
2	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0	
3	1	0	0	0	0	1	0	1	0	0	1	0	0	1	0	
4	1	0	0	0	0	1	0	1	0	0	1	0	0	1	0	
5	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0	
6	1	0	0	0	0	1	0	1	0	0	1	0	0	1	0	
7	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0	
8	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0	
9	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0	
10	1	0	0	0	0	1	0	1	0	0	1	0	0	1	0	
11	1	0	0	0	0	1	0	1	0	0	1	0	0	1	0	
12	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0	
13	1	0	0	0	0	1	0	1	0	0	1	0	0	1	0	
14	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0	
15	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0	
16	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0	
17	1	0	0	0	0	1	0	1	0	0	1	0	0	1	0	
18	1	0	0	0	0	1	0	1	0	0	1	0	0	1	0	
19	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0	
20	1	0	0	0	0	1	0	1	0	0	1	0	0	1	0	
21	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0	
22	1	0	0	0	0	1	1	1	0	0	1	0	0	1	0	

Figure 125 Number of Cells

And the total production cost is $509202343, and work policy test passed.

Since those products are processed in Miami, we don't need to consider transportation fee.

Then, the total cost would be $509202343. 509202343<974363296, therefore, it is wise to build a factory in Miami to process both WorkPal and MyPal products.

5.4 Conclusion

From the above result we can see that after we combine WorkPal and MyPal products, the cost has decreased significantly.

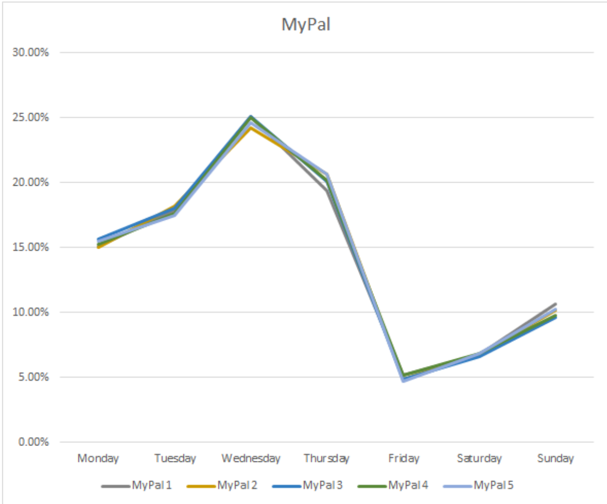
It makes sense because more group of products allows more changeover, and for MyPal products, they can be processed by WorkPal-type cells, then less installment, maintenance and daily operation fees are required.

Also, from the result we can see that some unconsidered network is able to generate lower cost.

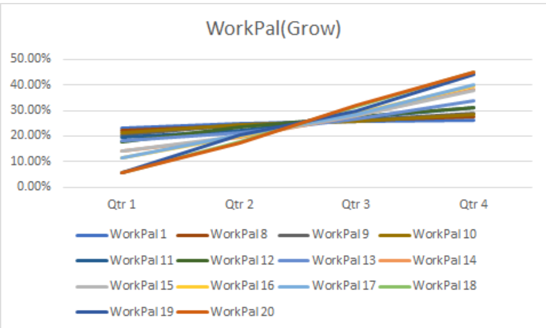
In our example, if operated independently with MyPal, WorkPal products have to be processed in Sandy Spring; while combined with MyPal, WorkPal products can be processed together with MyPal in Miami, and the total cost of the whole system will decrease.

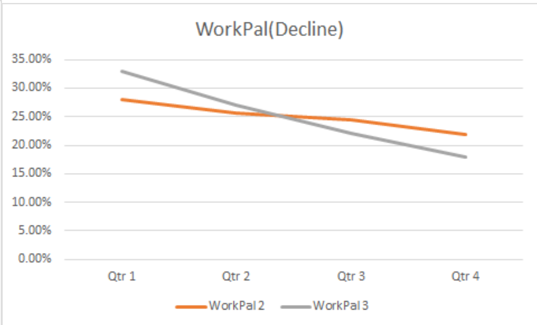
6 Appendix

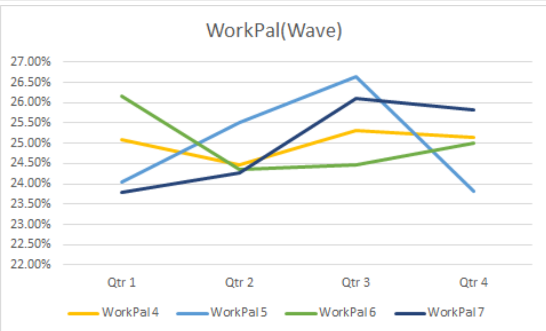
Appendix
Demand Constituents
Day in Week: = Demand on a Day / total demand

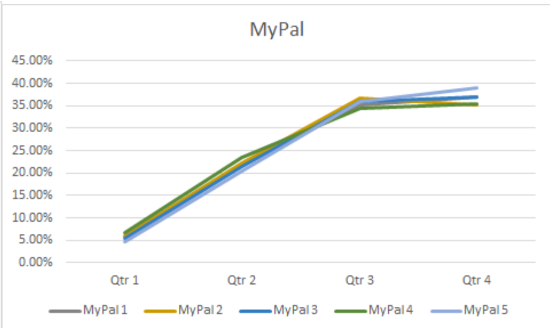


Seasonality Factor: =Demand in a season / total demand
(1) Quarterly:



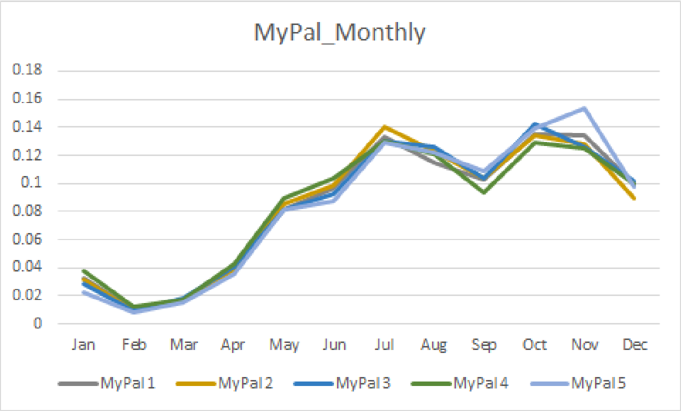






The trend of the WorkPals is not very clear for each product in the *first picture* because of the different scale of the factor. The following pictures show the pattern of the seasonality factor of each product and can be a proof of the previous categorization.

(2) Monthly



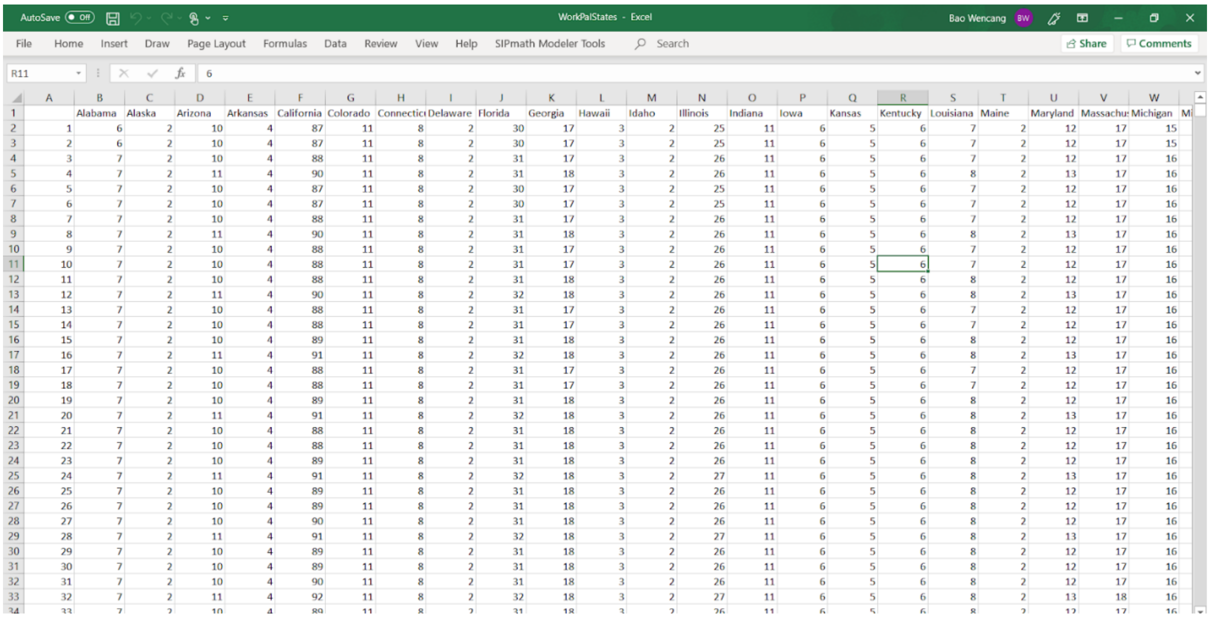
The features are almost the same with the quarterly ones except for that of WorkPal 1.
Forecasts
  Day, week, year
  Product, product line, aggregate

