MIE 1623 – Final Project: Hospital Efficiency
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1.0 INTRODUCTION

Assessing hospital performance and efficiency can be crucial to reducing overall costs and improving quality of care. In order to compare their performance and efficiency, 37 hospitals in Ontario have provided a variety of metrics from 2010. These hospitals range in size (small, medium and large), ability, and purpose (teaching or non-teaching hospital) and are looking to identify whether they are efficient compared to the other hospitals. This project designs an Excel DSS to address the challenge of fairly comparing each hospital and determining if they are efficient. Hospitals with low efficiency should be examined to learn potential improved practices from benchmark hospitals, which were listed as well.

2.0 OBJECTIVES

The main objectives of the Excel DSS are as follows:

1. Indicate which hospitals are most efficient within their compared groups.
2. For inefficient hospitals, identify hospitals that should be benchmarked.
3. Identify performance metrics that are good discriminators of hospital efficiency.

3.0 MODEL AND ASSUMPTIONS

Given Data:

- 37 hospitals in Ontario
- 20 features + 1 hospital ID label identifier

Assumptions:

- All other non-given resources are assumed to be equal or without shortage amongst the hospitals for comparison (e.g., surgeon availability, nurses etc.)

Model description (objective function, variables, constraints):

Linear Model Setup (Repeated for each chosen hospital):

Repeated the following for each chosen hospital:

$$output_{all} = \sum_{i=1}^{N} u_{ichosen} x_{iall}; \quad input_{all} = \sum_{j=1}^{M} v_{jchosen} y_{jall}$$

$$Productivity\ of\ all\ hosptials = \frac{\sum_{i=1}^{N} u_i x_{iall}}{\sum_{j=1}^{M} v_j y_{jall}}$$

Given,

$$y_{jany} = a\ matrix\ containing\ values\ of\ output\ i\ measured\ for\ all\ hospitals$$

$$x_{iany} = a\ matrix\ containing\ values\ of\ input\ j\ measured\ for\ all\ hospitals$$

$$u_i = weight\ of\ output\ i,\ N = number\ of\ selected\ output\ features$$

$$v_j = weight\ of\ input\ j, M = number\ of\ selected\ input\ features$$

Objective Function:

Maximize output of chosen hospital h

$$output_{chosen} = \sum_{i=1}^{N} u_{ichosen} x_{ichosen}$$

Decision Variables:

- Output Weights ($u_{ichosen}$) and Input Weights ($v_{jchosen}$)

Constraints:

- Productivity of hospital k and h must be <=1
    - $\sum_{i=1}^{N} u_{ichosen} x_{iall} \leq \sum_{j=1}^{M} v_{jchosen} y_{jall}$

- $output_{all} - input_{all}$ must be <= 0

- Input of chosen hospital must = 1
    - $input_{chosen} = \sum_{j=1}^{M} v_{jchosen} y_{jchosen} = 1$

4.0 METHODOLOGY

The following steps were taken with the raw data to build the Excel DSS and for subsequent analysis.

1. **Clean Missing Data and Remove Rows with collection error.**
    a. C-Section Rate – erroneous rate of 108.5% for Hospital Q was removed.
    b. Blank Data – removed automatically from comparison if no data.
    c. Convert percentages to decimal values.

2. **Split up hospitals by teaching and by size**

   There is a mixture of hospitals that allocate a higher percentage of resources to teaching and propagating information. As such, two distinct groups were made for comparison: teaching and nonteaching hospitals. The division was made on the overall average percentage. For hospitals with a teaching percentage higher than or equal to the average, they are classified as a teaching hospital, otherwise they are grouped into nonteaching.

The hospitals were further clustered by Surgical Case for an estimate of hospital size and capacity. This is to ensure that hospitals that are much larger in size are not being compared initially to smaller hospitals. The surgical cases data was divided into thirds to split hospitals into small, medium and large sized hospitals.

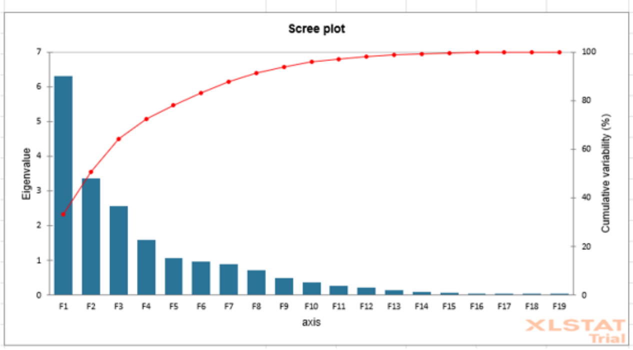
3. Normalization

Following the selection of metrics, the data was normalized within the hospital clusters. This ensures that any potential difference in scale among the individual clusters is also captured and scaled for fair comparison. This can be seen in the normalization output and input sheets in the Excel DSS.

4. PCA

As an initial check for feature importance, Principal Component Analysis (PCA) was performed with the help of the Excel add on XLSTAT [1]. PCA serves as a dimensionality reduction technique and offers insight into which features help capture the most variance in the data. As seen in Figure 1, the most variable metrics between hospitals are captured in the first group of features, which are highlighted in yellow. The purpose of this process was to determine which metrics fluctuated the most among hospitals as those would be the major factors into differing efficiency.

	F1	F2	F3	F4	F5
Eigenvalue	6.305	3.340	2.559	1.585	1.057
Variability (%)	33.185	17.581	13.469	8.343	5.566
Cumulative %	33.185	50.766	64.235	72.578	78.144



Squared cosines of the variables:

	F1	F2	F3
Cost per Patient-day	**0.313**	0.006	0.182
Surgical Cases	**0.894**	0.000	0.005
Death Rate	0.031	0.008	0.131
Cardiac Arrest Rate	0.015	0.044	0.071
Post-Surgery AMI Rate	0.099	0.001	0.015
Surgical Site Infections Rate	**0.257**	0.000	0.244
Sepsis Rate	**0.446**	0.188	0.100
C-Section Rate	0.211	0.002	**0.330**
Total Medical Inpatient Days	**0.775**	0.015	0.080
Medical ALC Days	**0.548**	0.051	0.119
Total Surgical Inpatient Days	**0.870**	0.008	0.036
Surgical ALC Days	**0.745**	0.000	0.047
Total Mental Health Inpatient Days	0.057	**0.409**	0.015
Mental Health ALC Days	0.099	**0.427**	0.063
Hip Fracture Cases	**0.440**	0.067	0.400
Hip Fracture Cases with Surgery in 24h	0.209	0.070	**0.592**
Median ED Delay (Hours)	0.014	**0.668**	0.044
Actual Cases with ED delay >= 2 Hours	0.137	**0.690**	0.035
Actual Cases with ED delay >=4 Hours	0.143	**0.685**	0.048

