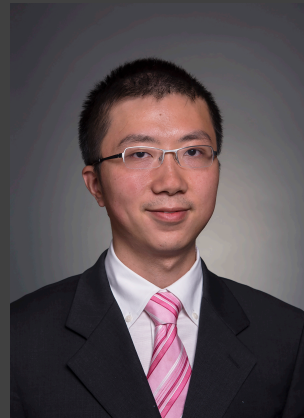# Identifying Inventory Excess And Service Risk In Medical Devices:

A Simulation Approach

Albert Xu

Maria Rey

Agenda

- Motivation & Background

- Goal Statements

- Methodology

  - Data Analysis

  - Simulation model

- Results

- Insights

- Conclusion

Motivation

- Distribution centers
  - High inventory holding costs

- Medical devices
  - High value
  - Non-interchangeable
  - Criticality

Background

- MedCo recently collected large amounts of transactional data
  - Inventory
  - Demand
  - Supply
  - Forecast accuracy
  - Location

- Need to reduce inventory without affecting service
- Currently use classical (s, S) inventory model, assuming normality

Goal Statements

- Determine inventory level for a material number, that ensures a LIFR of 98%

$$LIFR = \frac{Number\ of\ lines\ allocated\ to\ inventory}{Total\ number\ of\ order\ lines}$$

- Gain insights from the data
  - Understand what drives service performance

Methodology

Demand/Supply Characterization

- Use transactional data to find real demand distribution

- Find metrics that affect LIFR performance

|	LIFR	Order Qty	Countries	DOS	Supply COV	MAPE	Demand COV	Transactions
N	1486	1486	1464	1424	1031	1440	1424	1486
N Missing	0	0	22	62	455	46	62	0
Mean	0.91	58701	9.7	291	2.17	0.67	0.65	442
Std Dev	0.15	136472	7.6	1579	1.79	2.30	0.68	761
Min	0.00	1	1	0	0.00	0.00	0.12	1
Median	0.96	14274	8	68	1.62	0.36	0.39	190
Max	1.00	1625940	41	31839	8.46	60.63	3.62	9352

Summary statistics

Clustering

- Demand Coefficient of Variation (COV)
- Number of countries the SKU is shipped to (Countries)
- Average order size quantity (Order Qty)
- Days of supply (DOS)
- Order frequency (Transactions)

| Cluster	LIFR				Order Quantity			Countries			DOS			Demand COV			Transactions		
	N	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
1	987	0.929	0.00	1.00	23,784	28	180,480	8	1	22	91	1	1269	0.45	0.12	2	255	3	1337
2	13	0.943	0.88	0.97	1,128,427	608,436	1,625,940	30	21	41	34	19	113	0.39	0.18	1	4552	1105	9352
3	168	0.822	0.00	1.00	3,588	3	121,500	3	1	12	824	0	7160	2.10	1.09	4	21	1	222
4	11	0.994	0.94	1.00	656	12	2,700	2	1	5	15648	8660	31839	3.06	1.27	3	10	1	59
5	230	0.939	0.63	1.00	188,832	22,452	600,876	21	8	35	45	14	139	0.33	0.12	1	1433	291	4850

