Demand Forecasting for Ebola Responses

By Robert Rains

MIT SCM Master's Program

Author/Researcher: Robert Rains

- International Development in Crises and Conflicts
- PAE – International Logistics and Stabilization Team

  (Stabilization of Conflicted Afflicted Areas and Humanitarian Response)
- Ebola Specific Projects & Responses
  - Liberia 2014/15 West Africa Ebola Outbreak
  - Sierra Leone 2014/15 West Africa Ebola Outbreak
  - Uganda 2017-Current Ebola Preparedness
  - DRC 2018/?? North Kivu Outbreak

Key Insights:

- **Ebola-negative, instead of Ebola-positive, patients are the prime drivers of operational capacity and service requirements.**
- **Increasing the speed between sample collection and test results drastically improves the absorbative capacity of the isolation and treatment network.**
- **Managing Ebola-negative patients by improving diagnostic velocity becomes increasingly more important when dealing with larger catchment areas.**

Motivation

- “Whether it occurs by a quirk of nature or at the hand of a terrorist, epidemiologists say a fast-moving airborne pathogen could kill more than 30 million people in less than a year. And they say there is a reasonable probability the world will experience such an outbreak in the next 10 to 15 years.” –Bill Gates, Munich Security Conference

- Infectious diseases have likely claimed more lives than all wars, noninfectious diseases, and natural disasters taken together -- Inhorn & Brown, 1990

- The accelerating global trends of urbanization, interconnectivity, and population mobility are creating increasingly favorable conditions for outbreaks of high threat pathogens. This will drive an associated increase in frequency, severity, and velocity of future outbreaks. Expeditionary clinical interventions to contain outbreaks will play a critical role in localizing instead of globalizing this danger. -- Robert Rains, 2019

The Supply-Chain Problem

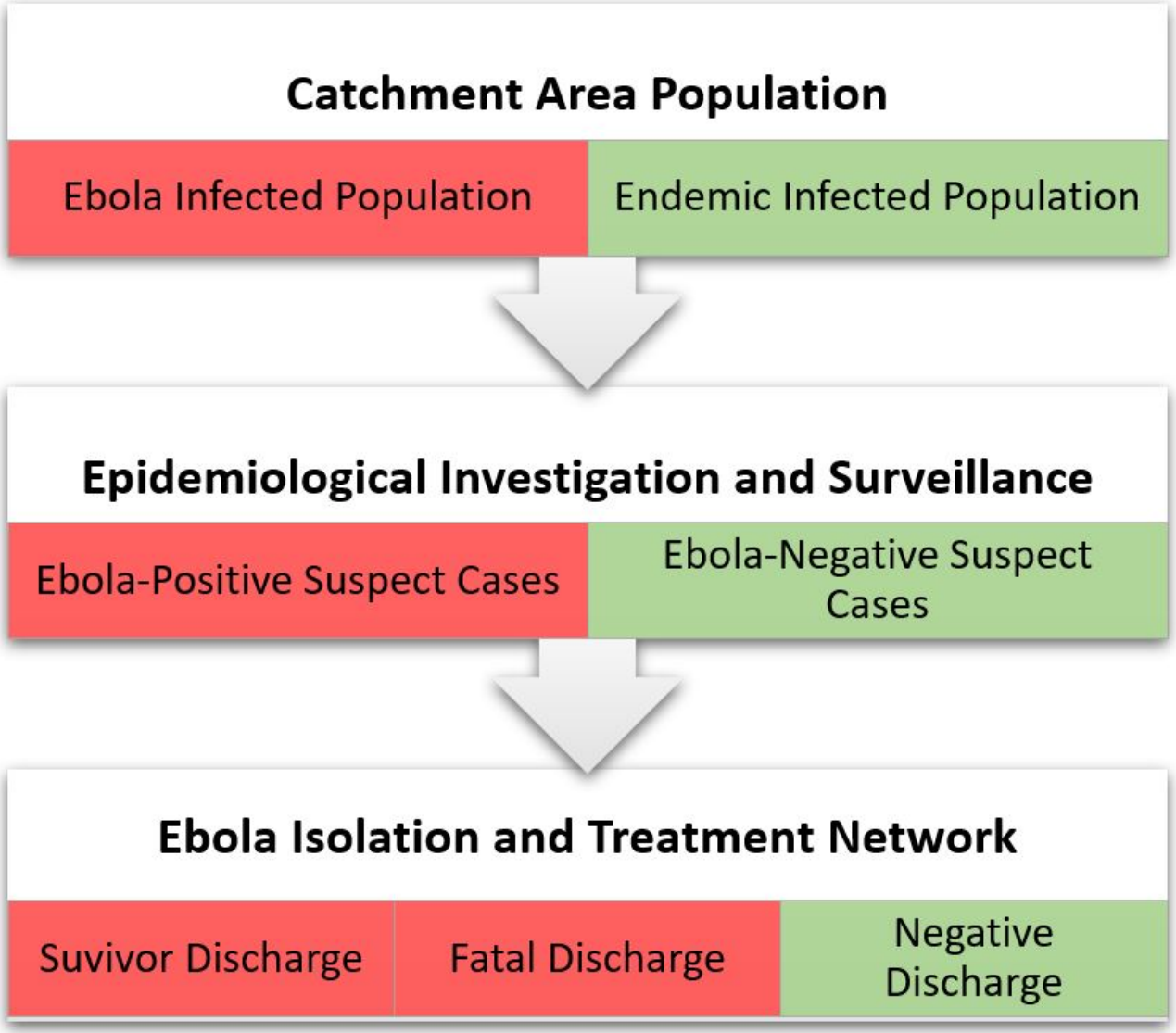
Mission requires zero service failures – Operational capacity for in-patients and materials for clinical and non-clinical care