Values in bold correspond for each variable to the factor for which the squa

Figure 1: PCA Results – Feature Importance by variability captured

5. Statistical Analysis

Statistical analysis, specifically standard deviation, was performed to measure the distribution of the metrics across all the hospitals. It determined the spread of metric values for each hospital compared to the mean. A small standard deviation indicates that the data does not vary off the mean while a large standard deviation indicates that the data spreads out far from the mean. As mentioned above, the Hospitals were firstly split up into 2 sets in terms of teaching hospitals and non-teaching hospitals and was further split up into 3 subsets for hospital sizes which was based on the number of surgical cases for each hospital. For each subset the standard deviation and mean was calculated as shown in Figure 2 and 3 below. The standard deviation is also shown as percent standard deviation to allow it to be compared on a relative scale across all metrics. This will aid in determining which metrics are relatively the same across all hospitals, which would not be a significant factor in overall comparisons and could potentially be omitted from future large-scale data collections.

Metrics	Teaching Hospitals	Teaching Emphasis	Cost per Patient-day	Surgical Cases	Death Rate	Cardiac Arrest Rate	Post-Surgery AMI Rate	Surgical Site Infections Rate	Sepsis Rate	C-Section Rate	Total Medical Inpatient Days	Medical ALC Days	Total Surgical Inpatient Days	Surgical ALC Days	Total Mental Health Inpatient Days	Mental Health ALC Days	Hip Fracture Cases	Hip Fracture Cases with Surgery in 24h	Median ED Delay (Hours)	Actual Cases with ED delay >= 2 Hours	Actual Cases with ED delay >=4 Hours
Large	AB	0.43053	1496.54	14201.2	0.09502	1.15623	6.48031	35.0887	3.96373	0.22962	147767	18808	117129	5179.12	4799.14	340.39	361.306	105.201	1.23882	431.791	241.429
	AJ	0.44418	1543.13	13835	0.0644	2.21069	7.6979	26.1426	6.99933	0.963	121369	15450.3	121096	12067.1	826.94	294.365	139.892	50.4095	1.33814	245.532	154.129
	E	0.43281	1581.99	13814.7	0.09419	3.09909	16.1597	32.9637	4.73626	0.40884	135522	34718.8	109198	12137.9	3433.14	382.925	285.671	107.388	1.56045	382.693	240.772
	L	0.43785	1538.96	13118.5	0.07437	1.76415	4.29833	29.4222	6.76599	0.3977	79657.3	13948.9	84156.5	7343.93	188.217	45.2733	221.105	91.6057	2.99298	574.377	354.142
	M	0.45123	1540.07	14996.5	0.08202	1.04725	7.13382	24.9786	4.8448		112986	8959.3	118465	4130.43	39473.1	433.785	277.669	133.668	1.11231	368.088	207.712
	Q	0.46792	1477.09	13691.2	0.07196	2.7363	10.1419	27.3615	2.02141	1.08481	98189.2	20366.4	137242	11810.7	19435.3	3352.29	346.133	71.4275	0.98364	62.7734	33.1342
	Z	0.46503	1476.1	16667.6	0.07392	1.99876	12.1407	29.5183	2.87256	0.34629	179034	31682.2	148288	13562.4	1745.79	159.7	373.855	146.554	1.55434	404.363	277.404
	Standard Deviation	0.01497	39.6468	1176.96	0.01158	0.76046	3.99798	3.63721	1.85134	0.35806	32865.9	9413.41	20444.9	3819.51	14585.4	1170.38	84.2931	33.4737	0.67524	160.595	101.2
	Mean	0.44708	1521.98	14332.1	0.07941	2.00178	9.15037	29.3536	4.60058	0.49004	124932	20562	119368	9461.66	9985.95	715.532	286.519	100.893	1.5401	352.802	215.532
	% Standard Deviation	3%	3%	8%	15%	38%	44%	12%	40%	73%	26%	46%	17%	40%	146%	164%	29%	33%	44%	46%	47%
Medium	AG	0.44315	1463.25	8898.36	0.07904	0.29109	6.99411	26.8711	3.2335	0.30988	92719.7	14998.1	73110.4	5603.15	34490.3	1436.6	265.439	93.1015	1.20477	143.132	83.1778
	AI	0.42871	1545.99	7603.16	0.07183	1.91988	10.6231	27.8535	2.98564	0.18681	63668.6	2305.01	66839.1	1588.47	11424.3	1360.45	88.3307	36.3914	0.39043	40.7302	24.4736
	G	0.44607	1564.33	9291.87	0.07463	3.11427	4.58019	12.7607	1.53087	0.20194	99230.7	15125.9	86466.1	3920.85	19691.8	272.618	410.582	250.523	1.0889	160.133	80.9666
	K	0.43263	1579.45	9624.24	0.05951	1.84163	12.3551	15.6373	5.14741	0.28574	64417.7	8802.08	61120.9	6904.17	188.707	77.3254	72.5832	16.8982	1.28475	445.34	209.439
	S	0.42763	1506.44	7779.1	0.08701	3.99897	7.54544	23.5607	3.17617	0.33408	119829	11873.6	63366	3067.25	26369.8	1668.7	110.734	60.6225	1.07606	195.811	117.81
	Standard Deviation	0.00846	47.0963	905.068	0.01011	1.4069	3.07738	6.78374	1.28695	0.06576	24029.4	5326.5	10167.1	2089.32	13270.2	731.665	145.562	93.3363	0.35633	150.296	68.1786
	Mean	0.43564	1531.89	8639.34	0.07441	2.23317	8.41959	21.3366	3.21472	0.26369	87973.2	10620.9	70180.5	4216.78	18433	963.14	189.534	91.5073	1.00898	197.029	103.173
	% Standard Deviation	2%	3%	10%	14%	63%	37%	32%	40%	25%	27%	50%	14%	50%	72%	76%	77%	102%	35%	76%	66%
Small	A	0.45107	1543.66	4905.87	0.0774	2.18043	3.53386	25.0107	2.61046	0.32798	40506.9	6120.48	38813.8	2727.98	25009	1557.45	132.59	42.7521	1.0337	94.6586	45.6556
	AF	0.44693	1503.87	6189.35	0.06492	1.95425	6.33325	21.9811	2.10626	0.22688	61786.6	7117.1	51990.8	1568.64	4168.08	0	0	0	1.17124	38.3708	19.7772
	AH	0.45104	1566.68	6303.09	0.0797	0.41237	17.7936	13.8758	4.01984	0.26041	61969.4	21618.7	46479.5	7706.02	1579.93	950.105	144.924	81.9044	3.83492	215.543	169.18
	H	0.43037	1533.14	2992.4	0.00207	0	0	12.6198	0	0.23193	1207.32	0	6707.11	89.0774	597.384	365.844	0	0	1.7315	111.148	36.9014
	P	0.46549	1584.35	7151.25	0.0875	1.53481	4.96855	17.4149	5.61909	0.29606	74493.6	15622.4	64475.7	5230.17	397.075	71.0093	173.724	77.522	5.6814	772.444	607.31
	U	0.46743	1527.64	6730.22	0.06472	4.88477	7.66008	20.3235	2.36236	0.22269	78538.1	26163.3	57921	7760.14	6699.05	1605.49	120.236	43.1758	0.99235	163.839	108.367
	Standard Deviation	0.01353	28.7559	1531.77	0.031	1.72717	6.03381	4.79503	1.89646	0.04288	28671.7	10050.5	20492.7	3225.41	9426.59	720.357	75.8807	35.7121	1.93035	271.276	223.876
	Mean	0.45206	1543.22	5712.03	0.06272	1.82777	6.71488	18.5376	2.78634	0.26099	53083.7	12773.7	44398	4180.34	6408.42	758.317	95.2456	40.8924	2.40752	232.667	164.532
	% Standard Deviation	3%	2%	27%	49%	94%	90%	26%	68%	16%	54%	79%	46%	77%	147%	95%	80%	87%	80%	117%	136%