CLUSTERS
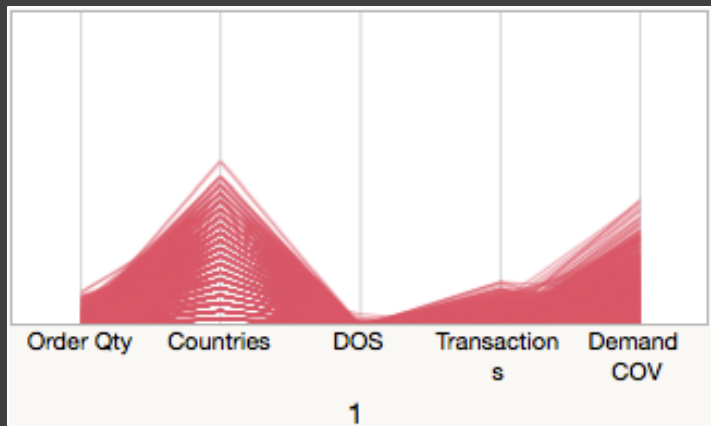
Commodities
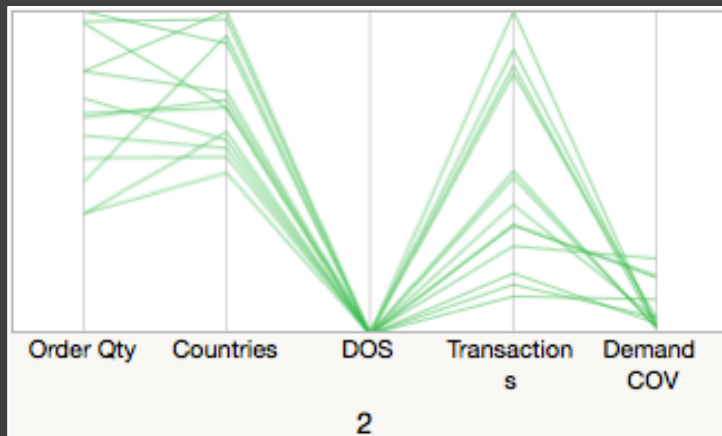
High Volume
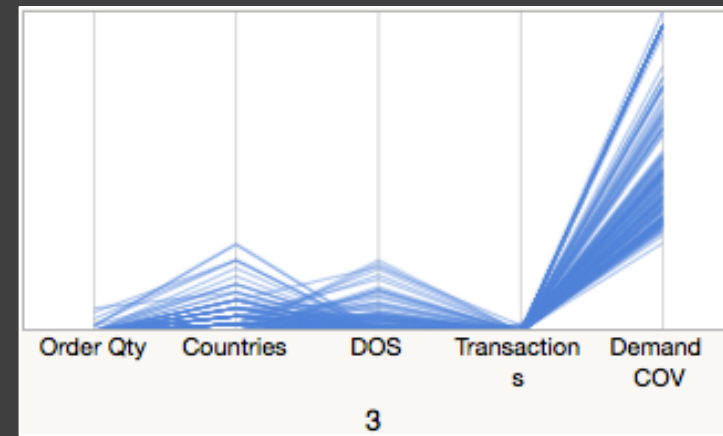
Service Risk
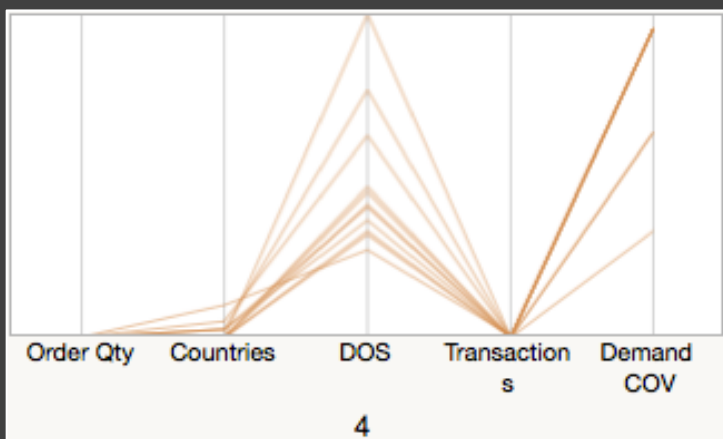
Sparse demand
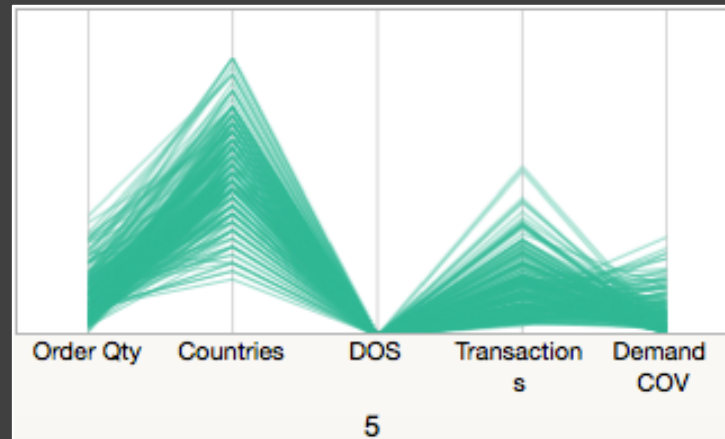
High Volume Commodities

CLUSTERS - MEAN COMPARISON
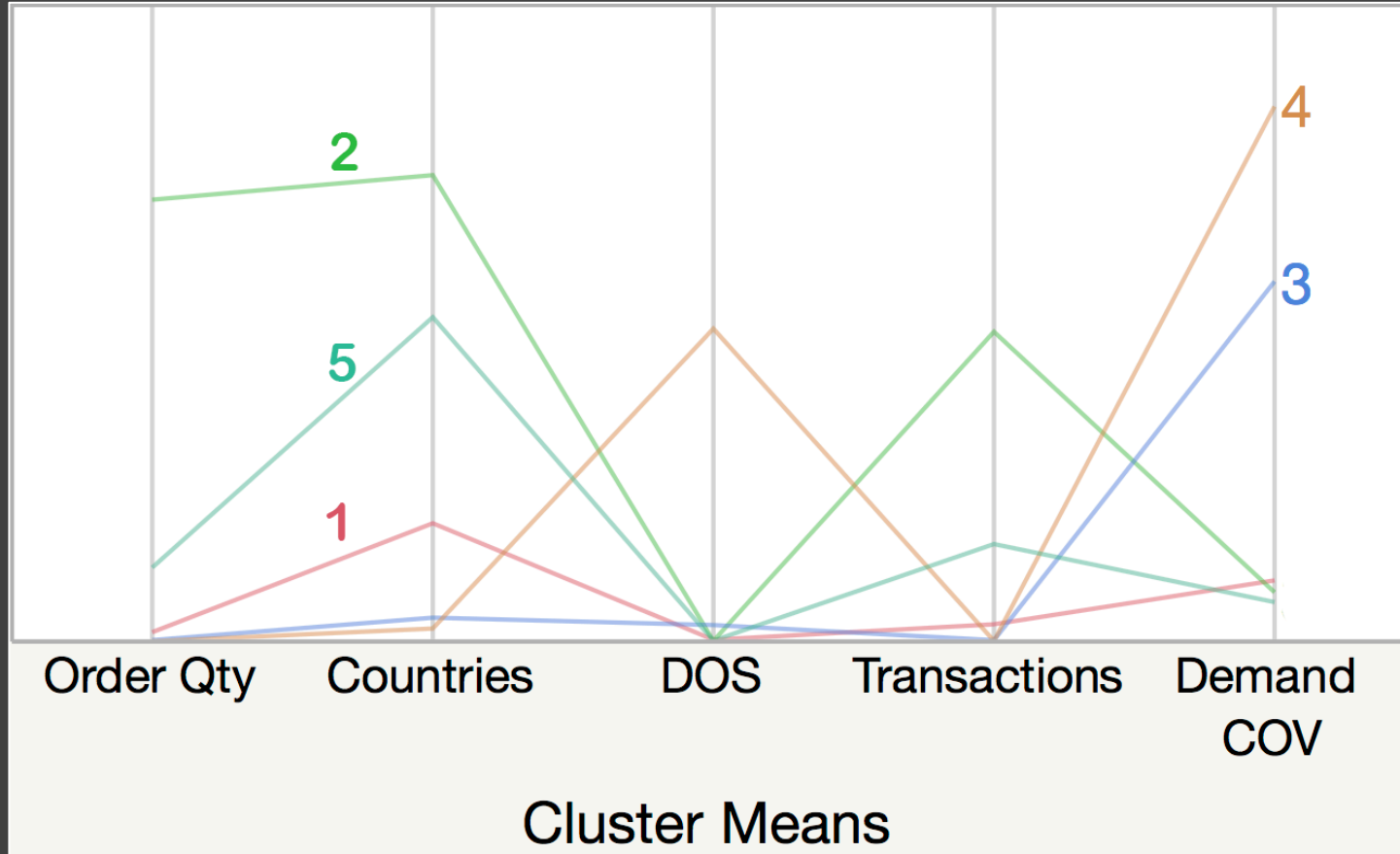
1. Commodities
2. High Volume
3. Service risk
4. Sparse demand
5. High volume commodities

