Musify

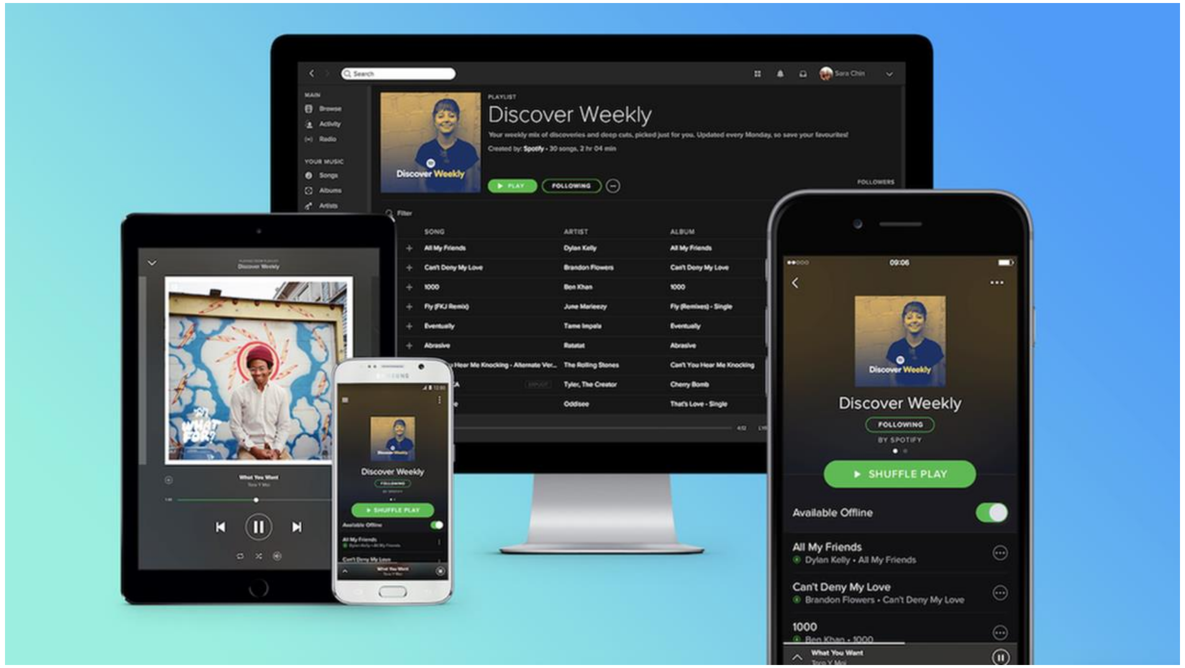
ANALYZE A DISTRIBUTED DATA CENTER ARCHITECTURE

EMIS 7352 – PROJECT 2 – GROUP 3

APOORVA JAIN

MUSIFY?

- Musify is a web-based, digital music service providing its subscribers with access to millions of songs.
- Songs can be digitally streamed at one of 3 bit-rates
  - Low: 112 kbps
  - Standard: 192 kbps
  - High: 240 kbps
- Songs can also be downloaded to the user's device for offline playback
- All songs are Data Rights Management (DRM)-protected (encrypted) to ensure that only authorized users are able to stream or download and play them
  - The System supports permission requests that provide users with the necessary DRM keys to play the songs.

