ESD 71 Final Project: Second-Mile Internet Data Backhaul in Kenya

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The Case

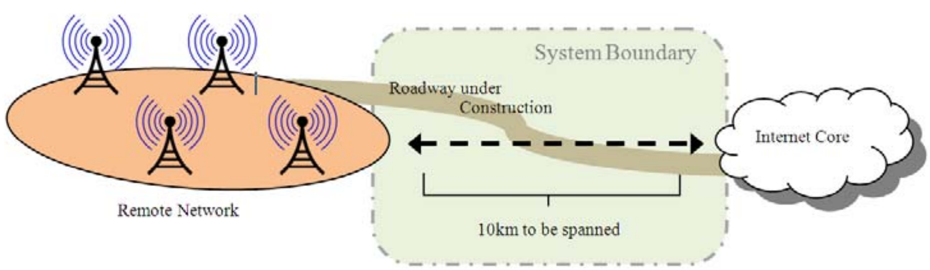
- An internet backhaul provider needs to service an isolated remote area with a 10km backhaul link
  - Common situation in developing or rural markets
- At current demand levels, the link bandwidth required is very small, but demand growth is very large
  - Initially, low-cost solutions are viable
  - Within 20 years the operator will need to deploy a fiber network to service demand
- The provider must decide how to design the best deployment for the local conditions
- 20-Year Excel simulation used to analyze design alternatives

Analysis Goals

- Identify the highest value deployment strategy for the network operator's preferences
  - Risk averse, sensitive to efficiency of CAPEX
  - Determine
    - Technology Mix
    - Decision Thresholds
    - Work with other concurrent projects? (road work)

- Apply flexibility-in-design methods to create a realistic simulation and avoid the scenario-based design trap

System Definition



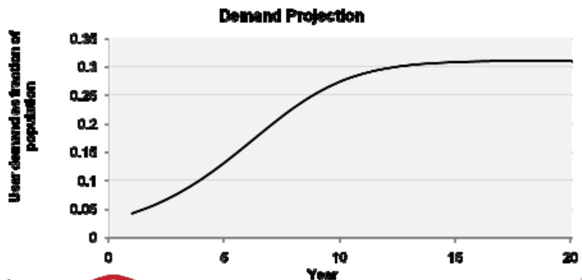
- Operator must span 10km to remote site with buried fiber optics or microwave radio
  - Cost/Performance trade off
- Serendipitous road construction provides an opportunity to control the cost of fiber installation

Uncertainties: User Demand Projection

- Initial demand
- Demand growth

$$D_t = D_{t-1}\left(1 + R(1 - HD_{t-1})\left(\frac{1}{1 - HD_0}\right)\right)$$

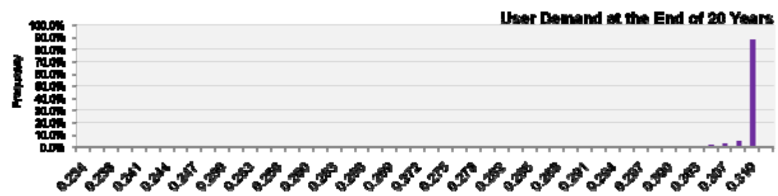
- Conflicting estimates increase uncertainty
- Projection must capture saturation effect

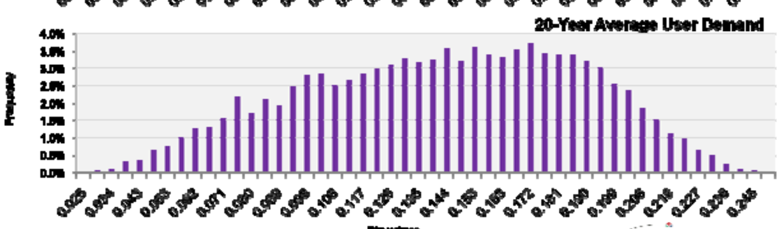


Uncertainties: User Demand Model

$$D_t = D_{t-1}\left(1 + (R - V_r + 2V_r * RAND())(1 - HD_{t-1})\left(\frac{1}{1 - HD_0}\right)\right)$$