Expeditionary in nature – reliant on international supply-chain due to scarce local material and service providers which are compounded by quarantines

Each Outbreak is Unique – Utilization of historical data on consumption has limited value due to changes in environment, response measures, and variability in implementing organizations

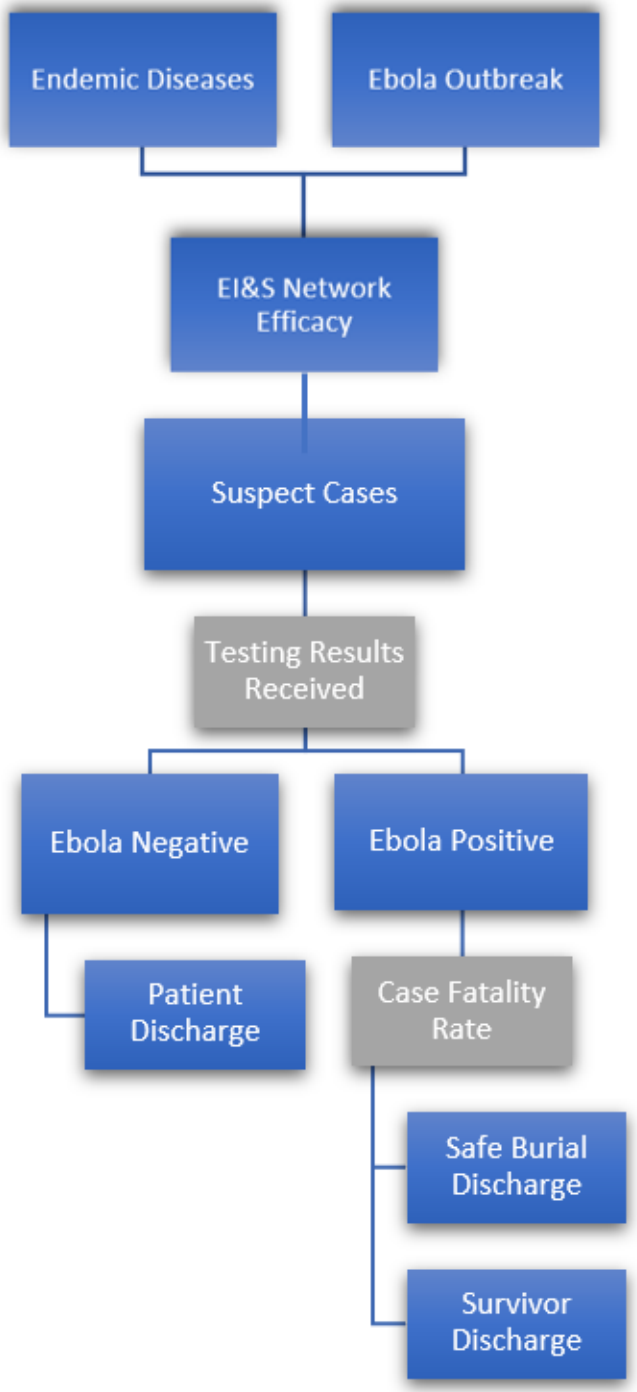
Local and General Settings

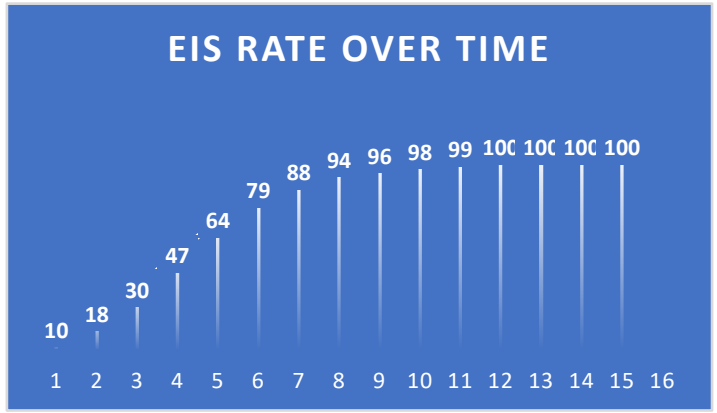
- Catchment area – the population inside the geographic area which the response activities serve
- Epidemiological Investigation and Surveillance – Aggregate of five to six activities to identify suspect cases
- Ebola Isolation and Treatment Network – Single or multiple facilities where suspect cases are isolated and confirmed cases are treated

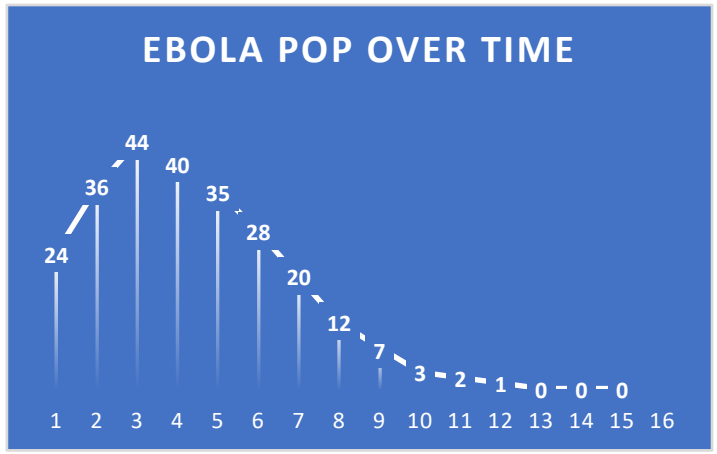


Model Overview