Figure 2: Standard deviation for Teaching Hospitals

Metrics	Non-Teaching Hospitals	Teaching Emphasis	Cost per Patient-day	Surgical Cases	Death Rate	Cardiac Arrest Rate	Post-Surgery AMI Rate	Surgical Site Infections Rate	Sepsis Rate	C-Section Rate	Total Medical Inpatient Days	Medical ALC Days	Total Surgical Inpatient Days	Surgical ALC Days	Total Mental Health Inpatient Days	Mental Health ALC Days	Hip Fracture Cases	Hip Fracture Cases with Surgery in 24h	Median ED Delay (Hours)	Actual Cases with ED delay >= 2 Hours	Actual Cases with ED delay >=4 Hours
Large	AD	0.198054	1112.775	8245.738	0.067368	1.607694	8.562411	18.21456	2.976864	0.298156	123880.7	14626.27	48005.22	4881.447	5221.048	141.3838	263.8308	109.7113	4.111979	1094.469	755.6845
	C	0.1903817	1104.826	9613.998	0.085016	1.139953	5.411801	20.42838	1.660049	0.229143	79401.36	17418.76	63528.31	5212.006	241.1699	42.19147	170.0752	26.84319	2.260419	325.4708	226.2462
	N	0.2004347	1107.129	7661.8	0.089682	2.006095	7.766984	9.849229	2.111261	0.333447	95569.7	10086.31	44565.98	2178.855	16816.91	486.2488	317.9885	142.5217	2.826043	265.5567	189.2306
	O	0.1982824	1067.868	7412.933	0.084402	2.789434	9.73993	15.00277	1.808617	0.199937	84271.33	23353.5	49993.38	8806.785	1740.506	919.5591	166.7625	105.5324	0.793093	88.59805	58.84699
	T	0.1914621	1026.8	8101.441	0.07084	1.321322	9.696027	14.76261	1.535678	0.321465	128177.7	33069.21	56169.41	6911.117	19126.33	1467.829	218.4326	144.1501	0.693684	17.43462	10.59903
	V	0.2019836	1083.394	10076.96	0.091016	1.028646	4.366459	11.25889	1.478379	0	155263.3	37998.46	63476.05	3777.422	22540.42	1190.198	721.5514	342.4801	0.736102	116.7605	68.99385
	X	0.1956034	1046.671	7018.645	0.079939	2.379769	12.08738	22.87878	1.421825	0.251394	98927.01	17267.57	49749.57	6327.414	420.5094	152.3996	247.6549	151.8127	2.240419	264.2332	139.6062
	Standard Deviation	0.0043721	32.94031	1137.429	0.009068	0.663208	2.661533	4.737191	0.547091	0.113941	27380.2	10165.28	7565.782	2162.178	9686.04	567.5444	192.9411	96.44206	1.291808	363.2388	253.5912
	Mean	0.1966003	1078.495	8304.503	0.08118	1.753273	8.232999	16.05646	1.856096	0.233363	109355.9	21974.3	53641.13	5442.149	9443.843	628.5442	300.8994	146.1502	1.951677	310.3604	207.0296
	% Standard Deviation	2%	3%	14%	11%	38%	32%	30%	29%	49%	25%	46%	14%	40%	103%	90%	64%	66%	66%	117%	122%
Medium	AC	0.197843	1070.974	4869.074	0.071872	0.635854	13.57356	17.25195	1.324575	0.248129	63430.51	4688.3	26036.86	1094.638	509.1978	18.76978	143.1987	88.16848	1.740107	160.1635	93.24991
	AE	0.192473	1070.243	6329.93	0.071002	2.564793	5.726448	13.13383	0.857118	0.278774	51487.58	6600.478	41839.7	2486.096	2480.73	62.3006	168.1895	107.5766	1.627848	233.5678	144.4414
	I	0.1963191	1069.808	4506.854	0.093916	0.815394	12.19095	18.79525	4.828811		39933.97	5081.26	33777.15	2574.051	246.2614	15.224	134.729	39.06045	2.149733	369.8511	174.9853
	J	0.2051292	1089.592	4818.884	0.101086	1.330802	12.70143	25.91452	3.020309	0.311963	55043.26	16796.52	31656.44	4761.783	2339.148	447.2253	154.688	86.72924	1.830021	142.2725	91.50894
	Standard Deviation	0.0052981	9.636922	815.0694	0.015334	0.870094	3.593399	5.326522	1.805042	0.031925	9744.598	5729.56	6547.409	1515.075	1179.614	208.6644	14.51589	29.14295	0.224339	103.4316	40.83232
	Mean	0.1979411	1075.154	5131.185	0.084469	1.336711	11.0481	18.77389	2.507703	0.209716	52473.83	8291.639	33327.54	2729.142	1393.834	135.8799	150.2013	80.3837	1.836927	226.4637	126.0464
	% Standard Deviation	3%	1%	16%	18%	65%	33%	28%	72%	15%	19%	69%	20%	56%	85%	154%	10%	36%	12%	46%	32%
Small	AA	0.1471963	777.3031	1614.645	0.095288	0	0	31.01406	2.669719		43518.36	14421.24	12697.54	1572.98	641.1596	131.1874	50.35975	32.16461	0.901415	90.41412	59.86542
	AK	0.1459904	762.3268	589.6241	0.1007	0	0	1.606584	0.762554	0	10461.94	789.0793	940.0645	0	13.85761	0	0	0			
	B	0.151103	761.9707	555.4683	0.06106	3.985379	9.873625	18.64797	0.821744	0.310754	24313.55	6930.036	3165.075	584.0046	4864.769	357.4462	0	0	2.441106	340.8297	159.0722
	D	0.1909785	1035.442	2706.679	0.074749	0.845207	1.599395	18.5258	1.027248	0.28805	22340.85	4226.835	10842.26	1439.12	100.4251	12.66299	160.7671	121.7754	1.627759	220.588	104.7459
	F	0.1432189	754.6567	46.71459	0.095006	1.839435	9.055997	20.67101	0.411729	0	17743.65	5241.135	769.2497	333.7089	187.2141	4.760896	0	0	0.301252	8.380384	2.165655
	R	0.2079365	1120.967	2985.211	0.114242	0.91903	6.163501	14.8201	0.704026	0.207381	31075.48	7387.394	14130.05	1311.176	531.4331	252.7533	128.555	47.72691	2.122377	147.3179	101.9948
	W	0.1493008	767.1432	937.5793	0.089105	2.891505	5.689377	18.0318	0.34004	0.326991	32823.26	5403.753	5756.35	171.9341	713.9714	2.117693	0	0	0.432668	38.56166	31.36179
	Y	0.1494722	744.2199	1443.756	0.060241	3.8591	0.051086	15.98741	1.310016	0.360501	45299.84	15135.55	7437.052	1503.035	3694.188	397.4025	34.36617	23.06625			
	Standard Deviation	0.0244963	148.7837	1046.806	0.019281	1.620229	4.156418	8.083033	0.740839	0.153138	12128	4953.533	5210.476	657.5717	1856.429	168.7187	63.92025	42.02141	0.893797	124.0537	56.75516
	Mean	0.1606496	840.5037	1359.96	0.086299	1.792457	4.054123	17.41309	1.005884	0.18671	28447.12	7441.878	6967.206	864.4949	1343.377	144.7914	46.756	28.09164	0.978322	105.7615	57.40072
	% Standard Deviation	15%	18%	77%	22%	90%	103%	46%	74%	82%	43%	67%	75%	76%	138%	117%	137%	150%	91%	117%	99%