Simulation Model
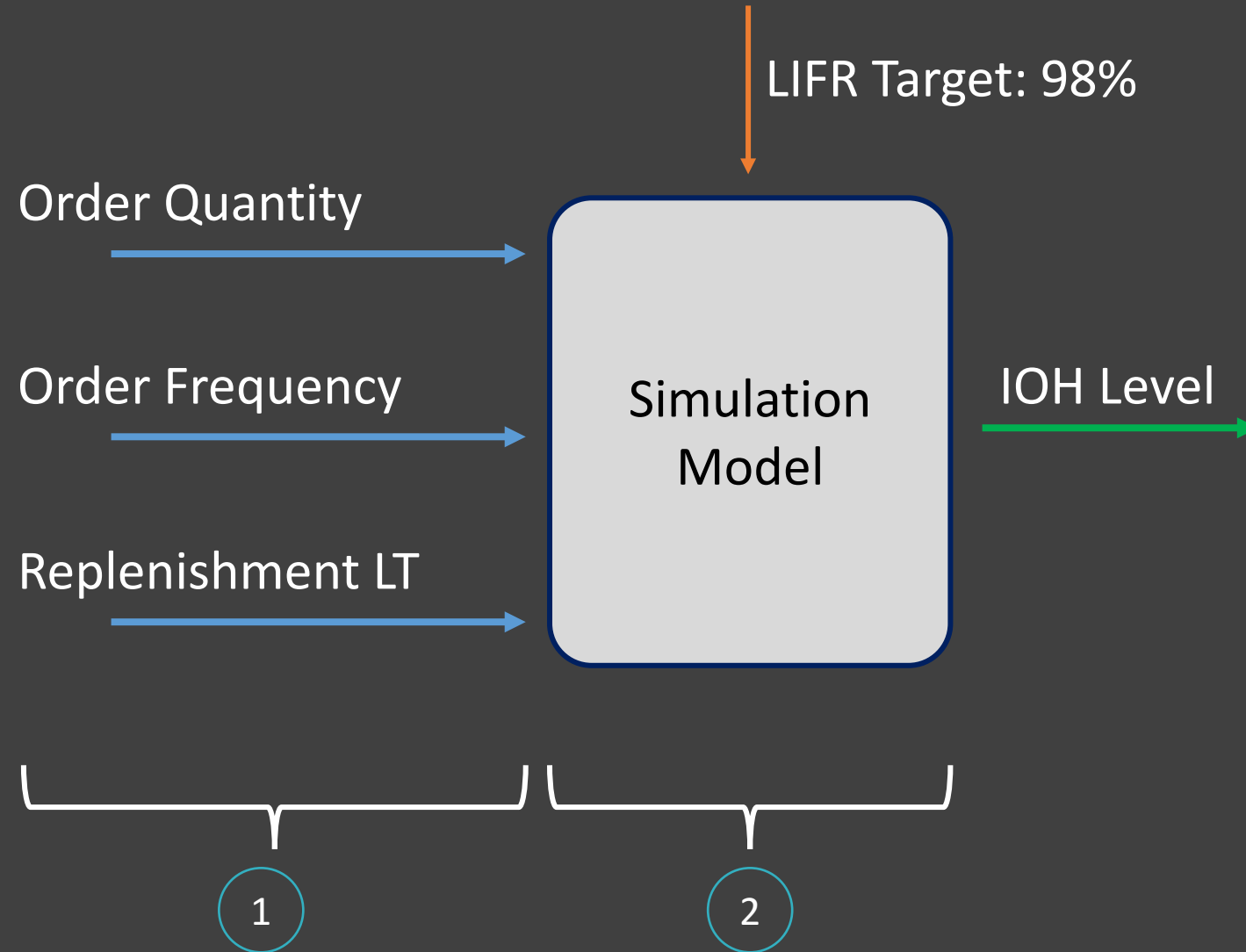
Order Quantity distribution: ~ Gamma