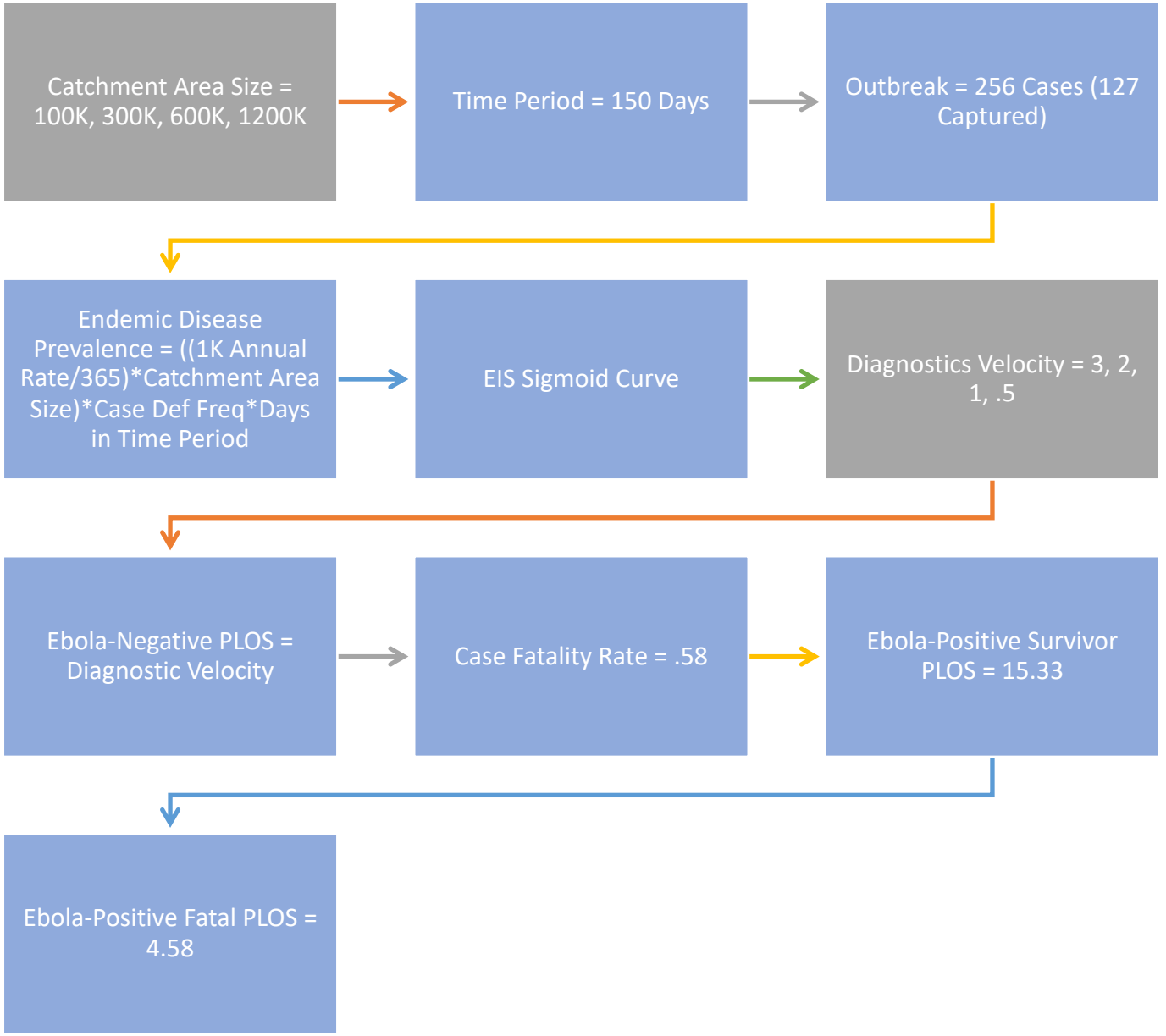
- Objective: Determine Patient Census throughout response
- Determine Cumulative Patient Days for admitted patients
- Capacity and Service Requirements are calculated based on the peak and total days of the patient census over time
- Endemic and Ebola Outbreak are the populations that represent the total potential flow into the Ebola Isolation & Treatment (EIT) Network
- Their flow-rate into the EIT is dictated by the efficacy of Epidemiological Investigation and Surveillance efficacy at capture “suspect” cases.
- All cases enter the EIT as suspect cases and receive diagnostic testing.
- Ebola-Negative cases are discharged immediately upon results
- Ebola-Positive cases will split based on the case fatality rate (CFR) with survivors and fatalities have different average patient-length-of-stays (PLOS)