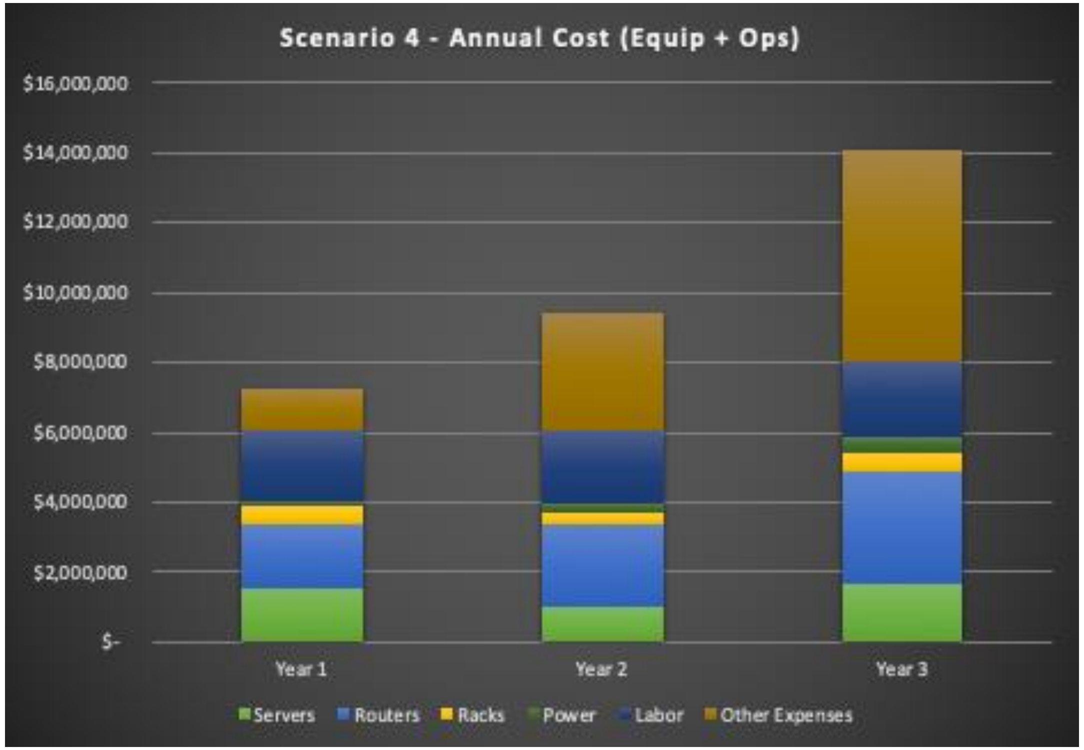


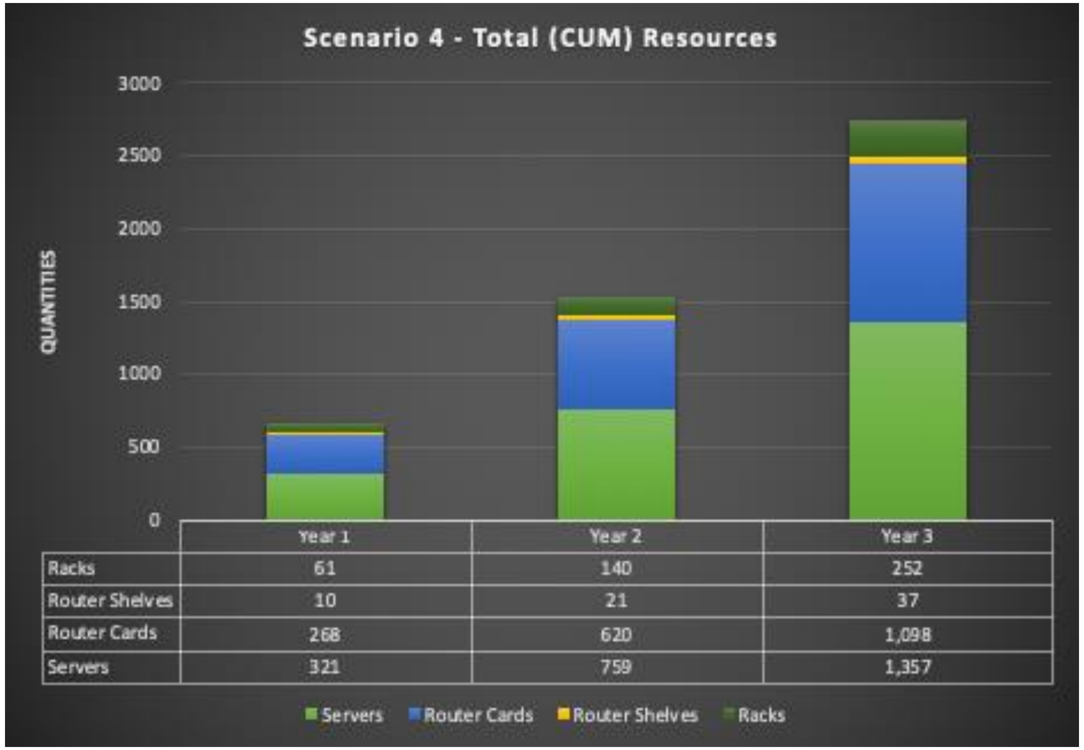
PROJECT 2 OVERVIEW

- Objectives:
  - Assess a Distributed Data Center architecture; compare/contrast with the recommended centralized data center scenario from Project 1
- Tasks:
  - Determine capacity distributions (users, workload, bandwidth, storage, etc.)
  - Develop DC Failover/Resiliency Approaches and calculate it's impact on DC capacities
  - Assess and Identify Data Center locations; selecting locations in each region with favorable quantified and qualified parameters
  - Size and Cost each region's data center(s) following a similar method for Project 1
    - Using cost factors for the selected DC locations
  - Evaluate the architecture and conduct quantified/qualified sensitivity analysis
  - Compare/Contrast a Centralized (Project 1) vs Distributed (Project 2) Data Center architecture and recommend one

PROJECT 1 REVIEW - RESULTS

Musify





	Year 1	Year 2	Year 3
Racks	61	140	252
Router Shelves	10	21	37
Router Cards	268	620	1,098
Servers	321	759	1,357

- Data Center: 16,128 total square feet, $14.95M in construction costs

Total (3-Year) Costs: $13.09M (Equip) + $17.71M (Ops) + $14.95M (Cap)

$45,747,903*

* NOTE: This price has been adjusted since Project 1 presentation to allow for a more direct and consistent comparison of cost with the Distributed DC architecture