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
1st Place	Pareto	Gamma	Gamma	Pareto	Exponential
2nd Place	Gamma	Pareto	Pareto	Triangular	Triangular
3rd Place	Triangular		Triangular		Gamma
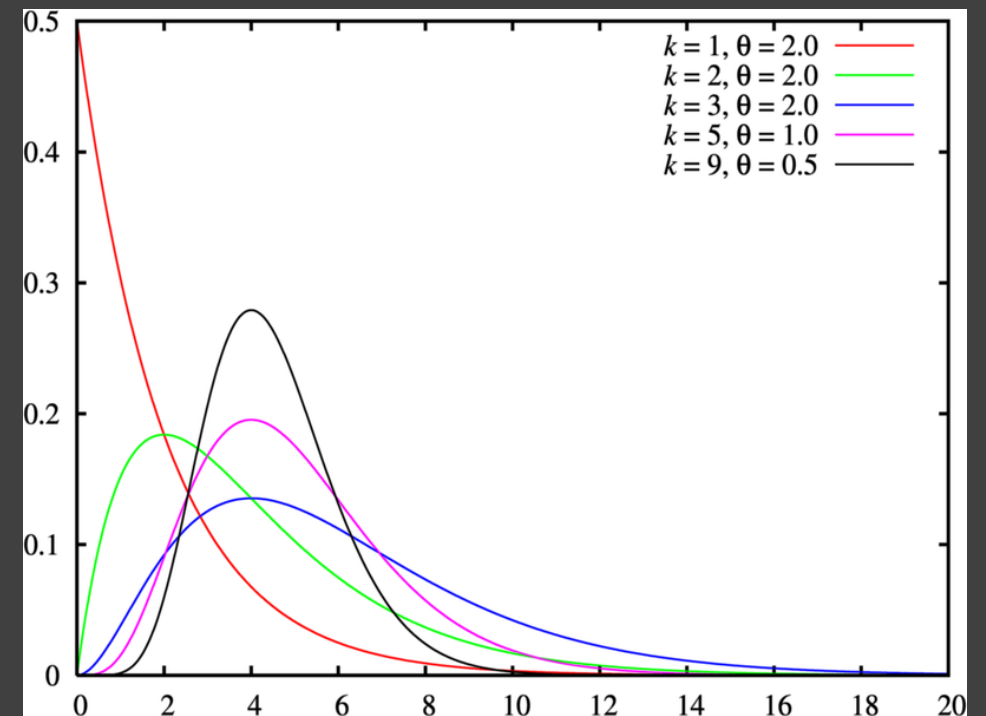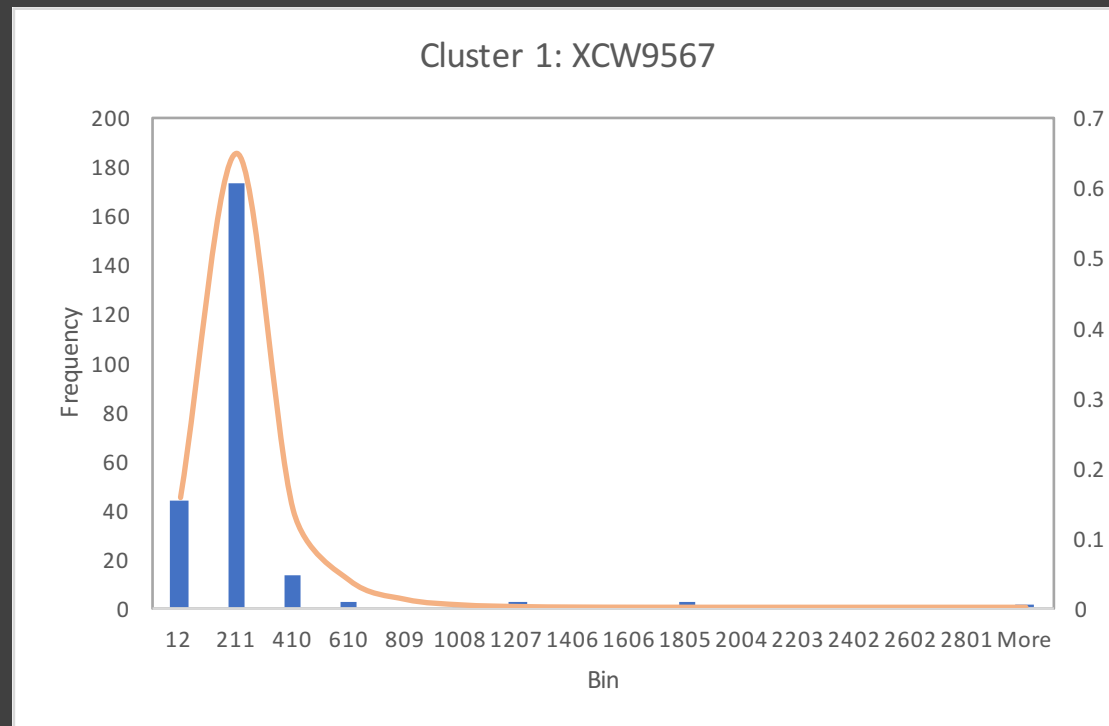
Order frequency distribution: ~ Normal
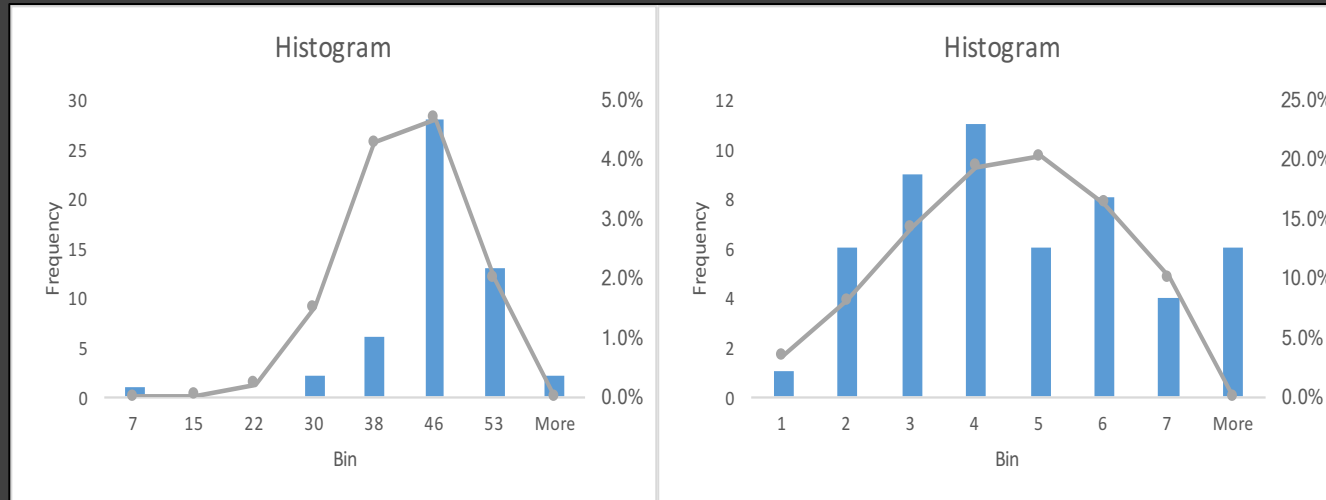
Issues with material numbers with few demand points
- Hard to fit a distribution
- They have high DOS levels