Data and Variable Selection



Determining Service Requirements

Types of Service Coverage and Frequency for In-Patient Service				
PLOS Variable Service	**Team Size**	**Coverage**	**Freq.**	**Staff Rounds Per Patient Per Day**
Clinical	2	8	6	1.5
Sanitation	2	12	12	2
Life-Support	2	24	3	.25
Facility Maintenance	2	24	2	.17
			Total =	**3.92**
Fixed Service	**Team Size**	**Coverage**	**Freq.**	**Staff Rounds Per Patient Per Day**
Transfer	2	1	Admit/Discharge	4 Per Patient Total
Formula				
Patient Service Requirements	(Patient Type Length of Stay x Sum Per Patient Per Day Req) + Fixed Service			
Ebola-Negative Patient	(Diagnostic Velocity x 3.92) + 4			
Ebola-Positive Survivor	(15.33 x 3.92) + 4			
Ebola-Positive Fatality	(4.58 x 3.92) + 4			

Ebola Negative Catchment Population 100,000																
Day	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	SUM
Endemic Pop.	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	252
Epi-Cover	10%	18%	30%	47%	64%	79%	88%	94%	96%	98%	99%	100%	100%	100%	100%	Null
Negative Cases	13	23	38	60	82	101	113	120	123	125	127	128	128	128	128	1437
3-Day Lab																
Negative Patient Days	38	69	115	180	246	303	338	361	369	376	380	384	384	384	384	4312
Total Patient Days	60	128	235	351	449	505	498	464	430	403	398	393	384	384	384	5467
Service Req	266	561	1025	1534	1969	2223	2211	2079	1942	1835	1817	1798	1760	1760	1760	24540
2-Day Lab																
Negative Patient Days	26	46	77	120	164	202	225	241	246	251	253	256	256	256	256	2875
Total Patient Days	47	105	197	291	368	403	385	343	307	278	271	265	256	256	256	4029
Service Req	216	470	874	1299	1648	1827	1770	1608	1461	1344	1321	1296	1259	1259	1259	18910
1-Day Lab																
Negative Patient Days	13	23	38	60	82	101	113	120	123	125	127	128	128	128	128	1437
Total Patient Days	35	82	158	231	286	302	273	223	184	152	145	137	128	128	128	2592
Service Req	166	380	724	1063	1327	1430	1329	1136	980	853	824	795	757	757	757	13280
.5-Day Lab																
Negative Patient Days	6	12	19	30	41	51	56	60	61	63	63	64	64	64	64	719
Total Patient Days	28	70	139	201	245	252	216	163	123	89	81	73	64	64	64	1873
Service Req	141	335	649	945	1167	1232	1108	901	739	607	576	544	507	507	507	10465