Figure 3: Standard deviation for Non-Teaching Hospitals

6. Perform Correlation analysis on metrics

In statistics, correlation is used to illustrate the strength of the relationship between two variables. In order to determine whether a variable is a good indicator for distinguishing good efficiency from poor efficiency, correlation analysis was employed in the tool and correlations between each selected input variable and output variable were calculated.

A high correlation between input and output variables suggests that changes in input variables will correspond to changes in output variables. If the input variable is weakly correlated with the output variable, then it may be difficult to predict changes in output and calculate hospitals' efficiency accurately based on that input variable. The results for correlation analysis are shown in Figure 4.

	Output																			
Input	Teaching Emphasis	Cost per Patient-day	Surgical Cases	Death Rate	Cardiac Arrest Rate	Post-Surgery AMI Rate	Surgical Site Infections Rate	Sepsis Rate	C-Section Rate	Total Medical Inpatient Days	Medical ALC Days	Total Surgical Inpatient Days	Surgical ALC Days	Total Mental Health Inpatient Days	Mental Health ALC Days	Hip Fracture Cases	Hip Fracture Cases with Surgery in 24h	Median ED Delay (Hours)	Actual Cases with ED delay >= 2 Hours	Actual Cases with ED delay >=4 Hours
Teaching Emphasis	1.00	0.94	0.71	0.25	0.31	0.36	0.62	0.65	0.46	0.52	0.33	0.74	0.58	0.38	0.41	0.32	0.19	0.30	0.30	0.28
Cost per Patient-day	0.94	1.00	0.72	0.46	0.34	0.47	0.66	0.65	0.45	0.58	0.40	0.70	0.56	0.35	0.36	0.41	0.32	0.41	0.38	0.35
Surgical Cases	0.71	0.72	1.00	0.31	0.22	0.45	0.61	0.67	0.49	0.88	0.62	0.97	0.81	0.38	0.31	0.70	0.53	0.25	0.45	0.43
Death Rate	0.25	0.46	0.31	1.00	0.23	0.42	0.53	0.34	0.10	0.41	0.39	0.28	0.24	0.17	0.11	0.37	0.34	0.27	0.20	0.21
Cardiac Arrest Rate	0.31	0.34	0.22	0.23	1.00	0.28	0.32	0.11	0.42	0.31	0.33	0.27	0.32	0.14	0.32	0.08	0.09	0.00	0.08	0.07
Post-Surgery AMI Rate	0.36	0.47	0.45	0.42	0.28	1.00	0.43	0.41	0.30	0.46	0.43	0.43	0.56	0.03	0.21	0.26	0.21	0.35	0.27	0.24
Surgical Site Infections Rate	0.62	0.66	0.61	0.53	0.32	0.43	1.00	0.59	0.43	0.54	0.40	0.63	0.52	0.20	0.26	0.28	0.13	0.19	0.30	0.26
Sepsis Rate	0.65	0.65	0.67	0.34	0.11	0.41	0.59	1.00	0.36	0.50	0.32	0.64	0.60	0.13	0.06	0.27	0.14	0.46	0.58	0.55
C-Section Rate	0.46	0.45	0.49	0.10	0.42	0.30	0.43	0.36	1.00	0.36	0.28	0.54	0.62	0.09	0.48	0.18	0.03	0.20	0.14	0.15
Total Medical Inpatient Days	0.52	0.58	0.88	0.41	0.31	0.46	0.54	0.50	0.36	1.00	0.80	0.84	0.73	0.42	0.32	0.80	0.69	0.22	0.42	0.42
Medical ALC Days	0.33	0.40	0.62	0.39	0.33	0.43	0.40	0.32	0.28	0.80	1.00	0.60	0.76	0.21	0.38	0.70	0.63	0.16	0.20	0.23
Total Surgical Inpatient Days	0.74	0.70	0.97	0.28	0.27	0.43	0.63	0.64	0.54	0.84	0.60	1.00	0.82	0.40	0.38	0.65	0.46	0.17	0.37	0.35
Surgical ALC Days	0.58	0.56	0.81	0.24	0.32	0.56	0.52	0.60	0.62	0.73	0.76	0.82	1.00	0.09	0.37	0.50	0.35	0.24	0.34	0.34
Total Mental Health Inpatient Days	0.38	0.35	0.38	0.17	0.14	0.03	0.20	0.13	0.09	0.42	0.21	0.40	0.09	1.00	0.61	0.47	0.44	-0.15	-0.08	-0.09
Mental Health ALC Days	0.41	0.36	0.31	0.11	0.32	0.21	0.26	0.06	0.48	0.32	0.38	0.38	0.37	0.61	1.00	0.32	0.18	-0.15	-0.23	-0.21
Hip Fracture Cases	0.32	0.41	0.70	0.37	0.08	0.26	0.28	0.27	0.18	0.80	0.70	0.65	0.50	0.47	0.32	1.00	0.92	0.21	0.31	0.30
Hip Fracture Cases with Surgery in 24h	0.19	0.32	0.53	0.34	0.09	0.21	0.13	0.14	0.03	0.69	0.63	0.46	0.35	0.44	0.18	0.92	1.00	0.18	0.21	0.21
Median ED Delay (Hours)	0.30	0.41	0.25	0.27	0.00	0.35	0.19	0.46	0.20	0.22	0.16	0.17	0.24	-0.15	-0.15	0.21	0.18	1.00	0.79	0.82
Actual Cases with ED delay >= 2 Hours	0.30	0.38	0.45	0.20	0.08	0.27	0.30	0.58	0.14	0.42	0.20	0.37	0.34	-0.08	-0.23	0.31	0.21	0.79	1.00	0.98
Actual Cases with ED delay >=4 Hours	0.28	0.35	0.43	0.21	0.07	0.24	0.26	0.55	0.15	0.42	0.23	0.35	0.34	-0.09	-0.21	0.30	0.21	0.82	0.98	1.00