- Result: "Certain" endstate but uncertain average demand





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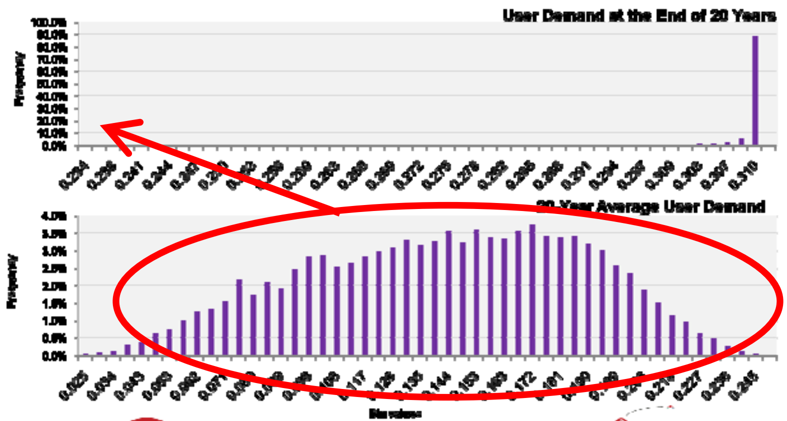


Uncertainties: Cost to Deploy Fiber

- Cost range between $15-95K/km
- Depends mainly on labor and logistics for trenching
- Cost and uncertainty can be minimized by pre-planning route and sharing costs with road construction
    - Co-construction: $25K/km
    - Pre-planned, deploy on demand: $30K/km
    - No plan, deploy on demand: $15-55K/km (random)

C = 40,000 * RAND ( ) + 15,000

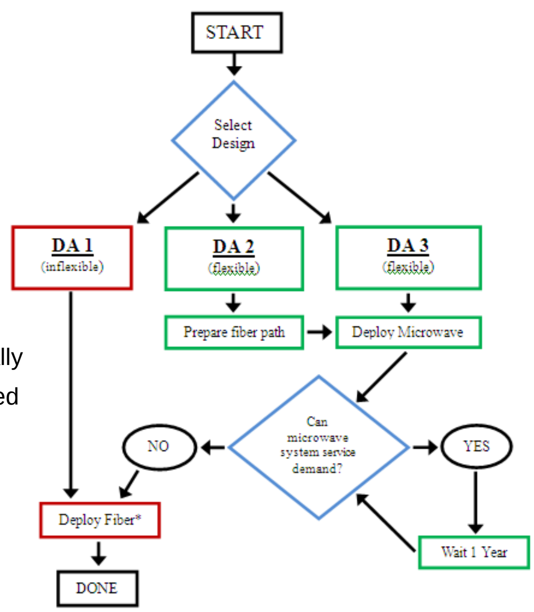
Technology and Design Alternatives

- Three design alternatives analyzed:

DA1: Fiber Full-Deploy	
Cost in year 1	$250k
Recurring cost	$1000/yr
DA2: Fiber Partial-Deploy (flexible)	
Cost in year 1	$10k + Microwave (DA3)
Recurring cost	$0/yr + Microwave (DA3)
Expansion cost when needed	$300k
Recurring cost after expansion	$1000/yr
DA3: No Fiber Prep (flexible)	
Cost in year 1	$50k
Recurring cost	$300/yr + $8201/yr (x .125, .25, .5, or 1 based on use)
Expansion cost when needed	Uncertain, mean $35K
Recurring cost after expansion	$1000/yr

Decision Rules

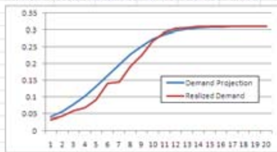
- Fixed system
  - Deploy fiber at outset
    - Fixed cost
- Flexible systems
  - Start with microwave
  - Evaluate demand annually
  - Deploy fiber when needed
    - Cost fixed or variable based on pre-planning
    - Operator must asses demand a full year in advance



Model Design

- Excel model simulates 20 year project lifespan with randomized initial demand and random growth variability
- Expansion decision triggered based on demand projection