Triple Exponential Smoothing Parameter Defination

Explanation of the statistics:

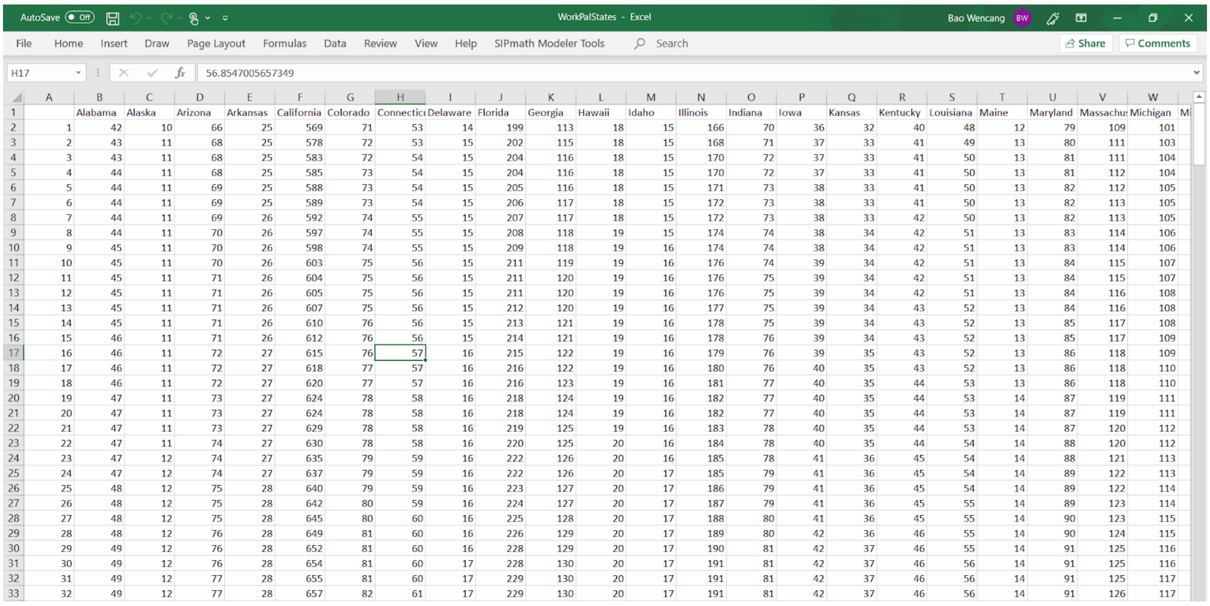
1. alpha base parameter
2. beta trend parameter
3. gamma seasonality parameter
4. MASE mean absolute scaled error
5. SMAPE symmetric mean absolute percentage error
6. MAE mean absolute percentage error
7. RMSE root mean squared error

Production Line Forecast Result:



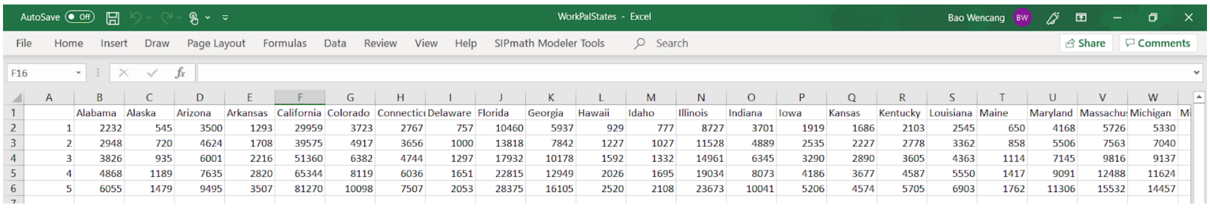
	A	Alabama	Alaska	Arizona	Arkansas	California	Colorado	Connecticu	Delaware	Florida	Georgia	Hawaii	Idaho	Illinois	Indiana	Iowa	Kansas	Kentucky	Louisiana	Maine	Maryland	Massachu	Michigan
2	1	6	2	10	4	87	11	8	2	30	17	3	2	25	11	6	5	6	7	2	12	17	15
3	2	6	2	10	4	87	11	8	2	30	17	3	2	25	11	6	5	6	7	2	12	17	15
4	3	7	2	10	4	88	11	8	2	31	17	3	2	26	11	6	5	6	7	2	12	17	16
5	4	7	2	11	4	90	11	8	2	31	18	3	2	26	11	6	5	6	8	2	13	17	16
6	5	7	2	10	4	87	11	8	2	30	17	3	2	25	11	6	5	6	7	2	12	17	16
7	6	7	2	10	4	87	11	8	2	30	17	3	2	25	11	6	5	6	7	2	12	17	16
8	7	7	2	10	4	88	11	8	2	31	17	3	2	26	11	6	5	6	7	2	12	17	16
9	8	7	2	11	4	90	11	8	2	31	18	3	2	26	11	6	5	6	8	2	13	17	16
10	9	7	2	10	4	88	11	8	2	31	17	3	2	26	11	6	5	6	7	2	12	17	16
11	10	7	2	10	4	88	11	8	2	31	17	3	2	26	11	6	5	6	7	2	12	17	16
12	11	7	2	10	4	88	11	8	2	31	18	3	2	26	11	6	5	6	8	2	12	17	16
13	12	7	2	11	4	90	11	8	2	32	18	3	2	26	11	6	5	6	8	2	13	17	16
14	13	7	2	10	4	88	11	8	2	31	17	3	2	26	11	6	5	6	7	2	12	17	16
15	14	7	2	10	4	88	11	8	2	31	17	3	2	26	11	6	5	6	7	2	12	17	16
16	15	7	2	10	4	89	11	8	2	31	18	3	2	26	11	6	5	6	8	2	12	17	16
17	16	7	2	11	4	91	11	8	2	32	18	3	2	26	11	6	5	6	8	2	13	17	16
18	17	7	2	10	4	88	11	8	2	31	17	3	2	26	11	6	5	6	7	2	12	17	16
19	18	7	2	10	4	88	11	8	2	31	17	3	2	26	11	6	5	6	7	2	12	17	16
20	19	7	2	10	4	89	11	8	2	31	18	3	2	26	11	6	5	6	8	2	12	17	16
21	20	7	2	11	4	91	11	8	2	32	18	3	2	26	11	6	5	6	8	2	13	17	16
22	21	7	2	10	4	88	11	8	2	31	18	3	2	26	11	6	5	6	8	2	12	17	16
23	22	7	2	10	4	88	11	8	2	31	18	3	2	26	11	6	5	6	8	2	12	17	16
24	23	7	2	10	4	89	11	8	2	31	18	3	2	26	11	6	5	6	8	2	12	17	16
25	24	7	2	11	4	91	11	8	2	32	18	3	2	27	11	6	5	6	8	2	13	17	16
26	25	7	2	10	4	89	11	8	2	31	18	3	2	26	11	6	5	6	8	2	12	17	16
27	26	7	2	10	4	89	11	8	2	31	18	3	2	26	11	6	5	6	8	2	12	17	16
28	27	7	2	10	4	90	11	8	2	31	18	3	2	26	11	6	5	6	8	2	12	17	16
29	28	7	2	11	4	91	11	8	2	32	18	3	2	27	11	6	5	6	8	2	13	17	16
30	29	7	2	10	4	89	11	8	2	31	18	3	2	26	11	6	5	6	8	2	12	17	16
31	30	7	2	10	4	89	11	8	2	31	18	3	2	26	11	6	5	6	8	2	12	17	16
32	31	7	2	10	4	90	11	8	2	31	18	3	2	26	11	6	5	6	8	2	12	17	16
33	32	7	2	11	4	92	11	8	2	32	18	3	2	27	11	6	5	6	8	2	13	18	16
34	33	7	2	10	4	89	11	8	2	31	18	3	2	26	11	6	5	6	8	2	12	17	16

Daily demand forecast for WorkPal Product Line in each state (figure above)