Figure 4: Correlation Analysis Results: Correlation between inputs and outputs

7. Allow selection of customized metrics and hospital

The tool itself was designed to be dynamic, and to allow the user to select desired features to measure against. A seen in Figure 5, the selector page allows users to select input metrics as metrics they wish to decrease, and output metrics as metrics they wish to increase. Suggested metrics have a green star next to them. The comparative hospitals are coloured according to size in both teaching and non-teaching hospital categories, and users can select hospitals of their choosing to measure against. The “Get Efficiencies” button is clicked, which will prompt the subsequent VBA DEA analysis. The full VBA functions can be found in Appendix A.

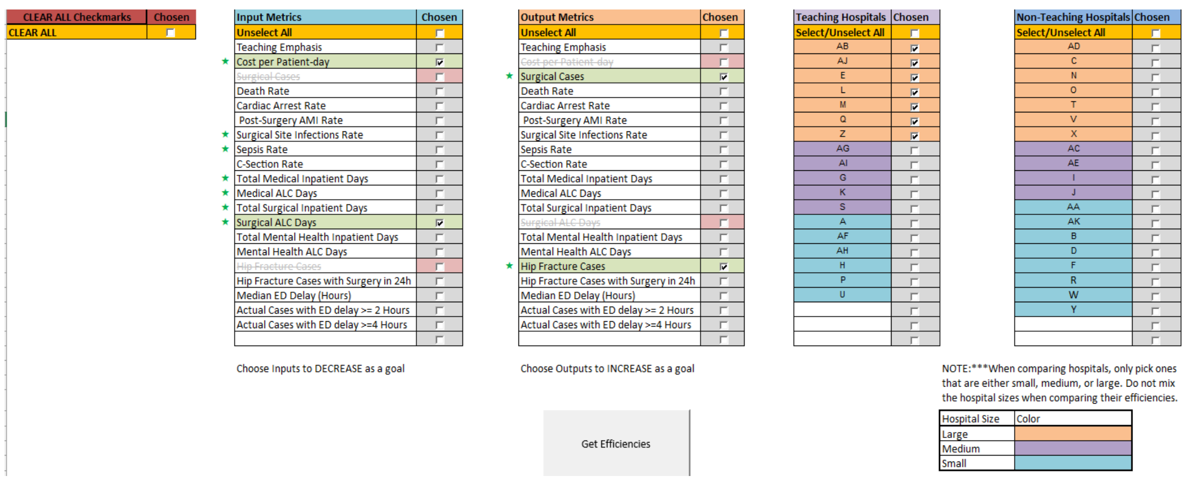


Figure 5: Excel DSS Selector Page

The following Table 1 shows the list of Tabs in the Excel Sheet.

Table 1: Excel DSS Sheets

Used by User	
Excel Sheet Name	**Purpose**
Selector	Allows user to choose metrics and hospitals for comparison
Results	Outputted efficiencies showing benchmark compositions
Target	Benchmark compositions translated into target metrics

Background sheets (calculation or information)	
Excel Sheet Name	**Purpose**
Output/Input	Identify chosen metrics and hospitals
Output/Input Normalized	Normalize chosen metrics
Calculations	Calculation for Excel Solver as per Section 3
ORG-Metrics	Cleaned Raw data
PCA	Metric Analysis using PCA
Correlation	Metric Analysis using Correlation
Standard Deviation	Metric Analysis using Std Dev.

8. Run DEA on selected hospitals and metrics

Once hospitals and metrics are selected, the raw data is normalized in a background calculation as shown in Appendix B. From there, DEA is applied using the linear programming model described in Section 3.0. This calculation sheet is shown in Appendix C. VBA code was written to run the solver for each hospital chosen and output the maximized efficiency. Efficiency values of 1 means that the hospital in question is efficient relative to the other hospitals in the comparable group, while efficiency values lower than 1 means they are less efficient. This efficiency output is displayed in the results tab as seen in Figure 6. If only two outputs and inputs are selected, the DEA plot tool can graph the efficiency frontier to provide a visualization as seen in Appendix D.