Year	0	1	2	3	4	5	6	7	8	9	10
Projected Demand fraction		0.04158	0.056967	0.076843	0.101552	0.130754	0.1631	0.19619	0.227061	0.253145	0.273141
Realized Demand fraction	0.032205404	0.033888475	0.042448	0.057247	0.067095	0.091283	0.140477	0.145516	0.191501	0.225757	0.2684
Demand (users)		616.0038786	782.7764	1070.995	1273.435	1757.647	2744.071	2883.734	3850.044	4604.562	5553.7
Bandwidth Required		98.56062057	125.2442	171.3591	203.7496	281.2236	439.0514	461.3974	616.0071	736.7299	888.592
Backhaul Capacity	500	500	500	500	500	500	500	500	10000	10000	10000
Build capacity		0	0	0	0	0	0	1	0	0	0
Revenue		13601.36564	17283.7	23647.56	28117.44	38808.85	60589.09	63672.84	85008.97	101668.7	122625.7
Operating costs	300	300	300	300	300	300	300	300	1000	1000	1000
Taxes and fees (max)	8201	8201	8201	8201	8201	8201	8201	8201	0	0	0
Taxes and Fees (actual)		2050.25	4100.5	4100.5	4100.5	8201	8201	8201	0	0	0
Acquisition costs	60000	0	0	0	0	0	0	300000	0	0	0
Cashflow		3050.115639	4682.202	11046.06	15515.94	22106.85	43887.09	-253029	84008.97	100668.7	121625.7
DCF		2652.274469	3540.417	7262.964	8871.291	10991.01	18973.6	-95123	27462.68	28616.34	30064.01
Present Value of Cash Flows	226978.6213										
starting Capacity Cost	60000										
NPV	166978.6213										

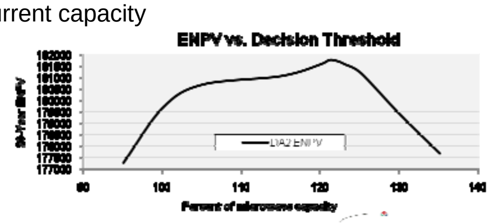


Model Tuning

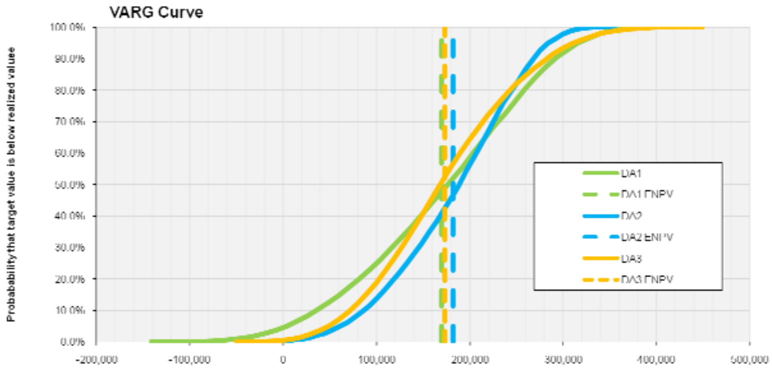
- Precision checking to 1% error

Number of Model Runs	Maximum error fraction for any design alternative
2000	.0237
5000	.0158
10000	.0139
25000	.0058

- Decision rule threshold tuned to find highest ENPV of all three designs at all reasonable thresholds
  - Expansion triggers when extrapolation of t-1 data predicts demand in year t+1 = 122% of current capacity



Results



Design alternative #	-95%	ENPV	+95%	Standard Deviation
Design alternative 1	169,627	170,823	172,020	96,545
Design alternative 2 (flex)	180,177	181,023	181,869	68,228
Design alternative 3 (flex)	171,135	172,102	173,069	78,032

Pre-planned, staged deployment provides highest value

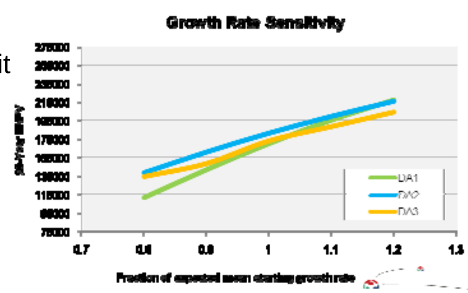
Results

- Flexible designs have lower capital costs and give more efficient ROI
- Operator pays a capital efficiency premium to achieve best ENPV and lowest variability

Design alternative #	B/C ratio
Design alternative 1	1.664
Design alternative 2 (flex)	1.755
Design alternative 3 (flex)	1.752

Design alternative #	$ENPV/CAPEX_0$	$ENPV/CAPEX_p$
Design alternative 1	0.678	0.678
Design alternative 2 (flex)	3.017	1.006
Design alternative 3 (flex)	3.442	1.033

- Flexible designs exhibit greater robustness to deviations in input assumptions



Results

- All designs are profitable in expectation
- Results suggest that the operator would benefit most from pre-planning a fiber path, but delaying full fiber deployment until demand requires it (design alternative 2, benefit ~$10,000)
  - Design is more profitable in expectation, less volatile, more robust, and has a better downside
  - Lower capital efficiency vs DA3 is worth considering
- With current assumptions, value of flexibility before costs is > $120,000
  - Value decreases as input conditions become more favorable