① Distributions

Cluster	Order Quantity			Order Frequency		Replenishment Lead Time	
	Gamma Distribution			Normal Distribution		Normal Distribution	
	Shape	Scale	Shift	Mean	StDev	Mean	StDev
1	0.714	175.83	12	4.7	1.9	7	2
2	0.331	2,761.20	36	49.4	8.3	3	1
3	0.569	147.68	36	1.0	-	3	1
4	0.232	125.00	36	1.2	0.4	12	3
5	0.421	1,367.10	12	7.5	2.2	3	1

Simulation Model Assumptions

- Customer orders are exogenous and independent of inventory level. Orders can come in even if there is no inventory on hand.
- Customer orders are not correlated
- Assuming lot for lot policy.
- Assuming supplier is not out of stock.
- Inventory availability is the only factor affecting service.
- Raw data do not have systematic trend / fluctuation across seasons. The randomness of the variables used in the simulation account for any seasonality present in the raw data.
- Assuming countries' demands are independent.
- Unfilled inventory will be backlogged. Customers will eventually accept inventory regardless of when they receive it.
- Order allocation is sequential, on a first-come-first-serve basis.
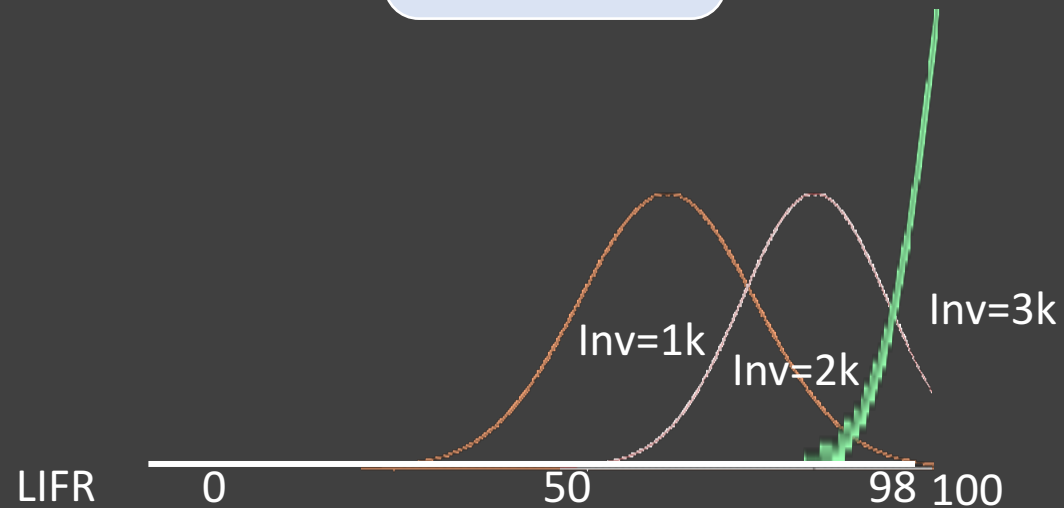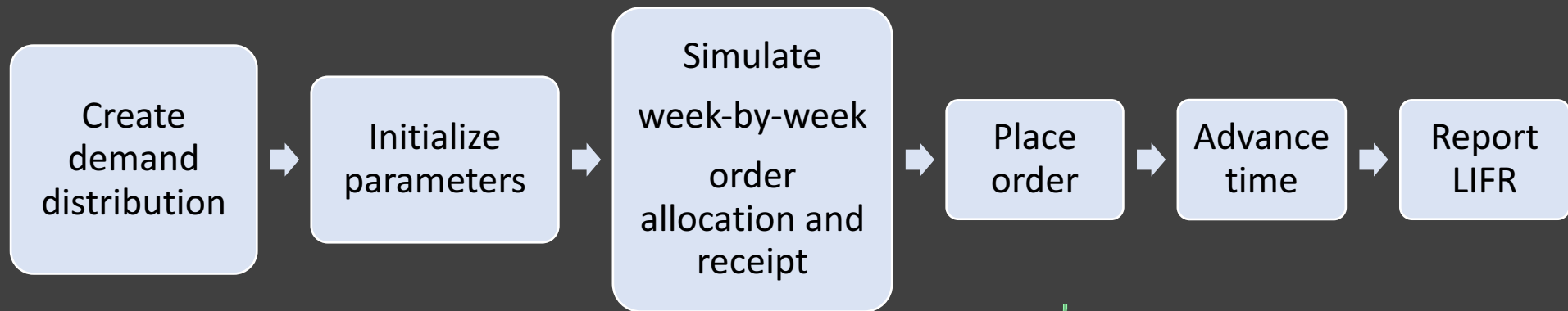
Results