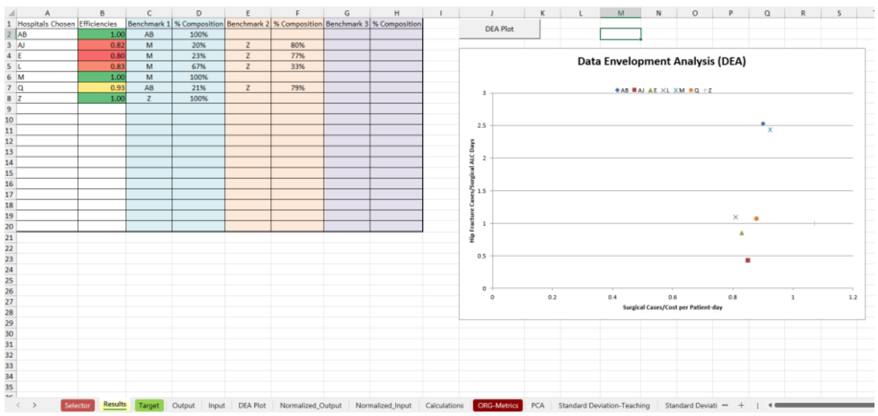


Figure 6: Results Tab Output

9. Collect Shadow Price to use as benchmarks

Sensitivity analysis within Excel is conducted each time the solver is run for each hospital, with a sample shown in Figure 7. With the sensitivity analysis, shadow prices can be used to identify the hospitals for inefficient hospitals to benchmark. Shadow Prices represent the makeup of a composite hospital that performs with better efficiency than the current hospital [2]. It is a linear combination of efficient hospitals found within the list of hospitals being compared. This composite hospital is what the hospital in question should be aiming for if they are inefficient. The breakdown of the shadow price has also been normalized such that the linear combination adds up to 1 to identify benchmark quantities more easily. These values can then be used to generate the target metrics by taking the percentages from the respective efficient hospital's metrics.

Microsoft Excel 16.0 Sensitivity Report
Worksheet: [V2_Hospital DSS.xlsm]Calculations
Report Created: 2023-04-05 3:09:49 PM

Variable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
H1	N/A	0.985073749	0	0.830054415	1E+30	0.443260005
I1	N/A	0	-0.428813578	0.374188272	0.428813578	1E+30
J1	N/A	0.850540207	0	0	0.135503068	0.590078576
K1	N/A	0.191465291	0	0	0.538240613	0.123599224

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
E4	AB Output	0.839309117	0	0	1E+30	0.038402791
E5	AJ Output	0.817664815	0	0	1E+30	0.182335185
E6	E Output	0.816463836	0	0	1E+30	0.205431532
E7	L Output	0.775319229	0	0	1E+30	0.155759448
E8	M Output	0.88630806	0.172287374	0	0	0.137357491
E9	Q Output	0.809163389	0	0	1E+30	0.151712662
E10	Z Output	0.985073749	0.675040957	0	0	0.743489042

Figure 7: Shadow Prices Example from Excel Sensitivity Analysis

5.0 RESULTS

With the methodology described in Section 4.0, example scenarios were carried out as follows:

Scenario 1: Large Teaching Hospitals

- Outputs: Surgery Cases, Hip Fracture Cases
- Inputs: Cost per Patient day and Surgical ALC days

As shown in Figure 8, Hospitals AB, M and Z are efficient with values of 1, while AJ, E, L and Q are inefficient relatively. It can be seen that AJ, E and L look to hospital M and Z as benchmarks, while hospital Q looks to hospitals AB and Z for benchmarking.

Hospitals Chosen	Efficiencies	Benchmark 1	% Composition	Benchmark 2	% Composition	Benchmark 3	% Composition
AB	1.00	AB	100%				
AJ	0.82	M	20%	Z	80%		
E	0.80	M	23%	Z	77%		
L	0.83	M	67%	Z	33%		
M	1.00	M	100%				
Q	0.93	AB	21%	Z	79%		
Z	1.00	Z	100%				

Figure 8: Efficiency of Large Teaching Hospitals and their Benchmark Hospitals

Taking Hospital AJ as an example, it means that there exists a composite hospital of 20% M and 80% Z that is more efficient than AJ. This translation into target metrics to aim for can be seen in Figure 9. For hospital AJ, they can become more efficient comparative to this group of hospitals by increasing the number of surgical cases (13.8k to 16.3k) and hip fracture cases (140 to 354) done, and decreasing their cost per patient day (1.54k to 1.49k) and surgical ALC days (12.1k to 11.6k).

ORIGINAL METRICS

Hospitals Chosen	Efficiencies	Surgical Cases	Hip Fracture Cases	Cost per Patient-day	Surgical ALC Days
AB	1.00	14,201.24	361.31	1,496.54	5,179.12
AJ	0.82	13,835.01	139.89	1,543.13	12,067.08
E	0.80	13,814.69	285.67	1,581.99	12,137.94
L	0.83	13,118.52	221.11	1,538.96	7,343.93
M	1.00	14,996.47	277.67	1,540.07	4,130.43
Q	0.93	13,691.17	346.13	1,477.09	11,810.67
Z	1.00	16,667.60	373.86	1,476.10	13,562.44

TARGET METRICS

Hospitals Chosen	Efficiencies	Surgical Cases	Hip Fracture Cases	Cost per Patient-day	Surgical ALC Days
AB	1.00	14,201.24	361.31	1,496.54	5,179.12
AJ	0.82	16,327.81	354.30	1,489.11	11,644.63
E	0.80	16,290.86	352.17	1,490.52	11,436.11
L	0.83	15,548.88	309.46	1,518.92	7,248.32
M	1.00	14,996.47	277.67	1,540.07	4,130.43
Q	0.93	16,159.80	371.27	1,480.31	11,836.39
Z	1.00	16,667.60	373.86	1,476.10	13,562.44

BENCHMARKS

AB		14201.24	361.31	1496.54	5179.12
M		14996.47	277.67	1540.07	4130.43
Z		16667.60	373.86	1476.10	13562.44

Figure 9: Original and Target Metrics for Large Teaching Hospitals

Scenario 2: Medium Non-Teaching Hospitals

- Outputs: Surgery Cases, Hip Fracture Cases
- Inputs: Cost per Patient day and Surgical ALC days

For the second scenario, Figure 10 shows that AC and AE are the most efficient out of the medium non-teaching hospitals for this combination of metrics. In this scenario, the two inefficient hospitals, I and J, both use only AE as a benchmark.

Hospitals Chosen	Efficiencies	Benchmark 1	% Composition	Benchmark 2	% Composition	Benchmark 3	% Composition
AC	1.00	AC	100%				
AE	1.00	AE	100%				
I	0.80	AE	100%				
J	0.90	AE	100%				

Figure 10: Efficiency of Medium Non-Teaching Hospitals and their Benchmark Hospitals

In the resulting target metrics, Figure 11 shows that both hospitals I and J should aim to increase their surgical case and hip fracture case numbers, while maintaining cost and lowering their surgical ALC days, as seen with the highlighted values.