	A	Alabama	Alaska	Arizona	Arkansas	California	Colorado	Connecticu	Delaware	Florida	Georgia	Hawaii	Idaho	Illinois	Indiana	Iowa	Kansas	Kentucky	Louisiana	Maine	Maryland	Massachu	Michigan
2	1	42	10	66	25	569	71	53	14	199	113	18	15	166	70	36	32	40	48	12	79	109	101
3	2	43	11	68	25	578	72	53	15	202	115	18	15	168	71	37	33	41	49	13	80	111	103
4	3	43	11	68	25	583	72	54	15	204	116	18	15	170	72	37	33	41	50	13	81	111	104
5	4	44	11	68	25	585	73	54	15	204	116	18	15	170	72	37	33	41	50	13	81	112	104
6	5	44	11	69	25	588	73	54	15	205	116	18	15	171	73	38	33	41	50	13	82	112	105
7	6	44	11	69	25	589	73	54	15	206	117	18	15	172	73	38	33	41	50	13	82	113	105
8	7	44	11	69	26	592	74	55	15	207	117	18	15	172	73	38	33	42	50	13	82	113	105
9	8	44	11	70	26	597	74	55	15	208	118	19	15	174	74	38	34	42	51	13	83	114	106
10	9	45	11	70	26	598	74	55	15	209	118	19	16	174	74	38	34	42	51	13	83	114	106
11	10	45	11	70	26	603	75	56	15	211	119	19	16	176	74	39	34	42	51	13	84	115	107
12	11	45	11	71	26	604	75	56	15	211	120	19	16	176	75	39	34	42	51	13	84	115	107
13	12	45	11	71	26	605	75	56	15	211	120	19	16	176	75	39	34	42	51	13	84	116	108
14	13	45	11	71	26	607	75	56	15	212	120	19	16	177	75	39	34	43	52	13	84	116	108
15	14	45	11	71	26	610	76	56	15	213	121	19	16	178	75	39	34	43	52	13	85	117	108
16	15	46	11	71	26	612	76	56	15	214	121	19	16	178	76	39	34	43	52	13	85	117	109
17	16	46	11	72	27	615	76	57	16	215	122	19	16	179	76	39	35	43	52	13	86	118	109
18	17	46	11	72	27	618	77	57	16	216	122	19	16	180	76	40	35	43	52	13	86	118	110
19	18	46	11	72	27	620	77	57	16	216	123	19	16	181	77	40	35	44	53	13	86	118	110
20	19	47	11	73	27	624	78	58	16	218	124	19	16	182	77	40	35	44	53	14	87	119	111
21	20	47	11	73	27	624	78	58	16	218	124	19	16	182	77	40	35	44	53	14	87	119	111
22	21	47	11	73	27	629	78	58	16	219	125	19	16	183	78	40	35	44	53	14	87	120	112
23	22	47	11	74	27	630	78	58	16	220	125	20	16	184	78	40	35	44	54	14	88	120	112
24	23	47	12	74	27	635	79	59	16	222	126	20	16	185	78	41	36	45	54	14	88	121	113
25	24	47	12	74	27	637	79	59	16	222	126	20	17	185	79	41	36	45	54	14	89	122	113
26	25	48	12	75	28	640	79	59	16	223	127	20	17	186	79	41	36	45	54	14	89	122	114
27	26	48	12	75	28	642	80	59	16	224	127	20	17	187	79	41	36	45	55	14	89	123	114
28	27	48	12	75	28	645	80	60	16	225	128	20	17	188	80	41	36	45	55	14	90	123	115
29	28	48	12	76	28	649	81	60	16	226	129	20	17	189	80	42	36	46	55	14	90	124	115
30	29	49	12	76	28	652	81	60	16	228	129	20	17	190	81	42	37	46	55	14	91	125	116
31	30	49	12	76	28	654	81	60	17	228	130	20	17	191	81	42	37	46	56	14	91	125	116
32	31	49	12	77	28	655	81	60	17	229	130	20	17	191	81	42	37	46	56	14	91	125	117
33	32	49	12	77	28	657	82	61	17	229	130	20	17	191	81	42	37	46	56	14	91	126	117

Weekly demand forecast for WorkPal Product Line in each state (figure above)



	A	Alabama	Alaska	Arizona	Arkansas	California	Colorado	Connecticu	Delaware	Florida	Georgia	Hawaii	Idaho	Illinois	Indiana	Iowa	Kansas	Kentucky	Louisiana	Maine	Maryland	Massachu	Michigan
2	1	2232	545	3500	1293	29959	3723	2767	757	10460	5937	929	777	8727	3701	1919	1686	2103	2545	650	4168	5726	5330
3	2	2948	720	4624	1708	39575	4917	3656	1000	13818	7842	1227	1027	11528	4889	2535	2227	2778	3362	858	5506	7563	7040
4	3	3826	935	6001	2216	51360	6382	4744	1297	17932	10178	1592	1332	14961	6345	3290	2890	3605	4363	1114	7145	9816	9137
5	4	4868	1189	7635	2820	65344	8119	6036	1651	22815	12949	2026	1695	19034	8073	4186	3677	4587	5550	1417	9091	12488	11624
6	5	6055	1479	9495	3507	81270	10098	7507	2053	28375	16105	2520	2108	23673	10041	5206	4574	5705	6903	1762	11306	15532	14457

Yearly demand forecast for WorkPal Product Line in each state (figure above)

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O14

	A	B	C	D	E	F	G	H	I	J	K	L	M
1		Arizon Sun	Cascadia	Florida	Front Rang	Great Lake	Gulf Coast	Northeast	Northern (	Piedmont /	Southern (	Texas Triangle	
2	1	195	144	186	163	514	264	1088	277	180	894	1442	
3	2	263	195	252	220	695	357	1471	375	244	1209	1949	
4	3	237	176	227	198	626	321	1325	337	220	1089	1755	
5	4	85	63	82	71	225	116	477	121	79	392	631	
6	5	60	44	57	50	157	81	333	85	55	273	441	
7	6	84	62	80	70	221	113	467	119	77	384	619	
8	7	133	99	127	111	352	180	744	189	123	612	986	
9	8	195	145	186	163	515	264	1089	277	180	895	1443	
10	9	264	196	253	221	698	358	1476	376	245	1213	1956	
11	10	237	176	227	198	626	321	1325	337	220	1089	1755	
12	11	87	65	83	73	230	118	486	124	81	400	644	
13	12	60	44	57	50	158	81	334	85	55	275	443	
14	13	84	62	80	70	222	114	470	120	78	386	622	
15	14	134	99	128	112	354	181	748	190	124	615	991	
16	15	196	145	187	164	517	265	1094	279	181	899	1450	
17	16	265	197	254	221	700	359	1480	377	245	1217	1961	
18	17	239	177	228	199	631	324	1334	340	221	1097	1768	
19	18	87	65	84	73	231	119	488	124	81	401	647	
20	19	60	45	58	50	159	82	336	86	56	277	446	
21	20	85	63	81	71	225	115	476	121	79	391	630	
22	21	135	100	129	112	355	182	752	191	125	618	996	
23	22	197	146	188	164	519	266	1098	280	182	902	1455	
24	23	265	197	254	221	700	359	1481	377	246	1218	1963	
25	24	240	178	229	200	632	324	1337	340	222	1099	1772	
26	25	87	65	83	73	230	118	486	124	81	400	644	
27	26	62	46	59	52	163	84	345	88	57	284	458	
28	27	86	64	82	72	226	116	479	122	79	393	634	
29	28	135	100	129	113	357	183	755	192	125	621	1001	
30	29	198	146	189	165	521	268	1103	281	183	907	1462	
31	30	267	198	255	223	704	361	1488	379	247	1223	1972	
32	31	241	178	230	201	635	326	1344	342	223	1105	1781	
33	32	90	66	86	75	237	121	501	128	83	412	663	
34	33	64	47	61	53	169	86	356	91	59	293	472	

Daily demand forecast for MyPal Product Line in each megaregion (figure above)

	Arizon Sun	Cascadia	Florida	Front Rang	Great Lake	Gulf Coast	Northeast	Northern (	Piedmont ,	Southern (	Texas Triangle
1	780	578	746	651	2059	1057	4356	1109	722	3581	5772
2	730	541	698	610	1928	989	4078	1038	676	3352	5404
3	705	522	674	588	1860	955	3935	1002	652	3234	5214
4	673	499	644	562	1777	912	3759	957	623	3089	4980
5	660	489	631	551	1743	894	3686	939	611	3030	4885
6	636	471	608	531	1678	861	3550	904	588	2917	4703
7	614	455	587	512	1620	831	3426	872	568	2816	4539
8	600	445	574	501	1584	813	3351	853	555	2754	4440
9	609	451	582	508	1608	825	3400	866	564	2795	4506
10	635	471	607	530	1677	860	3547	903	588	2915	4699
11	635	471	607	530	1677	860	3547	903	588	2915	4700
12	644	478	616	538	1700	873	3597	916	596	2956	4766
13	653	484	625	545	1724	885	3647	929	604	2997	4832
14	674	499	644	562	1778	912	3761	958	623	3091	4983
15	653	484	624	545	1723	884	3644	928	604	2995	4829
16	742	550	709	619	1958	1005	4141	1054	686	3404	5487
17	777	576	743	649	2051	1053	4338	1105	719	3566	5748
18	864	641	826	721	2281	1170	4824	1228	800	3965	6393
19	822	610	786	686	2170	1114	4591	1169	761	3773	6083
20	883	655	844	737	2331	1196	4930	1255	817	4052	6533
21	867	642	829	723	2287	1174	4838	1232	802	3977	6411
22	900	667	861	751	2376	1219	5026	1280	833	4131	6660
23	975	723	932	814	2573	1321	5444	1386	902	4474	7213
24	954	707	913	797	2519	1293	5328	1357	883	4379	7060
25	985	730	942	822	2600	1334	5500	1401	912	4521	7288
26	987	731	943	824	2604	1337	5509	1403	913	4528	7300
27	1010	749	966	843	2666	1368	5639	1436	935	4635	7472
28	1045	775	999	872	2758	1415	5834	1486	967	4795	7730
29	1070	793	1024	893	2825	1450	5976	1522	990	4912	7919
30	1087	806	1039	907	2869	1472	6069	1545	1006	4988	8041
31	1017	754	972	849	2684	1377	5677	1446	941	4666	7523
32	1061	787	1015	886	2802	1438	5926	1509	982	4871	7853
33	1032	765	987	862	2725	1399	5765	1468	955	4738	7638

Weekly demand forecast for MyPal Product Line in each megaregion (figure above)

	Arizon Sun	Cascadia	Florida	Front Rang	Great Lake	Gulf Coast	Northeast	Northern (	Piedmont ,	Southern (	Texas Triangle
1	72676	53873	69493	60661	191824	98442	405762	103320	67248	333505	537646
2	98299	72868	93994	82048	259455	133149	548822	139748	90958	451089	727204
3	138223	102462	132168	115371	364829	187226	771719	196505	127899	634293	1022548
4	193087	143132	184629	161165	509640	261542	1078037	274503	178666	886063	1428427
5	265930	197129	254281	221965	701903	360209	1484728	378060	246068	1220332	1967304

Yearly demand forecast for MyPal Product Line in each megaregion (figure above)

Task 3 Sensitivity Analysis (from 95% to 99.9% service level)
Since the original table or list is too large, here we just attached part of table or list.