IOH Comparison Cluster 2: Material B

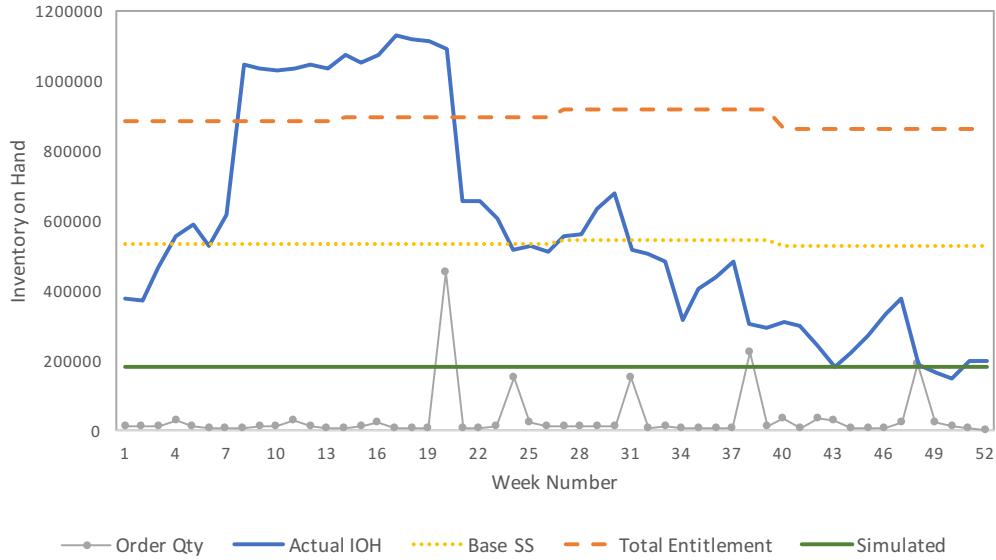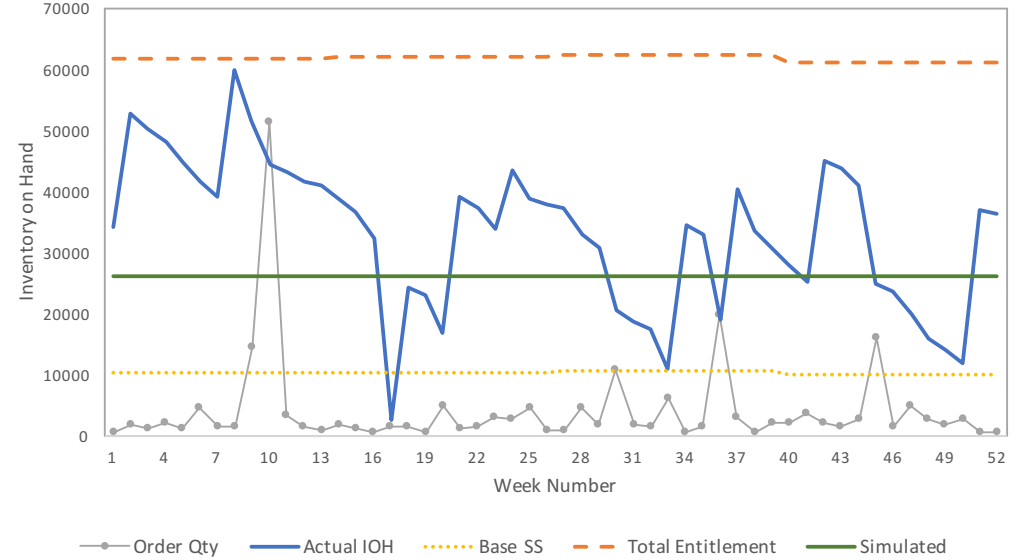|	min	max	median	mean	90th Percentile	stdev
80000	0.708383	0.836393	0.772162	0.773904	0.744294	0.026312
90000	0.753502	0.891860	0.821184	0.820563	0.788424	0.025888
100000	0.769781	0.922062	0.861600	0.857654	0.818075	0.029225
110000	0.824628	0.958469	0.892180	0.889042	0.852187	0.028857
120000	0.845211	0.963250	0.919349	0.916187	0.885120	0.022464
130000	0.865297	0.990449	0.944102	0.942313	0.915248	0.021919
140000	0.902429	1.000000	0.961390	0.959412	0.935283	0.020466
150000	0.928060	0.998006	0.974359	0.970269	0.948137	0.015482
160000	0.925926	1.000000	0.985401	0.983516	0.969201	0.012732
170000	0.946837	1.000000	0.992891	0.989524	0.974440	0.010729
180000	0.952343	1.000000	0.995640	0.992232	0.979821	0.009598