					ORIGINAL METRICS
Hospitals Chosen	Efficiencies	Surgical Cases	Hip Fracture Cases	Cost per Patient-day	Surgical ALC Days
AC	1.00	4,869.07	143.20	1,070.97	1,094.64
AE	1.00	6,329.93	168.19	1,070.24	2,486.10
I	0.80	4,506.85	134.73	1,069.81	2,574.05
J	0.90	4,818.88	154.69	1,089.59	4,761.78
					TARGET METRICS
Hospitals Chosen	Efficiencies	Surgical Cases	Hip Fracture Cases	Cost per Patient-day	Surgical ALC Days
AC	1.00	4,869.07	143.20	1,070.97	1,094.64
AE	1.00	6,329.93	168.19	1,070.24	2,486.10
I	0.80	6,329.93	168.19	1,070.24	2,486.10
J	0.90	6,329.93	168.19	1,070.24	2,486.10
					BENCHMARKS
AC		4869.07	143.20	1070.97	1094.64
AE		6329.93	168.19	1070.24	2486.10

Figure 11: Original and Target Metrics for Medium Non-Teaching Hospitals

Scenario 3: Medium Non-Teaching Hospitals – Different input metrics

- **Outputs:** Surgery Cases, Hip Fracture Cases
- **Inputs:** Surgical Site Infection Rate and Total Surgical Inpatient Days

In this scenario, the input metrics were changed. From Figure 12, AC and AE are again the most efficient hospitals in this group. However, the benchmark hospitals for hospital I have now changed to benchmark AC and AE, while hospital J benchmarks only AC.

Hospitals Chosen	Efficiencies	Benchmark 1	% Composition	Benchmark 2	% Composition	Benchmark 3	% Composition
AC	1.00	AC	100%				
AE	1.00	AE	100%				
I	0.79	AC	79%	AE	21%		
J	0.89	AC	100%				

Figure 12: Efficiency of Large Teaching Hospitals with varying metrics

Using hospital J as an example, the target metrics in Figure 13 show that in order to become more efficient relative to the hospitals in this group, hospital J should decrease the number of hip fracture cases they perform and focus on decreasing their surgical site infections instead. Overall, this would improve quality of care and can help to decrease surgical inpatient days too.

ORIGINAL METRICS

Hospitals Chosen	Efficiencies	Surgical Cases	Hip Fracture Cases	Surgical Site Infection	Total Surgical Inpatient Days
AC	1.00	4,869.07	143.20	0.17	26,036.86
AE	1.00	6,329.93	168.19	0.13	41,839.70
I	0.79	4,506.85	134.73	0.19	33,777.15
J	0.89	4,818.88	154.69	0.26	31,656.44

TARGET METRICS

Hospitals Chosen	Efficiencies	Surgical Cases	Hip Fracture Cases	Surgical Site Infection	Total Surgical Inpatient Days
AC	1.00	4,869.07	143.20	0.17	26,036.86
AE	1.00	6,329.93	168.19	0.13	41,839.70
I	0.79	5,181.78	148.55	0.16	29,419.52
J	0.89	4,869.07	143.20	0.17	26,036.86

BENCHMARKS

AC		4869.07	143.20	0.17	26036.86
AE		6329.93	168.19	0.13	41839.70

Figure 13: Number of Cases and Quality of Care Trade-off

6.0 CONCLUSION

The project is designed to create an Excel DSS that allows for a fair comparison of hospitals based on several performance indicators. The user can choose which metrics to place in the input and output, and which hospitals they would like to compare against. The model will then calculate efficiencies for each hospital that is chosen. Inefficient hospitals, relative to other selected hospitals, are identified and listed for further examination to determine potentially improved practices. Performance metrics that are good discriminators of hospital efficiencies are indicated as well.

The project enables users to make comparisons of hospital efficiencies from various dimensions. Users can select hospitals of different sizes and can also compare teaching and non-teaching hospitals of the same size.

It is worth noting that the model performs better in the larger hospitals given in the data since the smaller hospitals may not necessarily specialize in surgical cases or hip fracture cases. However, there is little information on other specialties or metrics such as emergency department volume, regular appointment volume, etc. More diverse data could be used to obtain a more accurate and complete overview of hospitals' efficiencies in future applications of this DSS.

REFERENCES

[1] "XLSTAT: Statistical software for Excel," XLSTAT, Your data analysis solution. [Online]. Available: https://www.xlstat.com/en/.

[2] C. T. Ragsdale, *Spreadsheet Modeling & Decision Analysis: A practical introduction to management science*. Mason: South-Western, 2021.

APPENDIX A

0	0	0	0	0	0	0	
Output	Output	Output	Output	Output	Output	Output	Ou
Surgical Cases	Hip Fracture Cases						
0.85	0.97	0.00	0.00	0.00	0.00	0.00	
0.83	0.37	0	0	0	0	0	
0.83	0.76	0	0	0	0	0	
0.79	0.59	0	0	0	0	0	
0.90	0.74	0	0	0	0	0	
0.82	0.93	0	0	0	0	0	
1.00	1.00	0	0	0	0	0	
0.00	0.00	0	0	0	0	0	
0.00	0.00	0	0	0	0	0	
0.00	0.00	0	0	0	0	0	
0.00	0.00	0	0	0	0	0	
0.00	0.00	0	0	0	0	0	
0.00	0.00	0	0	0	0	0	
0.00	0.00	0	0	0	0	0	
0.00	0.00	0	0	0	0	0	
0.00	0.00	0	0	0	0	0	
0.00	0.00	0	0	0	0	0	
0.00	0.00	0	0	0	0	0	
0.00	0.00	0	0	0	0	0	

Selector | Results | Target | Output | Input | DEA Plot | Normalized_Output | Normalized_Input

Figure A.1: Normalized Output values from selected output metrics

APPENDIX B

Hospital	N/A	N/A	N/A	N/A	N/A	N/A	1	0	0.863427949	0.194366454
7	N/A	N/A	N/A	N/A	N/A	N/A	Output	Output	Input	Input
Output	Enumeate	Hospitals Chosen	Efficiencies	Output	Input	Output-Input	Surgical Cases	Hip Fracture Cases	Cost per Patient-day	Surgical ALC Days
1	1	AB	1.00	0.85	0.89	-0.04	0.852026681	0.966431427	0.945983059	0.381872251
Input	2	AJ	0.82	0.83	1.02	-0.19	0.830054415	0.374188272	0.975433308	0.889742218
1	3	E	0.80	0.83	1.04	-0.21	0.828835239	0.764120661	1	0.894967231
	4	L	0.83	0.79	0.95	-0.16	0.787067192	0.591419616	0.972795955	0.541490339
	5	M	1.00	0.90	0.90	0.00	0.899737772	0.742717761	0.973496007	0.304549009
	6	Q	0.93	0.82	0.98	-0.15	0.821424172	0.925848368	0.933690295	0.870836236
	7	Z	1.00	1.00	1.00	0.00	1	1	0.933064012	1
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0
	0			0.00	0.00	0.00	0	0	0	0