Summary Results

POP: 100,000	Lab Velocity			
	3-Day	2-Day	1-Day	.5 Day
Total Positive Census	127	127	127	127
Total Negative Census	146	146	146	146
Total Survivor Days	818	818	818	818
Total Fatal Days	337	337	337	337
Total Negative Days	438	292	146	73
Cumulative Days	1593	1447	1301	1228
Peak Census	53	43	32	27

POP: 300,000	Lab Velocity			
	3-Day	2-Day	1-Day	.5 Day
Total Positive Census	127	127	127	127
Total Negative Census	432	432	432	432
Total Survivor Days	818	818	818	818
Total Fatal Days	337	337	337	337
Total Negative Days	1296	864	432	216
Cumulative Days	2451	2019	1587	1371
Peak Census	120	85	53	37

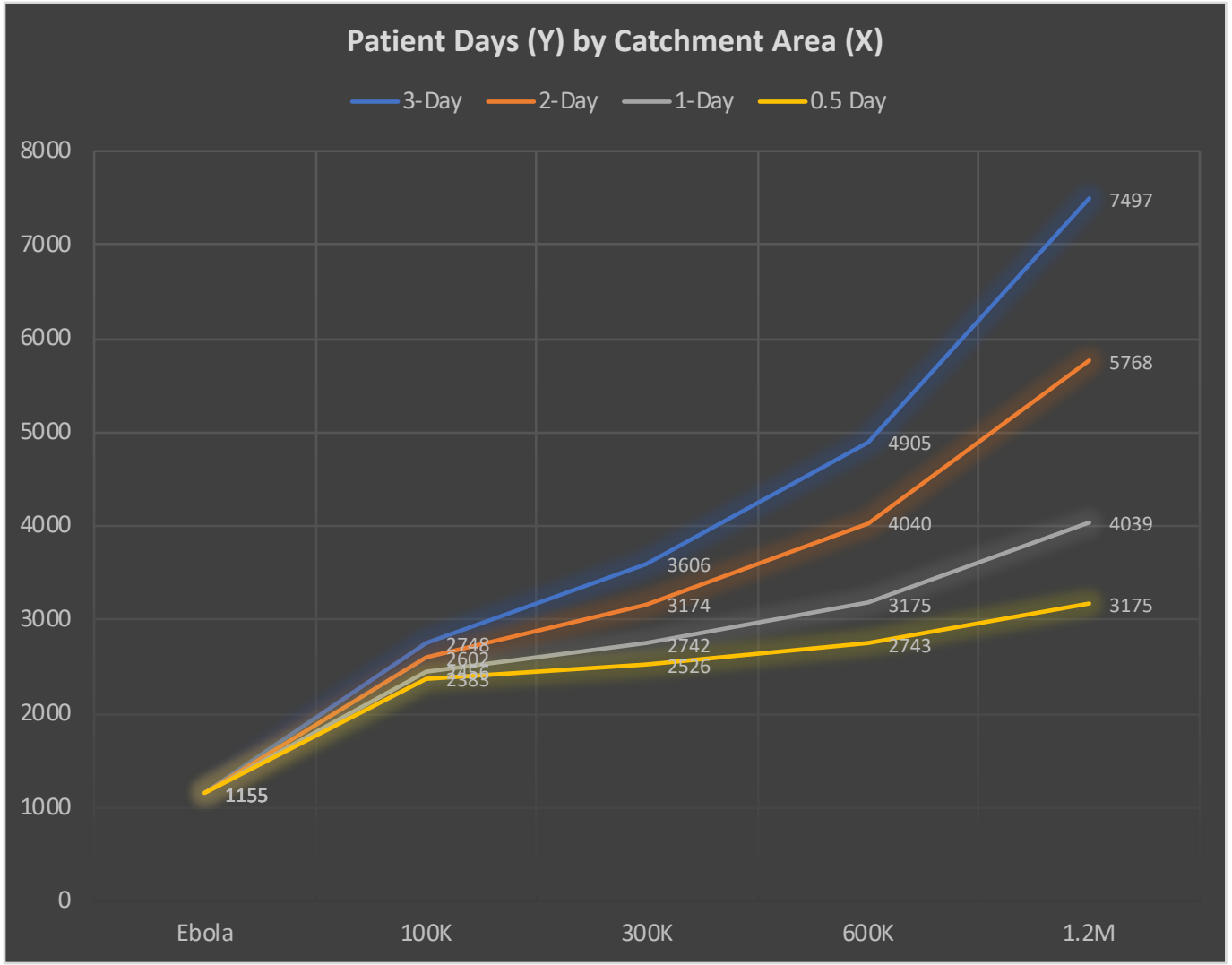
POP: 600,000	Lab Velocity			
	3-Day	2-Day	1-Day	.5 Day
Total Positive Census	127	127	127	127
Total Negative Census	865	865	865	865
Total Survivor Days	818	818	818	818
Total Fatal Days	337	337	337	337
Total Negative Days	2595	1730	865	432.5
Cumulative Days	3750	2885	2020	1588
Peak Census	232	156	84	52