IOH Comparison Cluster 5: Material E

	min	max	median	mean	90th Percentile	stdev
8000	0.659794	0.877660	0.761194	0.763505	0.704492	0.045146
10000	0.735084	0.937838	0.832891	0.833633	0.789855	0.037104
12000	0.786241	0.965147	0.889724	0.886164	0.839793	0.037107
14000	0.830769	0.997416	0.922892	0.921701	0.875895	0.034534
16000	0.838710	1.000000	0.958869	0.955532	0.927711	0.024856
18000	0.919708	1.000000	0.972705	0.970244	0.939547	0.020966
20000	0.928947	1.000000	0.989041	0.982673	0.954667	0.018358
22000	0.938967	1.000000	0.995012	0.990292	0.972840	0.012496
24000	0.936430	1.000000	1.000000	0.991353	0.971154	0.013259
26000	0.945679	1.000000	1.000000	0.997346	0.990453	0.007651
28000	0.973890	1.000000	1.000000	0.998817	0.997481	0.004232

Sample material number per cluster

SKU	ACTUAL LIFR	AVERAGE IOH	WEEKS W/O INV.	CURRENT INV. LEVEL	SIMULATED LEVEL
A	85.83%	3,160	2	4,100	3,500
B	96.94%	740,928	0	800,000	180,000
C	53.85%	632	1	300	1,000
D	100%	1,142	0	1,500	800
E	90.05%	49,923	0	61,000	26,000

Insights

Insight 1: Demand Pattern Analysis

Country Comparison Material B
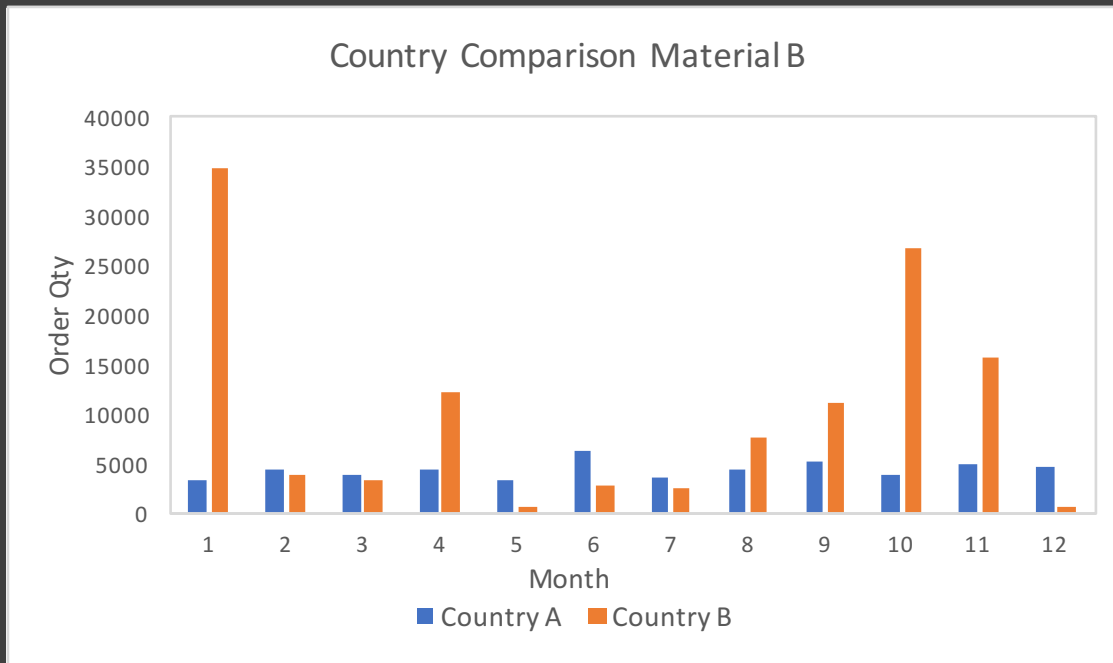
	COUNTRY A (BLUE)	COUNTRY B (ORANGE)
NO. OF ORDER	620	45
TOTAL UNITS ORDERED	51,696	121,860
LARGEST ORDER SIZE	504	23,040
DEMAND COV	0.21	1.07

Hypothesis: **Erratic ordering patterns** causes strain in the supply chain performance. It leads to higher inventory requirements given the same risk exposure.

Simulated Order Pattern Changes

Probalistic Distributions - Before

	min	max	median	mean	90th Percentile	stdev
1100	0.644231	0.881443	0.790055	0.786789	0.730337	0.047385
1500	0.739910	0.964824	0.883041	0.879968	0.831633	0.041869
1900	0.818182	0.994709	0.934343	0.929632	0.882353	0.036100
2300	0.903846	1.000000	0.970874	0.966514	0.928962	0.022970
2700	0.943590	1.000000	0.990000	0.985368	0.963134	0.015425
3100	0.932692	1.000000	1.000000	0.991322	0.969849	0.014304
3500	0.941489	1.000000	1.000000	0.995896	0.984043	0.009771
3900	0.955882	1.000000	1.000000	0.998558	1.000000	0.006238
4300	0.978947	1.000000	1.000000	0.999697	1.000000	0.002280
4700	0.990000	1.000000	1.000000	0.999900	1.000000	0.000995
5100	0.985782	1.000000	1.000000	0.999858	1.000000	0.001415