Final result of how many cells for each product at each time:

95%:

	WorkPal_1	WorkPal_1.1	WorkPal_3	WorkPal_4	WorkPal_5	WorkPal_6	WorkPal_7	WorkPal_8	WorkPal_9	WorkPal_10	WorkPal_11	WorkPal_12	WorkPal_13	WorkPal_14
1	7	0	0	2	0	3	5	5	5	2	6	5	2	4
2	7	0	0	1	0	3	5	5	6	1	5	5	2	4
3	7	0	0	1	0	2	5	6	5	1	5	5	3	4
4	7	0	0	1	0	3	5	5	5	2	5	5	3	4
5	7	0	0	1	0	3	6	6	5	1	6	5	2	3
6	8	0	0	1	0	3	5	5	5	1	5	5	3	4
7	8	0	0	1	0	4	5	5	6	2	5	5	3	4
8	8	0	0	1	0	3	5	5	5	2	5	5	2	4
9	8	0	0	1	0	3	5	5	5	1	6	4	3	4
10	7	0	0	1	0	3	5	5	6	1	5	5	2	4
11	7	0	0	1	0	3	5	5	5	1	5	5	2	3
12	7	0	0	2	0	3	5	5	5	2	5	5	2	4
13	7	0	0	2	0	3	5	5	6	2	6	5	2	4
14	7	0	0	1	0	3	5	5	5	1	5	5	3	4
15	8	0	0	1	0	3	5	5	5	2	5	5	3	4
16	8	0	0	1	0	3	5	5	5	2	5	5	3	4
17	7	0	0	1	0	3	5	5	5	2	5	5	3	4
18	8	0	0	1	0	3	5	6	5	2	6	5	2	4
19	7	0	0	1	0	3	5	5	5	1	5	5	2	4
20	8	0	0	1	0	3	5	5	5	2	6	5	2	4
21	8	0	0	1	0	3	5	5	5	2	6	5	2	4
22	8	0	0	1	0	3	5	6	5	1	5	5	2	3

96%:

	WorkPal_1	WorkPal_1.1	WorkPal_3	WorkPal_4	WorkPal_5	WorkPal_6	WorkPal_7	WorkPal_8	WorkPal_9	WorkPal_10	WorkPal_11	WorkPal_12	WorkPal_13	WorkPal_14
1	7	0	0	2	0	3	5	5	5	2	6	5	2	4
2	8	0	0	1	0	3	5	5	5	2	5	5	3	4
3	7	0	0	1	0	3	6	6	5	2	5	5	3	4
4	8	0	0	1	0	3	5	5	5	2	5	5	3	4
5	7	0	0	1	0	3	6	6	5	2	6	5	2	4
6	8	0	0	1	0	3	6	5	5	2	6	5	2	4
7	8	0	0	1	0	3	5	5	6	2	5	5	3	4
8	8	0	0	2	0	4	5	6	5	2	6	5	2	4
9	8	0	0	1	0	3	5	5	6	2	6	5	2	4
10	8	0	0	1	0	3	5	5	6	2	6	5	2	4
11	7	0	0	1	0	3	5	5	6	1	5	5	2	4
12	8	0	0	1	0	3	5	5	6	1	5	5	2	4
13	8	0	0	1	0	3	6	5	6	2	6	5	2	4
14	7	0	0	1	0	3	5	5	6	1	5	5	2	4
15	8	0	0	1	0	3	5	5	5	2	5	5	3	4
16	8	0	0	1	0	3	5	5	6	2	6	5	2	4
17	8	0	0	1	0	3	5	5	6	2	5	5	3	4
18	8	0	0	2	0	4	5	6	5	2	6	5	2	4
19	7	0	0	1	0	3	5	6	5	1	5	5	3	4
20	8	0	0	1	0	3	5	5	6	2	6	5	2	4
21	8	0	0	1	0	3	5	5	5	2	6	5	2	4
22	8	0	0	1	0	3	5	6	6	2	6	5	2	4

97%:

	WorkPal_1	WorkPal_1.1	WorkPal_3	WorkPal_4	WorkPal_5	WorkPal_6	WorkPal_7	WorkPal_8	WorkPal_9	WorkPal_10	WorkPal_11	WorkPal_12	WorkPal_13	WorkPal_14
1	8	0	0	1	0	3	6	6	5	2	6	6	2	4
2	8	0	0	1	0	3	5	6	5	1	5	5	3	4
3	8	0	0	1	0	3	6	6	6	2	6	5	2	4
4	8	0	0	1	0	3	5	6	5	2	5	5	3	4
5	8	0	0	1	0	4	6	6	6	2	6	5	3	4
6	8	0	0	1	0	3	6	5	6	2	6	5	2	4
7	8	0	0	1	0	4	6	5	6	2	5	5	3	4
8	8	0	0	2	0	4	6	6	5	2	6	5	2	4
9	9	0	0	1	0	3	5	6	5	2	6	5	3	4
10	8	0	0	1	0	3	5	6	5	1	6	5	2	4
11	8	0	0	1	0	3	5	5	6	2	6	5	2	4
12	8	0	0	1	0	4	5	6	5	2	6	4	3	4
13	8	0	0	1	0	3	6	6	6	2	6	5	3	4
14	8	0	0	1	0	3	5	6	5	2	5	5	3	4
15	8	0	0	1	0	3	5	5	5	1	6	5	2	4
16	8	0	0	2	0	3	5	5	6	2	6	5	2	4
17	8	0	0	2	0	3	6	6	5	2	6	5	2	4
18	8	0	0	2	0	4	5	6	6	2	6	5	3	4
19	8	0	0	1	0	3	6	6	5	2	6	5	2	4
20	8	0	0	1	0	3	6	5	6	2	6	5	2	4
21	8	0	0	2	0	4	5	6	5	2	6	5	3	4
22	8	0	0	2	0	3	5	6	6	2	6	5	2	4

98%:

	WorkPal_1	WorkPal_2	WorkPal_3	WorkPal_4	WorkPal_5	WorkPal_6	WorkPal_7	WorkPal_8	WorkPal_9	WorkPal_10	WorkPal_11	WorkPal_12	WorkPal_13	WorkPal_14
1	8	0	0	2	0	4	6	6	6	2	6	6	3	4
2	8	0	0	2	0	4	5	6	6	2	6	5	2	4
3	8	0	0	1	0	4	6	6	6	2	6	5	3	4
4	8	0	0	2	0	4	6	6	6	2	6	5	3	4
5	8	0	0	1	0	4	6	6	6	2	6	6	2	4
6	8	0	0	1	0	4	6	6	6	2	6	5	3	4
7	8	0	0	2	0	4	6	6	6	2	6	5	2	4
8	9	0	0	1	0	4	6	6	6	2	6	5	3	4
9	9	0	0	1	0	3	6	6	5	2	6	5	3	4
10	8	0	0	1	0	3	6	6	6	2	6	5	3	4
11	8	0	0	1	0	3	6	6	5	2	6	5	2	4
12	8	0	0	2	0	4	6	6	6	2	6	5	2	4
13	8	0	0	2	0	3	6	6	6	2	6	5	3	4
14	8	0	0	1	0	4	6	6	6	2	6	5	2	4
15	8	0	0	2	0	3	6	6	5	2	6	5	3	4
16	8	0	0	2	0	3	6	6	5	2	6	5	3	4
17	8	0	0	2	0	4	6	6	6	2	6	5	3	4
18	9	0	0	1	0	4	6	6	6	2	6	6	3	4
19	8	0	0	1	0	3	6	6	6	2	6	5	2	4
20	9	0	0	1	0	3	6	6	6	2	6	6	2	4
21	8	0	0	1	0	3	6	6	6	2	6	5	3	4
22	8	0	0	2	0	3	6	7	6	2	6	5	3	4

99%:

	WorkPal_1	WorkPal_2	WorkPal_3	WorkPal_4	WorkPal_5	WorkPal_6	WorkPal_7	WorkPal_8	WorkPal_9	WorkPal_10	WorkPal_11	WorkPal_12	WorkPal_13	WorkPal_14
1	9	0	0	1	0	4	6	7	5	2	7	6	2	4
2	9	0	0	1	0	3	6	6	7	2	6	5	3	4
3	9	0	0	1	0	4	7	7	6	2	6	6	3	4
4	9	0	0	1	0	4	6	7	6	2	6	6	3	4
5	9	0	0	1	0	4	7	7	6	2	6	6	3	4
6	9	0	0	2	0	4	7	6	6	2	6	6	3	4
7	9	0	0	2	0	4	6	6	7	2	6	6	3	4
8	10	0	0	1	0	4	6	7	6	2	6	6	2	4
9	10	0	0	1	0	4	6	6	6	2	7	5	2	4
10	9	0	0	1	0	4	6	6	6	2	6	6	2	3
11	9	0	0	1	0	4	6	6	6	2	6	6	3	4
12	9	0	0	1	0	4	6	6	6	2	6	5	3	4
13	9	0	0	2	0	4	6	6	7	2	6	6	3	4
14	8	0	0	2	0	4	6	7	6	2	6	6	3	4
15	9	0	0	2	0	4	6	6	6	2	6	6	3	4
16	9	0	0	2	0	4	6	6	6	2	6	6	3	4
17	9	0	0	2	0	4	7	7	6	2	6	6	3	4
18	10	0	0	1	0	4	6	7	6	2	6	6	3	4
19	9	0	0	1	0	4	6	7	6	2	6	6	2	3
20	9	0	0	1	0	4	7	6	6	2	6	6	3	4
21	9	0	0	2	0	4	6	6	6	2	6	6	3	4
22	9	0	0	2	0	4	6	7	7	2	6	6	3	4

99.9%:

	WorkPal_1	WorkPal_2	WorkPal_3	WorkPal_4	WorkPal_5	WorkPal_6	WorkPal_7	WorkPal_8	WorkPal_9	WorkPal_10	WorkPal_11	WorkPal_12	WorkPal_13	WorkPal_14
1	10	0	0	2	0	5	8	8	7	2	7	7	3	4
2	11	0	0	1	0	5	7	8	7	3	7	6	3	5
3	10	0	0	1	0	5	8	8	7	3	7	6	3	5
4	10	0	0	1	0	5	8	8	7	2	7	6	3	4
5	10	0	0	2	0	5	8	8	7	2	7	7	3	4
6	11	0	0	2	0	5	8	8	7	2	7	6	3	5
7	11	0	0	2	0	5	8	8	7	3	7	6	3	5
8	11	0	0	2	0	5	8	8	7	3	7	6	3	5
9	11	0	0	1	0	4	8	8	7	2	7	6	3	5
10	11	0	0	1	0	4	7	8	7	2	7	6	3	5
11	10	0	0	1	0	5	7	7	7	2	7	6	2	4
12	11	0	0	1	0	5	8	8	7	2	7	6	3	5
13	11	0	0	2	0	4	8	8	7	3	7	6	3	5
14	10	0	0	1	0	5	7	8	7	3	7	6	3	5
15	11	0	0	1	0	4	7	7	7	2	7	6	2	4
16	11	0	0	2	0	4	7	7	7	3	7	6	3	5
17	11	0	0	2	0	5	8	8	7	3	7	7	3	5
18	11	0	0	1	0	5	7	8	8	2	7	6	3	4
19	10	0	0	1	0	5	8	8	7	2	7	6	3	4
20	11	0	0	2	0	4	8	8	7	2	7	7	3	4
21	11	0	0	2	0	5	8	8	7	2	7	7	3	5
22	10	0	0	2	0	4	7	9	7	2	7	7	3	4

Change Pace (the first column is the type of product, the second column is the time t):

95%:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	changepace																
2	Group1	7	6	6	7	6	7	6	7	6	6	6	6	7	7	6	6
3	Time	3	5	12	13	14	17	18	19	21	26	29	34	34	38	41	44

96%:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	changepace																
2	Group1	6	7	6	6	7	6	6	7	6	7	6	6	7	6	7	6
3	Time	1	1	4	10	11	14	17	19	21	24	26	32	37	41	51	56

97%:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	changepace																
2	Group1	6	6	6	6	6	6	7	6	7	6	6	6	6	6	6	6
3	Time	1	10	17	56	69	90	96	97	106	133	141	149	158	169	171	198

98%:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	changepace																
2	Group1	7	6	7	7	6	6	7	6	7	6	6	7	7	7	6	6
3	Time	5	13	17	27	29	45	49	56	60	63	71	77	82	94	98	102
4																	

99%:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	changepace																
2	Group1	7	6	7	6	7	7	6	6	7	6	7	7	6	6	6	6
3	Time	1	7	11	18	19	24	34	56	60	63	66	79	82	94	98	102
4																	

99.9%:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	changepace																
2	Group1	7	6	6	7	7	7	7	7	7	7	7	7	7	7	6	6
3	Time	5	7	18	27	29	47	49	60	63	71	77	82	94	96	98	100
4																	

Extending work (the rows mean the time from day1 to day1826, the columns mean the type of product):

95%:

1	0.00000000	0	0	0.000000000	0	0	0	0.0000000	0.0000000	0	0.0000000	0.00000000	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.0000000	0	0	0	0	0	0
2	0.48677378	0	0	0.000000000	0	0	0	0.0000000	0.0000000	0	0.0000000	0.00000000	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.0000000	0	0	0	0	0	0
3	0.00000000	0	0	0.000000000	0	0	0	0.0000000	1.5725506	0	0.5131814	0.00000000	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.0000000	0	0	0	0	0	0
4	0.40948650	0	0	0.000000000	0	0	0	0.0000000	0.5167889	0	0.0000000	0.00000000	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.0000000	0	0	0	0	0	0
5	0.00000000	0	0	0.000000000	0	0	0	0.0000000	0.1983905	0	0.0000000	0.00000000	0	0.7346800	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.0000000	0	0	0	0	0	0
6	0.00000000	0	0	0.000000000	0	0	0	0.0000000	0.2626720	0	0.8904324	0.00000000	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.0000000	0	0	0	0	0	0
7	0.00000000	0	0	0.000000000	0	0	0	0.0000000	0.0000000	0	0.0000000	0.00000000	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.0000000	0	0	0	0	0	0
8	0.00000000	0	0	0.000000000	0	0	0	1.1039486	0.6133830	0	1.6345503	0.00000000	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.0000000	0	0	0	0	0	0
9	0.00000000	0	0	0.000000000	0	0	0	0.0000000	1.6948353	0	0.0000000	0.00000000	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.0000000	0	0	0	0	0	0
10	1.92113795	0	0	0.136029665	0	0	0	0.0000000	0.0000000	0	1.7292876	0.00000000	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.0000000	0	0	0	0	0	0
11	0.00000000	0	0	0.193928251	0	0	0	0.0000000	1.0447671	0	0.3597557	0.00000000	0	0.7211403	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.0000000	0	0	0	0	0	0
12	0.81635440	0	0	0.000000000	0	0	0	0.0000000	0.9076891	0	0.0000000	0.00000000	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.0000000	0	0	0	0	0	0
13	2.40190532	0	0	0.000000000	0	0	0	0.0000000	0.0000000	0	0.0000000	0.00000000	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.0000000	0	0	0	0	0	0
14	0.00000000	0	0	0.000000000	0	0	0	0.0000000	1.0448492	0	0.0000000	0.00000000	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.0000000	0	0	0	0	0	0
15	0.00000000	0	0	0.307784225	0	0	0	0.0000000	0.0000000	0	0.3138555	0.00000000	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.0000000	0	0	0	0	0	0
16	0.00000000	0	0	0.000000000	0	0	0	0.0000000	0.0000000	0	0.8359727	0.00000000	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.0000000	0	0	0	0	0	0
17	2.48841508	0	0	0.000000000	0	0	0	0.0000000	1.6734889	0	0.4526859	0.00000000	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.4244248	0	0	0	0	0	0
18	0.00000000	0	0	0.000000000	0	0	0	0.0000000	0.0000000	0	0.0000000	0.00000000	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.0000000	0	0	0	0	0	0
19	0.00000000	0	0	0.348252229	0	0	0	0.9452409	0.0000000	0	0.4294730	0.00000000	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.0000000	0	0	0	0	0	0
20	0.00000000	0	0	0.000000000	0	0	0	0.0000000	0.0000000	0	0.0000000	0.00000000	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.0000000	0	0	0	0	0	0
21	0.00000000	0	0	0.000000000	0	0	0	0.0000000	0.0000000	0	0.0000000	0.00000000	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.0000000	0	0	0	0	0	0
22	0.00000000	0	0	0.170413788	0	0	0	0.0000000	0.0000000	0	0.8942189	0.00000000	0	0.8622664	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.0000000	0	0	0	0	0	0

96%:

1	1.45891760	0	0	0.000000000	0	0	0	1.09486154	0.38325385	0	0.0000000	1.05676176	0	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0	0.00000000	0	0	0	0	0	0
2	0.00000000	0	0	0.000000000	0	0	0	0.19666741	0.00000000	0	0.0000000	0.00000000	0	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0	0.00000000	0	0	0	0	0	0
3	0.75693705	0	0	0.000000000	0	0	0	0.00000000	0.00000000	0	1.5568063	0.00000000	0	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0	0.00000000	0	0	0	0	0	0
4	0.00000000	0	0	0.000000000	0	0	0	1.28506263	1.70027075	0	0.0000000	0.00000000	0	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0	0.00000000	0	0	0	0	0	0
5	1.21118610	0	0	0.000000000	0	0	0	0.00000000	1.43105660	0	0.0000000	0.38959095	0	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0	0.00000000	0	0	0	0	0	0
6	0.00000000	0	0	0.000000000	0	0	0	0.00000000	1.50612712	0	0.0000000	0.00000000	0	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0	0.02336322	0	0	0	0	0	0
7	0.00000000	0	0	0.000000000	0	0	0	0.00000000	0.00000000	0	0.0000000	0.00000000	0	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0	0.34795206	0	0	0	0	0	0
8	0.00000000	0	0	0.000000000	0	0	0	0.00000000	0.00000000	0	0.0000000	0.00000000	0	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0	0.00000000	0	0	0	0	0	0
9	0.00000000	0	0	0.000000000	0	0	0	0.00000000	0.00000000	0	0.0000000	0.00000000	0	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0	0.00000000	0	0	0	0	0	0
10	0.00000000	0	0	0.000000000	0	0	0	0.07757926	0.00000000	0	0.0000000	0.00000000	0	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0	0.47727758	0	0	0	0	0	0
11	1.86464142	0	0	0.000000000	0	0	0	0.00000000	0.00000000	0	1.4114586	0.00000000	0	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0	0.00000000	0	0	0	0	0	0
12	0.00000000	0	0	0.000000000	0	0	0	0.98734507	0.00000000	0	0.7225100	0.00000000	0	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0	0.56835825	0	0	0	0	0	0
13	0.00000000	0	0	0.000000000	0	0	0	0.00000000	0.00000000	0	0.0000000	0.00000000	0	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0	0.00000000	0	0	0	0	0	0
14	0.00000000	0	0	0.000000000	0	0	0	1.31561956	0.00000000	0	0.3957173	0.00000000	0	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0	0.00000000	0	0	0	0	0	0
15	0.00000000	0	0	0.000000000	0	0	0	0.00000000	0.18101737	0	1.4648824	0.00000000	0	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0	0.00000000	0	0	0	0	0	0
16	0.00000000	0	0	0.000000000	0	0	0	0.00000000	0.00000000	0	0.0000000	0.00000000	0	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0	0.12362428	0	0	0	0	0	0
17	0.00000000	0	0	0.000000000	0	0	0	1.38061767	0.00000000	0	1.5145682	0.35794427	0	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0	0.00000000	0	0	0	0	0	0
18	0.00000000	0	0	0.000000000	0	0	0	0.00000000	0.00000000	0	0.0000000	0.13766505	0	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0	0.00000000	0	0	0	0	0	0
19	0.00000000	0	0	0.000000000	0	0	0	0.00000000	0.00000000	0	1.4689579	0.00000000	0	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0	0.00000000	0	0	0	0	0	0
20	0.00000000	0	0	0.000000000	0	0	0	0.00000000	0.00000000	0	0.0000000	0.30131875	0	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0	0.11498039	0	0	0	0	0	0
21	0.00000000	0	0	0.000000000	0	0	0	0.00000000	1.15725745	0	0.0000000	0.00000000	0	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0	0.00000000	0	0	0	0	0	0
22	0.00000000	0	0	0.000000000	0	0	0	0.00000000	0.00000000	0	0.0000000	0.00000000	0	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0	0.00000000	0	0	0	0	0	0

97%:

1	0.000000000	0	0	0.0000000	0	0	0	0.00000000	0.00000000	0	0.0000000	0.0000000	0	0.000000000	0.000000000	0.0000000	0.00000000	0.000000000	0	0.67802018	0	0	0	0	0	0
2	0.000000000	0	0	0.0000000	0	0	0	0.00000000	0.00000000	0	0.8164148	0.0000000	0	0.000000000	0.000000000	0.0000000	0.00000000	0.000000000	0	0.52693238	0	0	0	0	0	0
3	0.000000000	0	0	0.0000000	0	0	0	0.00000000	0.00000000	0	0.0000000	0.5141950	0	0.000000000	0.000000000	0.0000000	0.00000000	0.000000000	0	0.59538899	0	0	0	0	0	0
4	0.000000000	0	0	0.0000000	0	0	0	0.00000000	0.00000000	0	1.1050766	0.6094287	0	0.000000000	0.000000000	0.0000000	0.00000000	0.000000000	0	0.00000000	0	0	0	0	0	0
5	0.000000000	0	0	0.0000000	0	0	0	0.00000000	0.00000000	0	0.0000000	0.0000000	0	0.000000000	0.000000000	0.0000000	0.00000000	0.000000000	0	0.00000000	0	0	0	0	0	0
6	0.000000000	0	0	0.0000000	0	0	0	1.29688557	0.00000000	0	0.0000000	0.0000000	0	0.000000000	0.000000000	0.0000000	0.00000000	0.000000000	0	0.89481846	0	0	0	0	0	0
7	0.000000000	0	0	0.0000000	0	0	0	1.77780962	0.00000000	0	0.9763075	0.0000000	0	0.000000000	0.000000000	0.0000000	0.00000000	0.000000000	0	0.00000000	0	0	0	0	0	0
8	2.543983823	0	0	0.0000000	0	0	0	0.00000000	0.00000000	0	0.0000000	0.0000000	0	0.000000000	0.000000000	0.0000000	0.00000000	0.000000000	0	0.00000000	0	0	0	0	0	0
9	0.000000000	0	0	0.0000000	0	0	0	0.00000000	0.00000000	0	0.0000000	0.0000000	0	0.000000000	0.000000000	0.0000000	0.00000000	0.000000000	0	0.00000000	0	0	0	0	0	0
10	0.000000000	0	0	0.0000000	0	0	0	0.00000000	0.00000000	0	0.0000000	0.0000000	0	0.000000000	0.000000000	0.0000000	0.00000000	0.000000000	0	0.00000000	0	0	0	0	0	0
11	0.000000000	0	0	0.0000000	0	0	0	0.00000000	0.00000000	0	0.0000000	0.0000000	0	0.000000000	0.000000000	0.0000000	0.00000000	0.000000000	0	0.82768162	0	0	0	0	0	0
12	0.000000000	0	0	0.0000000	0	0	0	0.00000000	0.00000000	0	0.0000000	0.0000000	0	0.000000000	0.000000000	0.0000000	0.00000000	0.000000000	0	0.00000000	0	0	0	0	0	0
13	0.000000000	0	0	0.0000000	0	0	0	0.00000000	0.00000000	0	0.0000000	0.0000000	0	0.000000000	0.000000000	0.0000000	0.00000000	0.000000000	0	0.27804026	0	0	0	0	0	0
14	0.000000000	0	0	0.0000000	0	0	0	0.00000000	0.00000000	0	1.6319813	0.0000000	0	0.000000000	0.000000000	0.0000000	0.00000000	0.000000000	0	0.00000000	0	0	0	0	0	0
15	0.000000000	0	0	0.0000000	0	0	0	0.00000000	1.60255446	0	0.0000000	0.6144527	0	0.000000000	0.000000000	0.0000000	0.00000000	0.000000000	0	0.00000000	0	0	0	0	0	0
16	0.000000000	0	0	0.0000000	0	0	0	0.00000000	0.00000000	0	0.0000000	0.0000000	0	0.000000000	0.000000000	0.0000000	0.00000000	0.000000000	0	0.98825847	0	0	0	0	0	0
17	0.000000000	0	0	0.0000000	0	0	0	0.00000000	0.00000000	0	0.0000000	0.0000000	0	0.000000000	0.000000000	0.0000000	0.00000000	0.000000000	0	0.00000000	0	0	0	0	0	0
18	2.572199967	0	0	0.0000000	0	0	0	0.00000000	0.00000000	0	0.0000000	1.6410477	0	0.000000000	0.000000000	0.0000000	0.00000000	0.000000000	0	0.58860974	0	0	0	0	0	0
19	0.000000000	0	0	0.0000000	0	0	0	0.00000000	1.08854034	0	0.0000000	0.0000000	0	0.000000000	0.000000000	0.0000000	0.00000000	0.000000000	0	0.12246356	0	0	0	0	0	0
20	0.000000000	0	0	0.0000000	0	0	0	1.27080169	0.00000000	0	0.0000000	1.7602571	0	0.000000000	0.000000000	0.0000000	0.00000000	0.000000000	0	0.95875228	0	0	0	0	0	0
21	0.000000000	0	0	0.0000000	0	0	0	0.00000000	0.00000000	0	0.0000000	0.0000000	0	0.000000000	0.000000000	0.0000000	0.00000000	0.000000000	0	0.70506522	0	0	0	0	0	0
22	0.000000000	0	0	0.0000000	0	0	0	0.00000000	0.00000000	0	0.0000000	0.6923678	0	0.000000000	0.000000000	0.0000000	0.00000000	0.000000000	0	0.75329896	0	0	0	0	0	0

98%:

1	0.00000000	0	0	0	0	0	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000	0	0.0000000	0	0	0	0	0
2	0.00000000	0	0	0	0	0	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000	0	0.0000000	0	0	0	0	0
3	0.00000000	0	0	0	0	0	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000	0	0.0000000	0	0	0	0	0
4	0.00000000	0	0	0	0	0	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000	0	0.6910327	0	0	0	0	0
5	0.00000000	0	0	0	0	0	0	0.3830450	0.00000000	0.00000000	0.00000000	0.00000000	0	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000	0	0.8830414	0	0	0	0	0
6	2.03545812	0	0	0	0	0	0	0.0000000	0.00000000	0.00000000	0.00000000	1.45710368	0	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000	0	0.0000000	0	0	0	0	0
7	2.63370115	0	0	0	0	0	0	0.0000000	0.00000000	0.00000000	0.00000000	1.59689543	0	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000	0	0.0000000	0	0	0	0	0
8	0.00000000	0	0	0	0	0	0	0.0000000	0.00000000	0.00000000	0.00000000	0.13847530	0	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000	0	0.8626991	0	0	0	0	0
9	0.00000000	0	0	0	0	0	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000	0	0.1852041	0	0	0	0	0
10	0.81249583	0	0	0	0	0	0	0.0000000	0.00000000	0.00000000	0.00000000	0.48193571	0	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000	0	0.0000000	0	0	0	0	0
11	0.00000000	0	0	0	0	0	0	0.0000000	0.00000000	0.00000000	0.00000000	0.99323594	0	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000	0	0.0000000	0	0	0	0	0
12	0.00000000	0	0	0	0	0	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000	0	0.0000000	0	0	0	0	0
13	1.49692695	0	0	0	0	0	0	0.0000000	0.00000000	0.00000000	0.00000000	0.98253346	0	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000	0	0.0000000	0	0	0	0	0
14	0.00000000	0	0	0	0	0	0	0.0000000	0.00000000	0.00000000	0.00000000	1.39408233	0	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000	0	0.9192507	0	0	0	0	0
15	1.64766716	0	0	0	0	0	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000	0	0.9468132	0	0	0	0	0
16	1.64669598	0	0	0	0	0	0	0.0000000	0.00000000	0.04486182	0.00000000	0.84937850	0	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000	0	0.0000000	0	0	0	0	0
17	1.41329743	0	0	0	0	0	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000	0	0.0000000	0	0	0	0	0
18	0.00000000	0	0	0	0	0	0	0.5778611	0.00000000	0.00000000	0.00000000	0.00000000	0	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000	0	0.0000000	0	0	0	0	0
19	0.00000000	0	0	0	0	0	0	0.0000000	0.00000000	0.00000000	0.00000000	0.62169465	0	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000	0	0.0000000	0	0	0	0	0
20	0.00000000	0	0	0	0	0	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000	0	0.0000000	0	0	0	0	0
21	2.20420824	0	0	0	0	0	0	0.0000000	0.00000000	0.00000000	0.00000000	1.70879454	0	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000	0	0.0000000	0	0	0	0	0
22	2.54199467	0	0	0	0	0	0	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0	0.00000000	0.00000000	0.000000000	0.000000000	0.000000000	0	0.0000000	0	0	0	0	0

99%:

1	0.000000000	0	0	0	0	0	0	0.000000000	0.000000000	0.00000000	0.000000e+00	0.0000000	0.0000000	0.0000000	0.00000000	0.00000000	0.00000000	0.000000000	0	0.000000000	0	0	0	0
2	0.000000000	0	0	0	0	0	0	1.144662272	0.000000000	0.00000000	0.000000e+00	0.0000000	0.0000000	0.0000000	0.00000000	0.00000000	0.41531862	0.000000000	0	0.000000000	0	0	0	0
3	0.000000000	0	0	0	0	0	0	0.000000000	0.213314304	0.00000000	0.000000e+00	0.0000000	0.0000000	0.0000000	0.00000000	0.00000000	0.00000000	0.000000000	0	0.000000000	0	0	0	0
4	0.000000000	0	0	0	0	0	0	0.000000000	0.000000000	0.00000000	0.000000e+00	0.0000000	0.0000000	0.0000000	0.00000000	0.68426083	0.00000000	0.000000000	0	0.000000000	0	0	0	0
5	0.000000000	0	0	0	0	0	0	0.000000000	0.000000000	0.00000000	1.204259e+00	0.0000000	0.0000000	0.0000000	0.00000000	0.00000000	0.00000000	0.000000000	0	0.000000000	0	0	0	0
6	0.000000000	0	0	0	0	0	0	0.000000000	0.000000000	0.02860406	0.000000e+00	0.0000000	0.0000000	0.0000000	0.00000000	0.00000000	0.00000000	0.000000000	0	0.000000000	0	0	0	0
7	0.000000000	0	0	0	0	0	0	0.252055217	0.000000000	0.00000000	0.000000e+00	0.0000000	0.0000000	0.0000000	0.00000000	0.00000000	0.00000000	0.000000000	0	0.000000000	0	0	0	0
8	0.000000000	0	0	0	0	0	0	0.000000000	0.000000000	0.00000000	0.000000e+00	0.0000000	0.0000000	0.0000000	0.00000000	0.00000000	0.00000000	0.000000000	0	0.000000000	0	0	0	0
9	0.000000000	0	0	0	0	0	0	0.319726489	0.319451715	0.25519870	0.000000e+00	0.0000000	0.0000000	0.0000000	0.39676690	0.00000000	0.00000000	0.000000000	0	0.000000000	0	0	0	0
10	0.000000000	0	0	0	0	0	0	0.682227459	1.102135119	0.00000000	0.000000e+00	0.0000000	0.0000000	0.0000000	0.00000000	0.00000000	0.00000000	0.331118601	0	0.000000000	0	0	0	0
11	0.000000000	0	0	0	0	0	0	0.000000000	0.000000000	0.00000000	0.000000e+00	0.0000000	0.0000000	0.0000000	0.00000000	0.55411824	0.00000000	0.000000000	0	0.000000000	0	0	0	0
12	0.000000000	0	0	0	0	0	0	1.545340440	0.000000000	0.00000000	0.000000e+00	1.1788287	0.0000000	0.0000000	0.00000000	0.35968804	0.00000000	0.000000000	0	0.000000000	0	0	0	0
13	0.000000000	0	0	0	0	0	0	0.451057017	0.000000000	0.00000000	1.916387e+00	0.0000000	0.0000000	0.0000000	0.00000000	0.00000000	0.00000000	0.000000000	0	0.000000000	0	0	0	0
14	0.000000000	0	0	0	0	0	0	0.000000000	0.000000000	0.00000000	0.000000e+00	0.0000000	0.0000000	0.0000000	0.00000000	0.00000000	0.00000000	0.000000000	0	0.000000000	0	0	0	0
15	0.000000000	0	0	0	0	0	0	0.000000000	0.000000000	0.00000000	0.000000e+00	0.0000000	0.0000000	0.0000000	0.00000000	0.00000000	0.00000000	0.000000000	0	0.000000000	0	0	0	0
16	0.000000000	0	0	0	0	0	0	0.000000000	0.521660425	0.00000000	0.000000e+00	0.0000000	0.0000000	0.0000000	0.00000000	0.00000000	0.00000000	0.000000000	0	0.000000000	0	0	0	0
17	0.000000000	0	0	0	0	0	0	0.000000000	0.185901863	0.00000000	0.000000e+00	0.0000000	0.0000000	0.0000000	0.00000000	0.69800157	0.00000000	0.000000000	0	0.000000000	0	0	0	0
18	0.000000000	0	0	0	0	0	0	0.000000000	0.000000000	0.00000000	0.000000e+00	0.0000000	0.0000000	0.0000000	0.00000000	0.00000000	0.10986151	0.000000000	0	0.000000000	0	0	0	0
19	0.000000000	0	0	0	0	0	0	0.000000000	0.000000000	0.57558179	0.000000e+00	0.0000000	0.0000000	0.0000000	0.03590340	0.00000000	0.00000000	0.000000000	0	0.000000000	0	0	0	0
20	0.019504173	0	0	0	0	0	0	0.000000000	0.078629030	0.00000000	0.000000e+00	0.0000000	0.0000000	0.0000000	0.55792657	0.00000000	0.00000000	0.000000000	0	0.000000000	0	0	0	0
21	0.000000000	0	0	0	0	0	0	1.015792085	0.000000000	0.00000000	0.000000e+00	0.0000000	0.0000000	0.0000000	0.00000000	0.00000000	0.00000000	0.000000000	0	0.000000000	0	0	0	0
22	0.000000000	0	0	0	0	0	0	0.000000000	0.000000000	0.00000000	0.000000e+00	0.0000000	0.0000000	0.0000000	0.28599447	0.00000000	0.66995568	0.229836795	0	0.000000000	0	0	0	0

99.9%:

1	0.00000000	0	0	0	0	0	0	0.00000000	0.00000000	0.0000000	1.7813772	0.00000000	0.00000000	0.00000000	0.91224682	1.05500585	0.00000000	0.0000000	0.000000000	0.00000000	0	0	0	0
2	0.00000000	0	0	0	0	0	0	0.00000000	0.00000000	0.0000000	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0.00000000	0	0	0	0
3	0.00000000	0	0	0	0	0	0	0.34170882	0.00000000	0.0000000	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0.00000000	0	0	0	0
4	0.00000000	0	0	0	0	0	0	0.00000000	0.00000000	0.0000000	0.0000000	0.00000000	0.00000000	0.93950874	1.02734801	0.00000000	0.00000000	0.0000000	0.000000000	0.00000000	0	0	0	0
5	0.00000000	0	0	0	0	0	0	2.16263899	0.00000000	0.0000000	0.0801945	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0.00000000	0	0	0	0
6	0.00000000	0	0	0	0	0	0	0.00000000	0.00000000	0.0000000	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0.00000000	0	0	0	0
7	0.00000000	0	0	0	0	0	0	0.00000000	0.00000000	0.0000000	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0.00000000	0	0	0	0
8	2.21904757	0	0	0	0	0	0	1.04462641	0.00000000	0.0000000	0.0000000	0.58256792	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0.00000000	0	0	0	0
9	2.74864927	0	0	0	0	0	0	0.00000000	0.00000000	0.0000000	1.7476261	0.00000000	0.00000000	0.00000000	0.00000000	1.02319841	0.00000000	0.0000000	0.000000000	0.00000000	0	0	0	0
10	0.00000000	0	0	0	0	0	0	0.00000000	0.51538102	0.0000000	0.0000000	1.64248891	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0.00000000	0	0	0	0
11	0.00000000	0	0	0	0	0	0	0.56381813	0.00000000	0.0000000	0.0000000	1.87103785	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0.00000000	0	0	0	0
12	0.00000000	0	0	0	0	0	0	0.00000000	0.00000000	0.0000000	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0.00000000	0	0	0	0
13	0.00000000	0	0	0	0	0	0	0.00000000	0.00000000	0.0000000	1.0236605	1.84888164	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0.00000000	0	0	0	0
14	0.00000000	0	0	0	0	0	0	0.00000000	0.00000000	0.0000000	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0.00000000	0	0	0	0
15	0.00000000	0	0	0	0	0	0	0.80085630	0.00000000	0.0000000	0.0000000	0.00000000	0.00000000	0.71794436	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0.00000000	0	0	0	0
16	0.00000000	0	0	0	0	0	0	1.17933385	0.14497604	0.0000000	0.0000000	1.93521977	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0.00000000	0	0	0	0
17	0.00000000	0	0	0	0	0	0	0.00000000	0.00000000	0.0000000	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0.86584378	0	0	0	0
18	2.50345181	0	0	0	0	0	0	2.38920588	0.00000000	0.0000000	0.0000000	0.00000000	0.00000000	0.73663460	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0.00000000	0	0	0	0
19	0.00000000	0	0	0	0	0	0	0.00000000	0.00000000	0.0000000	0.0000000	1.43410964	0.00000000	0.95854355	0.00000000	0.00000000	0.00000000	0.6183744	0.000000000	0.00000000	0	0	0	0
20	0.00000000	0	0	0	0	0	0	0.00000000	0.00000000	0.0000000	0.0000000	0.00000000	0.00000000	0.06101604	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0.00000000	0	0	0	0
21	0.00000000	0	0	0	0	0	0	0.00000000	0.00000000	0.0000000	0.0000000	0.00000000	0.01377065	0.00000000	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0.00000000	0	0	0	0
22	0.00000000	0	0	0	0	0	0	0.00000000	2.07866573	0.0000000	0.0000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.0000000	0.000000000	0.00000000	0	0	0	0

Within Group (the first four columns mean the type of product needed to changeover, the last column means the time of changeover happens):

95%:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1		wtingrp															
2	1	Group1	11	14	16	19	1	11	19	1	19	1	19	1	19	19	1
3	2	Group2	13	15	17	20	4	12	20	4	20	4	20	4	20	20	4
4	3	Group3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	4	Group4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	5	Time	1	1	1	1	2	2	2	2	3	3	3	3	4	4	4
7																	
8																	

96%:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1		wtingrp															
2	1	Group1	11	14	1	14	1	14	18	11	19	1	11	1	14	18	1
3	2	Group2	13	15	4	15	4	15	19	13	20	4	13	4	15	19	4
4	3	Group3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	4	Group4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	5	Time	1	1	2	2	3	3	4	4	4	5	5	5	6	6	6
7																	
8																	
9																	

97%:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1		wtingrp															
2	1	Group1	1	8	12	14	1	8	1	8	14	1	11	14	11	18	8
3	2	Group2	4	9	13	15	4	9	4	9	15	4	12	15	13	20	9
4	3	Group3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	4	Group4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	5	Time	1	1	1	1	2	2	3	3	4	4	4	5	5	5	6
7																	

98%:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1		wtingrp															
2	1	Group1	19	6	11	19	11	1	12	19	14	1	1	14	11	1	8
3	2	Group2	20	7	13	20	12	4	13	20	15	4	4	15	13	4	9
4	3	Group3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	4	Group4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	5	Time	1	2	2	2	3	3	3	4	5	5	6	7	7	8	9
7																	
8																	
9																	

99%:

B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
wtingrp																					
Group1	1	8	11	19	1	11	19	1	19	1	19	1	19	19	1	12	19	1	11	19	1
Group2	4	9	13	20	4	12	20	4	20	4	20	4	20	20	4	13	20	4	12	20	4
Group3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Group4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Time	1	1	1	1	2	2	2	3	3	4	4	5	5	7	8	8	8	9	9	9	10

99.9%:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1		wtingrp															
2	1	Group1	8	1	8	14	16	18	11	14	16	18	1	14	11	1	9
3	2	Group2	10	4	9	15	17	19	12	15	17	19	4	15	13	4	10
4	3	Group3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	4	Group4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	5	Time	1	2	2	2	2	2	3	3	3	3	4	4	4	4	5
7																	

Outside Group (the first column means the original type of product, the second column means the changeover type of product, the last column means the time):

95%:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1		woutgrp															
2	1	Group1	11	9	8	14	8	8	7	1	16	9	18	21	16	18	1
3	2	Group2	4	6	4	4	7	4	11	10	13	4	9	4	7	10	6
4	3	Time	1	2	3	4	5	5	8	9	9	10	10	13	16	18	18
5																	
6																	

96%:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1		woutgrp															
2	1	Group1	11	1	1	11	8	11	11	1	16	9	18	21	11	6	1
3	2	Group2	9	5	5	6	4	14	14	10	13	4	9	4	10	10	6
4	3	Time	1	2	4	6	8	10	10	13	13	16	16	18	18	19	23
5																	
6																	

97%:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1		woutgrp															
2	1	Group1	12	11	8	11	8	11	1	6	16	9	18	21	4	7	14
3	2	Group2	10	7	4	4	7	14	8	9	13	4	9	4	8	11	11
4	3	Time	1	3	5	6	9	10	13	14	19	30	32	38	39	41	44
5																	
6																	

98%:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1		woutgrp															
2	1	Group1	12	6	1	4	9	11	1	6	16	13	18	21	4	4	14
3	2	Group2	4	9	6	12	6	14	8	9	13	16	9	4	8	12	11
4	3	Time	5	8	9	18	20	20	23	25	27	27	28	31	32	35	35
5																	
6																	

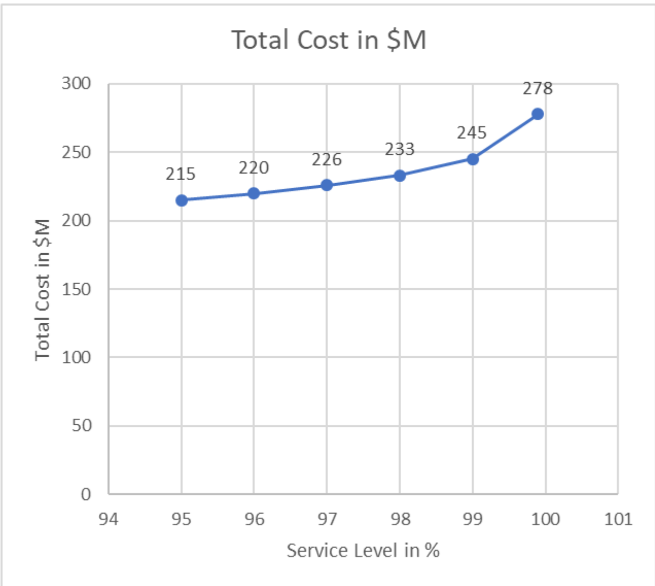
99%:

B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
woutgrp																					
Group1	11	12	1	11	1	8	1	1	16	9	18	1	16	18	1	18	16	19	18	8	1
Group2	6	13	14	20	4	4	4	4	13	4	9	4	7	10	4	10	4	4	6	6	4
Time	1	8	9	9	18	19	32	45	45	46	50	51	52	52	54	56	60	68	70	72	73

99.9%:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1		woutgrp															
2	1	Group1	14	16	1	8	4	11	1	7	16	13	18	21	4	4	4
3	2	Group2	4	9	6	12	14	14	8	4	13	16	9	4	8	12	21
4	3	Time	2	3	8	9	10	10	10	13	14	14	17	17	18	21	22
5																	
6																	

Total cost:



As we can see, as the service level increases, the total cost increases.
The increase is much higher when we go from 99% to 99.9%