Results | Output | Input | DEA Plot | Normalized_Output | Normalized_Input | Calculations | ORG-Metrics | PCA | Hospital Parsing | Correlation | Teaching Hospitals (Size)

Figure B.1: DEA calculation for each selected hospital and metric with VBA Excel Solver

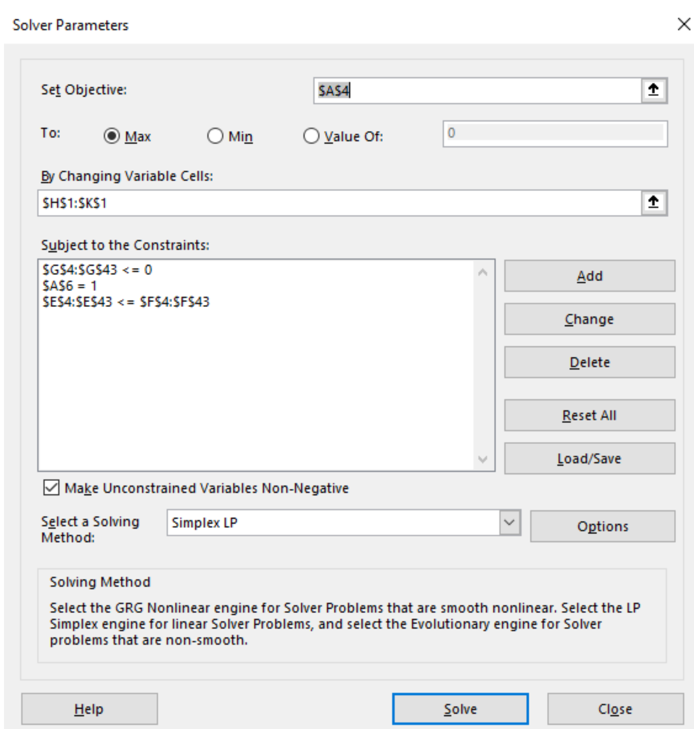


Figure B.2: Solver Parameter sample iteration

APPENDIX C

Table C.1: VBA functions present in the Excel DSS

VBA Function	Purpose
CLEARAllCheckboxes()	Clear all checkboxes selected by user for scenario running
BringCol()	Bring normalized outputs and inputs for selected metrics to the calculation sheet
RunSolver()	Run Excel solver and generate Sensitivity Report for each hospital chosen
Shadow()	Capture Shadow Prices in each Sensitivity Report and normalize, then copy to results sheet per hospital
RunEfficiency()	Macro attached to Run Efficiency button to run BringCol, RunSolver and Shadow with one click

APPENDIX D

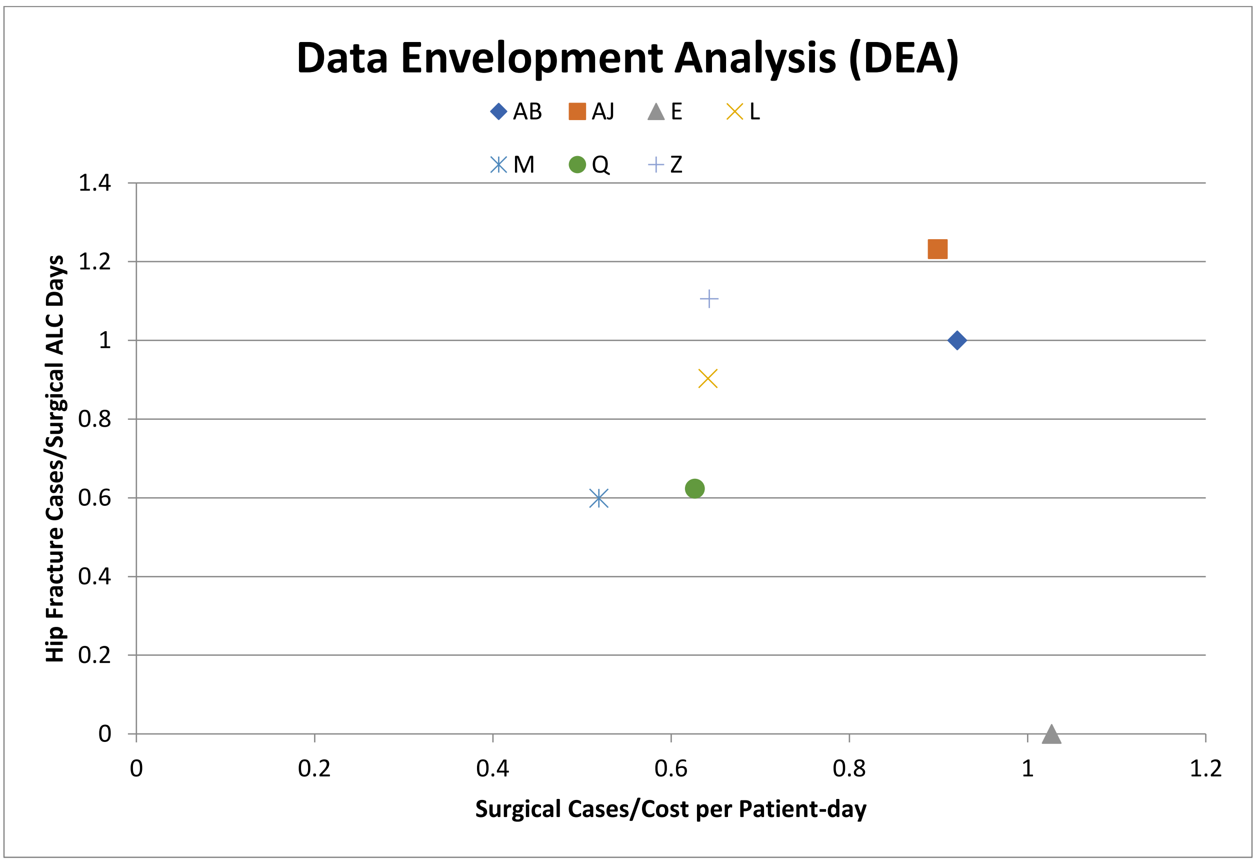


Figure D.1: Example DEA plot for Two Output only