Probalistic Distributions - After

	min	max	median	mean	90th Percentile	stdev
1100	0.692683	0.900000	0.792929	0.791713	0.743719	0.039654
1500	0.798122	0.983607	0.887179	0.888469	0.843602	0.036310
1900	0.863158	1.000000	0.954023	0.949429	0.917526	0.026173
2300	0.922481	1.000000	0.983957	0.979221	0.954338	0.018508
2700	0.944162	1.000000	1.000000	0.993075	0.979899	0.010696
3100	0.951220	1.000000	1.000000	0.997780	0.990050	0.006474
3500	0.980000	1.000000	1.000000	0.999209	1.000000	0.003346
3900	0.990610	1.000000	1.000000	0.999856	1.000000	0.001053
4300	1.000000	1.000000	1.000000	1.000000	1.000000	0.000000
4700	1.000000	1.000000	1.000000	1.000000	1.000000	0.000000
5100	1.000000	1.000000	1.000000	1.000000	1.000000	0.000000

- Recommendation: reduce order variability, advanced notices before ordering above threshold

Insight 2: Forecasting

- We increase 1 period of forecasting by assuming we know 80% of the next period's demand

	min	max	median	mean	90th Percentile	stdev
1100	0.644231	0.881443	0.790055	0.786789	0.730337	0.047385
1500	0.739910	0.964824	0.883041	0.879968	0.831633	0.041869
1900	0.818182	0.994709	0.934343	0.929632	0.882353	0.036100
2300	0.903846	1.000000	0.970874	0.966514	0.928962	0.022970
2700	0.943590	1.000000	0.990000	0.985368	0.963134	0.015425
3100	0.932692	1.000000	1.000000	0.991322	0.969849	0.014304
3500	0.941489	1.000000	1.000000	0.995896	0.984043	0.009771
3900	0.955882	1.000000	1.000000	0.998558	1.000000	0.006238
4300	0.978947	1.000000	1.000000	0.999697	1.000000	0.002280
4700	0.990000	1.000000	1.000000	0.999900	1.000000	0.000995
5100	0.985782	1.000000	1.000000	0.999858	1.000000	0.001415

	min	max	median	mean	90th Percentile	stdev
1100	0.737113	0.916667	0.825000	0.826008	0.773481	0.039476
1500	0.797980	0.979275	0.903743	0.898659	0.850000	0.037041
1900	0.847619	1.000000	0.945274	0.939100	0.892377	0.033312
2300	0.904348	1.000000	0.967742	0.965771	0.929577	0.025534
2700	0.892019	1.000000	0.993789	0.985719	0.962162	0.018988
3100	0.934132	1.000000	1.000000	0.992952	0.977778	0.013228
3500	0.931193	1.000000	1.000000	0.996288	0.985849	0.009214
3900	0.989130	1.000000	1.000000	0.999392	1.000000	0.002184
4300	0.967568	1.000000	1.000000	0.998955	1.000000	0.004528
4700	0.979381	1.000000	1.000000	0.999794	1.000000	0.002052
5100	1.000000	1.000000	1.000000	1.000000	1.000000	0.000000

- Results show it moderately improves inventory performance under current 1 week lead time

Insight 3: Lead time

- We simulated a 'supply shock' where our replenishment lead-time suddenly inflates from 1 week to 1 month

	min	max	median	mean	90th Percentile	stdev
1100	0.644231	0.881443	0.790055	0.786789	0.730337	0.047385
1500	0.739910	0.964824	0.883041	0.879968	0.831633	0.041869
1900	0.818182	0.994709	0.934343	0.929632	0.882353	0.036100
2300	0.903846	1.000000	0.970874	0.966514	0.928962	0.022970
2700	0.943590	1.000000	0.990000	0.985368	0.963134	0.015425
3100	0.932692	1.000000	1.000000	0.991322	0.969849	0.014304
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4300	0.978947	1.000000	1.000000	0.999697	1.000000	0.002280
4700	0.990000	1.000000	1.000000	0.999900	1.000000	0.000995
5100	0.985782	1.000000	1.000000	0.999858	1.000000	0.001415

	min	max	median	mean	90th Percentile	stdev
1100	0.378238	0.780749	0.587065	0.581785	0.502890	0.070047
1500	0.481283	0.849673	0.674528	0.673114	0.579487	0.076113
1900	0.577586	0.937107	0.746341	0.743535	0.656085	0.074262
2300	0.594203	0.960000	0.820755	0.818354	0.736842	0.067761
2700	0.691964	0.985222	0.890000	0.872576	0.779570	0.065561
3100	0.687500	1.000000	0.921348	0.909691	0.823864	0.065067
3500	0.822430	1.000000	0.945000	0.936152	0.868182	0.046489
3900	0.861111	1.000000	0.979167	0.967708	0.912281	0.034506
4300	0.882979	1.000000	0.989011	0.975742	0.937824	0.028990
4700	0.894231	1.000000	1.000000	0.984499	0.951456	0.022908
5100	0.906863	1.000000	1.000000	0.990855	0.968421	0.018212

- Inventory performance drops drastically. We need to double the baseline inventory to guarantee service level

Conclusion

- Data-driven approach to inventory management

- Understanding demand characteristics
  - Clustering
  - Machine learning

- Applicable to many industries
  - Criticality of product availability
  - Risk Management
  - Manage order patterns

Q&A