POP: 1,200,000	Lab Velocity			
	3-Day	2-Day	1-Day	.5 Day
Total Positive Census	127	127	127	127
Total Negative Census	1729	1729	1729	1729
Total Survivor Days	818	818	818	818
Total Fatal Days	337	337	337	337
Total Negative Days	5187	3458	1729	864.5
Cumulative Days	6342	4613	2884	2020
Peak Census	463	308	155	85

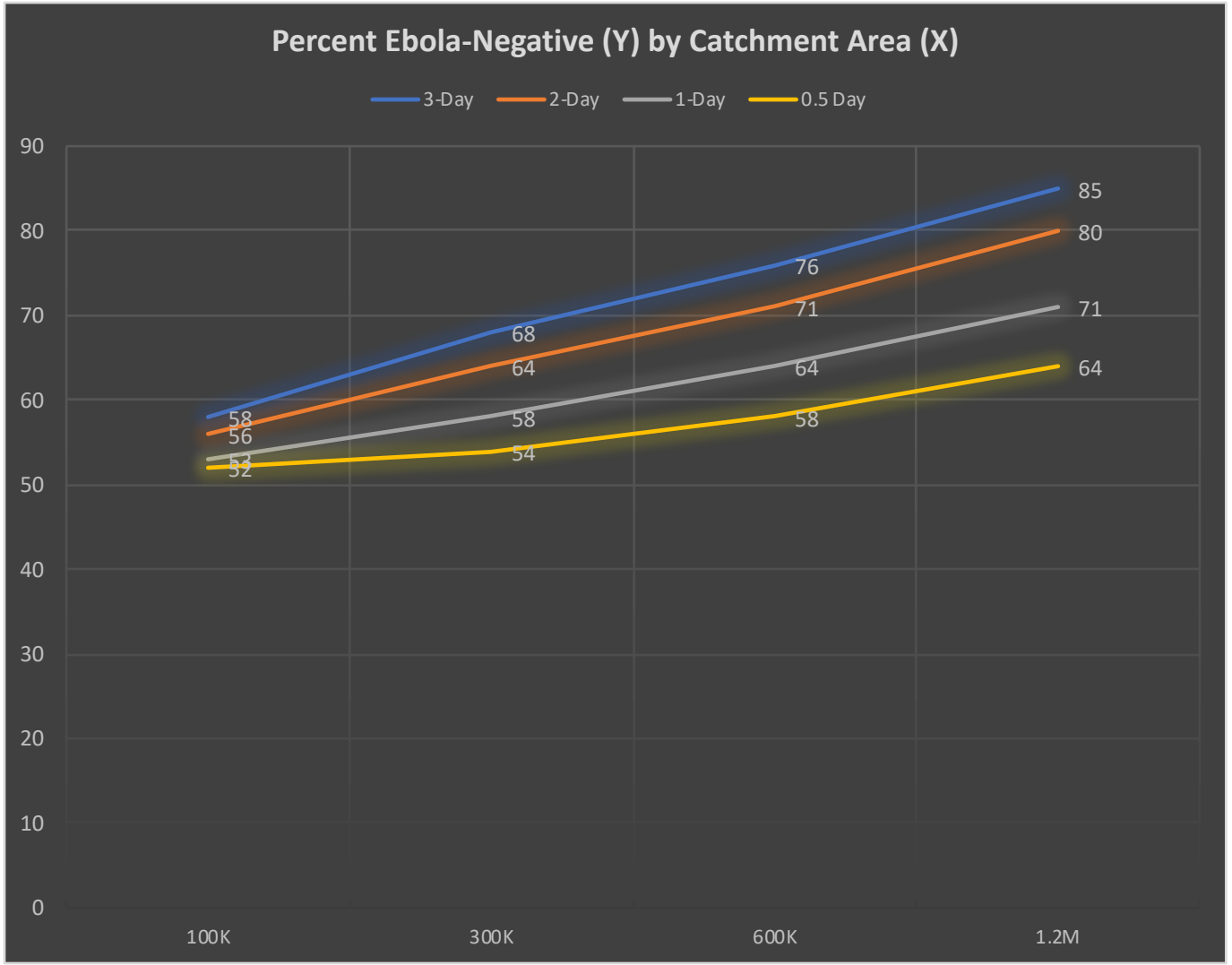
Scenario Service Requirements

Patient Days for Determining Service Requirements (P/(N+P)/P Ratio Rows Show Ebola-Positive Population Percentage of Patient Days and Requirements Sum)								
	Total Service Requirements (Includes Fixed) by Diagnostic Requirements							
	3-Day	Req	2-Day	Req	1-Day	Req	.5 Day	Req
Ebola-Positives (P)	1155	4528	1155	4528	1155	4528	1155	4528
100K Negative (N)	1593	7337	1447	6764	1301	6192	1228	5906
P/(N+P) Ratio	42%	38%	44%	40%	47%	42%	48%	43%
300K Negative (N)	2451	11844	2019	10150	1587	8457	1371	7610
N/P Ratio	32%	28%	36%	31%	42%	35%	46%	37%
600K Negative (N)	3750	18668	2885	15277	2020	11886	1588	10193
N/P Ratio	24%	20%	29%	23%	36%	28%	42%	31%
1.2M Negative (N)	6342	32285	4613	25507	2884	18729	2020	15342
N/P Ratio	15%	12%	20%	15%	29%	19%	36%	23%

