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MBA/LGO 2018 - Section-B

15.071 Analytics Edge - Homework Assignment # 4 Dartboard Corporation

Problem-1.) By creating the log-log model with 10 year lag term we obtain the following demand forecast equation for year 2025. (The R-code output with coefficients is copied below)

$$\mathbf{D_{2025} = e^{0.157} * (D_{2015})^{0.9909}} \quad \rightarrow \quad \boxed{\mathbf{D_{2025} = 1.17 * (D_{2015})^{0.9909}}}$$

Comparing the R-squared value of each model, we observe that the R-squared value (=0.9275) of the log-log model is higher than the R-squared value (=0.86) of the linear prediction model developed in the class, therefore we conclude that log-log model does a better job of forecasting the demand. Thus I have decided to use log-log forecasting model.

```
Call:
lm(formula = log(Demand) ~ log(t.10), data = dartboard)

Residuals:
    Min      1Q  Median      3Q     Max 
-1.6933 -0.2559 -0.0090  0.2416  2.7563 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept) 0.1573352  0.0085575   18.39   <2e-16 ***
log(t.10)   0.9909714  0.0009901 1000.90   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.3875 on 78308 degrees of freedom
  (27258 observations deleted due to missingness)
Multiple R-squared:  0.9275,	Adjusted R-squared:  0.9275 
F-statistic: 1.002e+06 on 1 and 78308 DF,  p-value: < 2.2e-16
```

A portion of the log-log model prediction is copied below:

	FIPS.Code	Latitude	Longitude	Area.Name	fut_deman
102852	9001	41.244	-73.363	Fairfield Co.	133234.7417
102853	9003	41.82	-72.718	Hartford Co.	123790.5664
102854	9005	41.776	-73.202	Litchfield Co.	51008.97135
102855	9007	41.447	-72.529	Middlesex Co.	39208.04805
102856	9009	41.33	-72.927	New Haven Co.	245431.8297
102857	9011	41.457	-72.127	New London Co.	46064.25239
102858	9013	41.842	-72.308	Tolland Co.	36142.77708
102859	9015	41.836	-72.02	Windham Co.	30047.18457
102860	10001	39.134	-75.448	Kent Co.	34259.1897
102861	10003	39.573	-75.597	New Castle Co.	108532.844
102862	10005	38.7	-75.353	Sussex Co.	57987.59884
102863	11001	38.893	-77.014	District of Columbia	140161.3648
103220	18001	40.745	-84.937	Adams Co.	5477.867783
103221	18003	41.091	-85.07	Allen Co.	50395.47043
103222	18005	39.194	-85.885	Bartholomew Co.	18986.10342
103223	18007	40.606	-87.31	Benton Co.	1260.795638
103224	18009	40.472	-85.323	Blackford Co.	3175.668352
103225	18011	40.05	-86.467	Boone Co.	16052.35815

Problem-2.) Disregarding the current warehouse infrastructure and entering our new 2015 demand prediction values that obtained in Problem-1 (log-log model with a 10-year lag), we obtain the following results. 8 warehouses should be opened with locations and optimal sq-ft capacities as summarized below:

#	Location	Optimal Capacity* (sq-ft)
1	Kalamazoo	686,616.3
2	Toledo	818,692.9
3	Youngstown	976,520.7
4	Lancaster	1,534,925.0
5	Richmond	562,438.1
6	Scranton	2,062,851.9
7	Worchester	1,601,973.0
8	Chillicothe	1,348,303.1

This model results in the minimum optimal cost = **$1,833,497,563**

	1	2	3	4	5	6	7	8
	Kalamazoo	**Toledo**	**Youngstown**	**Lancaster**	**Richmond**	**Scranton**	**Worcester**	**Chillicothe**
	0.13125	0.06625	0.08	0.0675	0.135	0.10125	0.09	0.31125
Build?	1	1	1	1	1	1	1	1
Sqf	686616.295	818692.899	976520.728	1534925.05	562438.139	2062851.86	1601972.99	1348303.15

Problem-3.) Taking into account the existing infrastructure of 8 warehouse and their existing capacities, we create a new base case model. The optimization solution shows that we need:

i.) Build 2 new warehouses at the following locations with the following capacities:

#	Location	Capacity (sq-feet)	Capacity Utilization
1	Toledo	698,855 sq-feet	100%
2	Scranton	1,541,701 sq-feet	100%

ii.) Use the existing 8 warehouses with the following capacities:

#	Location	Optimal Capacity* (sq-ft)	Original Capacity	Capacity Utilization	Capacity Added
1	Kalamazoo	899888.65	900,000	99.99%	N/A
2	Youngstown	946592.88	900,000	100%	46592.88
3	Richmond	1025507.65	1,200,000	85.46%	N/A
4	Burlington	581027.99	1,200,000	48.42%	N/A
5	Baltimore	900116.52	900,000	100%	116.52
6	Norwalk	599780.19	600,000	99.96%	N/A
7	Providence	1199784.65	1,200,000	99.98%	N/A
8	Chillicothe	1199066.06	900,000	100%	299066.06

The resulting optimal cost is: **$1,054,857,649** which is **$778,639,914** lower than the calculated cost in Problem-2. This decrease in the cost is expected because using existing infrastructure saves us money in construction/expansion capital expenditures. Using existing warehouse has much lower fixed cost compared to building new warehouses.

Problem-4.) Yes, we have warehouses that are not being fully (100%) utilized in 2025. Especially we observe that Burlington and Richmond are underutilized at levels 48.42% and 85.46% respectively.

This underutilization occurs because the demand is satisfied from other warehouses (including the newly built ones) and the transportation costs require us not to use a warehouse to its full capacity if there is not enough demand to justify the 100% utilization of that warehouse.

Problem-5.) After adding the minimum %90 utilization constraint, we obtain the following warehouse footprint with each warehouse above 90% utilization.

Existing Warehouses:

#	Location	Optimal Capacity* (sq-ft)	Original Capacity	Capacity Utilization	Capacity Added
1	Kalamazoo	899888.65	900,000	99.99%	N/A
2	Youngstown	899910.39	900,000	99.99%	N/A
3	Richmond*	1135069.37	1,200,000	94.59%	N/A
4	Burlington*	1176838.05	1,200,000	98.07%	N/A
5	Baltimore	881944.06	900,000	97.99%	N/A
6	Norwalk	600328.21	600,000	100.00%	328.21
7	Providence	1182849.36	1,200,000	98.57%	N/A
8	Chillicothe	1205978.12	900,000	100.00%	305978.12

Newly Built Warehouses:

#	Location	Capacity (sq-feet)	Capacity Utilization
1	Toledo	703509.26	100%
2	Scranton	906005.45	100%

We observe that the selection of new warehouses to be built has not been impacted by the minimum 90% utilization constraint. The biggest impact is that we see Richmond and Burlington warehouses are now over 90% utilized.

We also observe that the optimal cost now has risen to **$1,092,245,794**. This is a **$37,388,145** increase in the overall cost compared to the base case. This increase is expected, since adding a new constraint can results in a less optimal solution.

Problem-7.) Imposing a limited budget of $200M in capital expenditures for the new and/or existing warehouses expansion result in the following warehouse capacity footprint:

#	Location	Optimal Capacity* (sq-ft)	Original Capacity	Capacity Utilization	Capacity Added
1	Kalamazoo	899824.42	900,000	99.98%	N/A
2	Youngstown	1018501.18	900,000	100.00%	118501.18
3	Richmond	1199756.55	1,200,000	99.98%	N/A
4	Burlington	1166432.02	1,200,000	97.20%	N/A
5	Baltimore	898647.23	900,000	99.85%	N/A
6	Norwalk	596858.14	600,000	99.48%	N/A
7	Providence	1190125.48	1,200,000	99.18%	N/A
8	Chillicothe	1161904.30	900,000	100.00%	261904.30

Newly built warehouses:

#	Location	Capacity (sq-feet)	Capacity Utilization
1	Toledo	769098.92	100%
2	Scranton	691172.67	100%

We observe that the capacity utilization levels in our existing warehouses increase compared the base model. Richmond and Burlington warehouses capacity utilization have approached almost to 100%. Besides that, less capacity expansion happened in the existing warehouses compared to the base case. These are both expected results since limiting capital expenditures forces the model use the existing capacities at a higher utilization level and avoid spending money on capacity expansions.

However we also observe that the total cost now has risen to **$1,108,438,261**. This is a **$53,580,612** increase in the overall cost compared to the base case. This increase is expected, since adding a new constraint would result in a less optimal solution. At the optimal solution, the total capital expenditure is $182,466,265. We observe that limiting capital expenditures has indeed increased the overall cost due to the rising transportation costs. Thus we can say that the CapEx limitation had the opposite effect of what it is intended to do.

Problem-9.) Decreasing inventory turnover rate to 54 days resulted in total capital expenditure of $199,486,933 which is below $200M. The total optimal cost has also decreased to **$999,232,687**. That's a total saving of $55,624,962 compared to the base model. We observe that decreasing turnover rate has a significant impact on cost reduction.