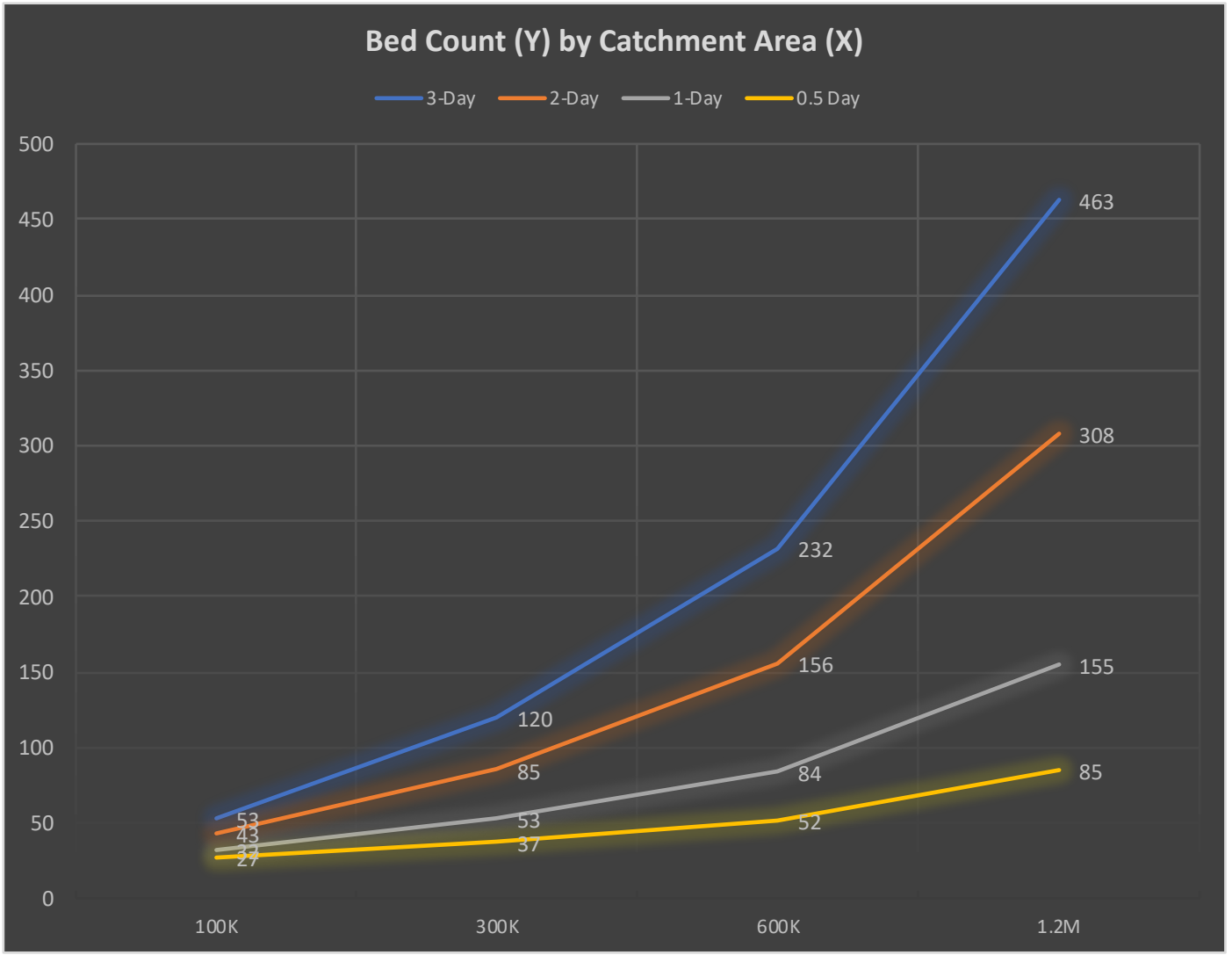
Patient Days by Catchment Area



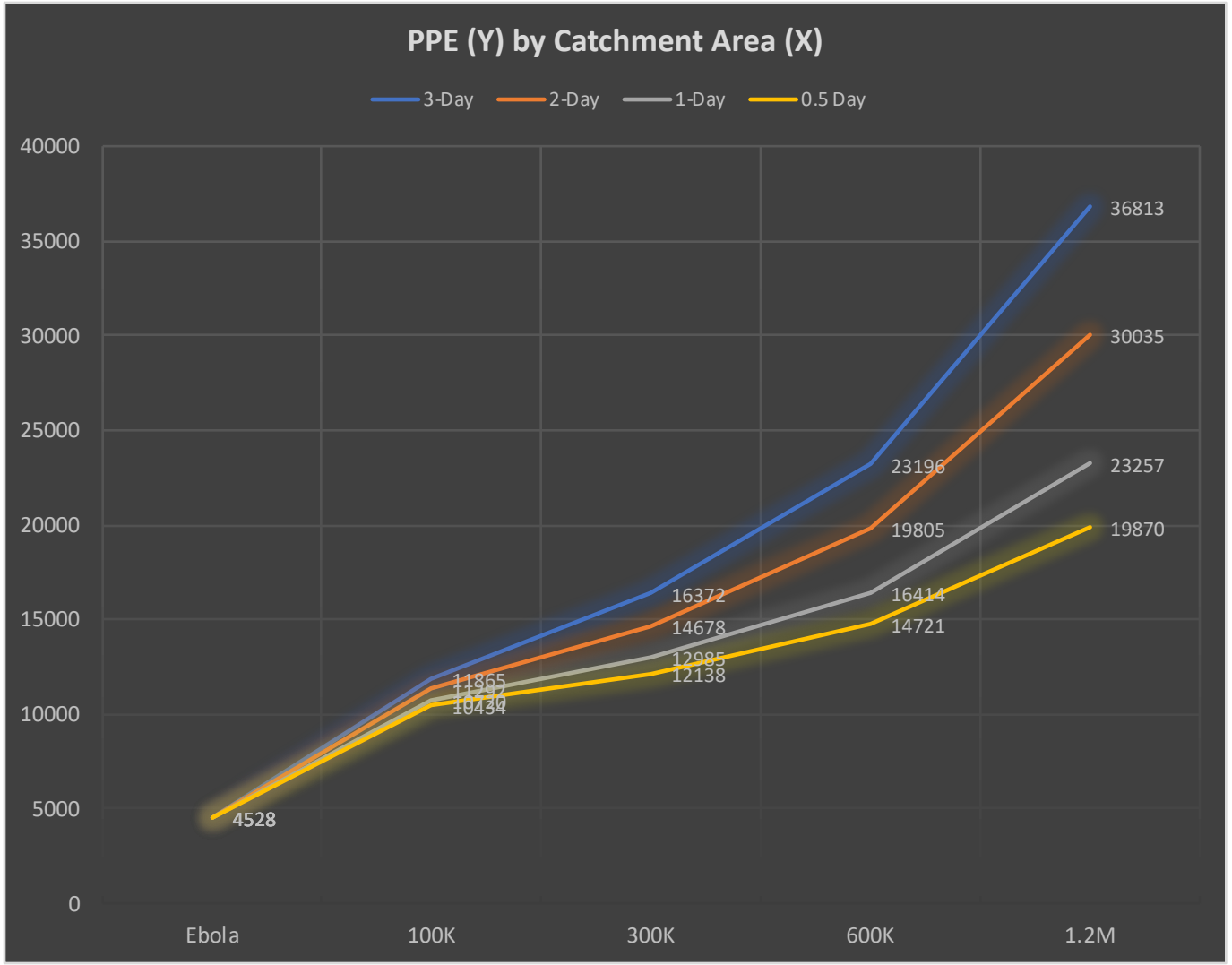
Percent of Patient Days from Ebola-Negative



Bed Count by Catchment Area



PPE by Catchment Area



Recommendations

- Response operations will need to be scaled to the catchment area – not the outbreak
- Improving the speed of diagnostics can act as a force multiplier
- This will become increasingly important for future outbreaks
- Efforts to decrease endemic disease prevalence can open up capacity in the network – e.g. anti-malarial

Photo Credit: Diana Zeyneb Alhindawi for The New York Times

Future Research

- Analysis of patient flow in current DRC outbreak to confirm or strengthen model and results
- Stochastic modeling of sample collection and processing
- Better definitions of EIS activities and their contributions to suspect patient flow
- Impact of anti-malarial campaigns

Questions