The resulting warehouse footprint is as follows:

#	Location	Optimal Capacity* (sq-ft)	Original Capacity	Capacity Utilization	Capacity Added
1	Kalamazoo	897635.11	900,000	99.74%	N/A
2	Youngstown	899999.46	900,000	100.00%	N/A
3	Richmond	874888.43	1,200,000	72.91%	N/A
4	Burlington	445251.92	1,200,000	37.10%	N/A
5	Baltimore	900305.96	900,000	100.00%	305.96
6	Norwalk	639456.85	600,000	100.00%	39456.85
7	Providence	1172840.38	1,200,000	97.74%	N/A
8	Chillicothe	1049589.61	900,000	100.00%	149589.61

Newly built warehouses:

#	Location	Capacity (sq-feet)	Capacity Utilization
1	Toledo	566388.49	100%
2	Scranton	1186732.6	100%

Problem-12.) There are multiple parameters we can do sensitivity analysis on and come up with what-if analysis. These scenarios can include:

- Increasing the pallets per truck capacity
- Decreasing the transportation fee ($/mile) by using different transportation methods
- Decreasing the average days in inventory (inventory turnover rate)
- Increasing/decreasing the size of pallets
- Increasing the number of levels in warehouse
- Changing the discount rate (Choosing a lower discount rate would increase the NPV value of the expansion projects)

I did a sensitivity analysis decreasing the transportation cost to 80 cents/mile from 0.96 cents/mile and obtained the following optimal minimum cost and warehouse footprint.

The optimal total cost has decreased to **$916,956,121**. That's a significant total savings of $137,901,528 compared to the base model.

The resulting warehouse footprint is as follows:

#	Location	Optimal Capacity* (sq-ft)	Original Capacity	Capacity Utilization	Capacity Added
1	Kalamazoo	900076.84	900,000	100.00%	76.84
2	Youngstown	899897.02	900,000	99.99%	N/A
3	Richmond	1168011.45	1,200,000	97.33%	N/A
4	Burlington	644646.93	1,200,000	53.72%	N/A
5	Baltimore	899841.08	900,000	99.98%	N/A
6	Norwalk	599780.19	600,000	99.96%	N/A
7	Providence	1199784.65	1,200,000	99.98%	N/A
8	Chillicothe	1193026.76	900,000	100.00%	293026.76

Newly built warehouses:

#	Location	Capacity (sq-feet)	Capacity Utilization
1	Toledo	715214.12	100%
2	Scranton	1372041.9	100%

Problem-13.) My final recommendation to the management would be not to impose artificial constraints on the capital expenditure, warehouse capacity utilization or other measures. As we have seen in the cases above, imposing constraints does not improve the overall cost value. Limiting capital expenditures can increase transportation costs and vice versa.

Instead I would recommend management to focus on operational efficiency measures such as decreasing the turnover rate, decreasing the transportation costs by using a more fuel-efficient transportation trucks, increasing the storage space by increasing the number of levels in warehouses, etc… As we saw in in

Problem-9 (decreasing the turnover rate) and Problem-12 (decreasing the $/mile transportation cost) have significant impact on cost reduction.

APPENDIX: R-Code and Outputs:

R-Code

```
### HW4
### Problem-1

library(dplyr)

dartboard = read.csv("Dartboard_Demand_2015.csv")
dartboard$X = NULL

# Log-Log Models with 10-year lag
summary(lm(log(Demand)~log(t.10), data=dartboard))

# Log - Log model to predict the demand in 2025
model2 = lm(log(Demand)~log(t.10), data=dartboard)
betas2=model2$coefficients
dartboard$fut_deman = exp(betas2[1]) * dartboard$Demand ^ betas2[2]
output = subset(dartboard, Year=="X2015" & NE==1)
for (i in 1:10)
{
  output[[paste0("t.", i)]] <- NULL
}
output$Year = NULL
output$Demand = NULL
output$NE = NULL
write.csv(output, "Fut_Log_Demand.csv")
```

R-Output:

```
> dartboard = read.csv("Dartboard_Demand_2015.csv")
> dartboard$X = NULL
> summary(lm(log(Demand)~log(t.10), data=dartboard))

Call:
lm(formula = log(Demand) ~ log(t.10), data = dartboard)

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```
> model2 = lm(log(Demand)~log(t.10), data=dartboard)
> betas2=model2$coefficients
> dartboard$fut_deman = exp(betas2[1]) * dartboard$Demand ^ betas2[2]
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> for (i in 1:10)
+ {
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