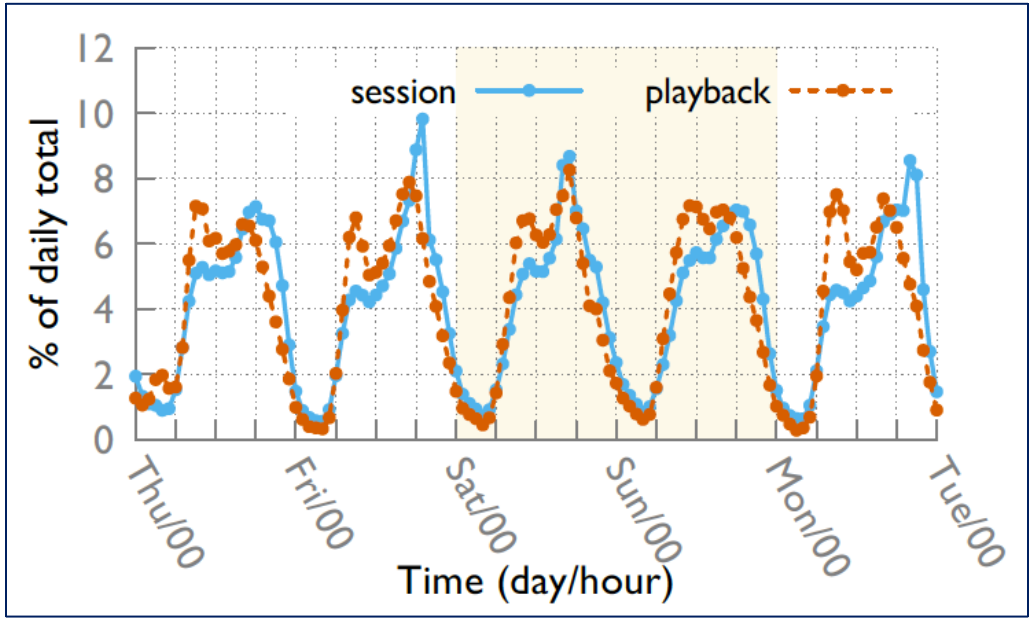
PROJECT 1 REVIEW

- Resources
  - XL Servers for Web/App Servers (Requests and Authorizations), and Rate Adaptation/Encryption servers
  - Dell EMC Isilon NAS used for Song Storage and Streaming/Download
- Redundancy
  - Configured similar to a Tier III+ data center (99.9+% availability)
- Expansion Rate
  - Annual Frequency (start-of-year capacity supports end of year forecasts)
- Song Library
  - Static Library of 40,000,000 songs

PROJECT 1 REVIEW

Musify

- Active Users follow a common diurnal pattern
  - Peak during the daylight; rapid ramp-up in morning, ramp down at night; minimal activity overnight



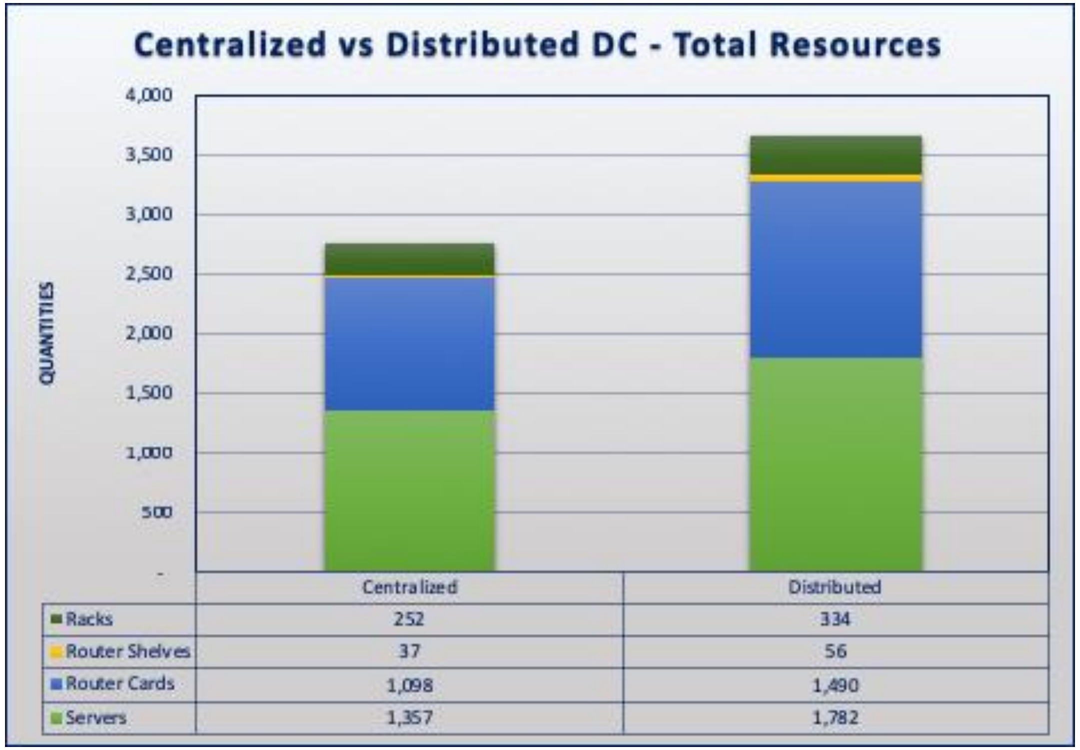
- Four (4) peak hours per day identified: 7-9am, 8-10pm

- Peak-to-Average Ratio (PAR) : 1.75:1

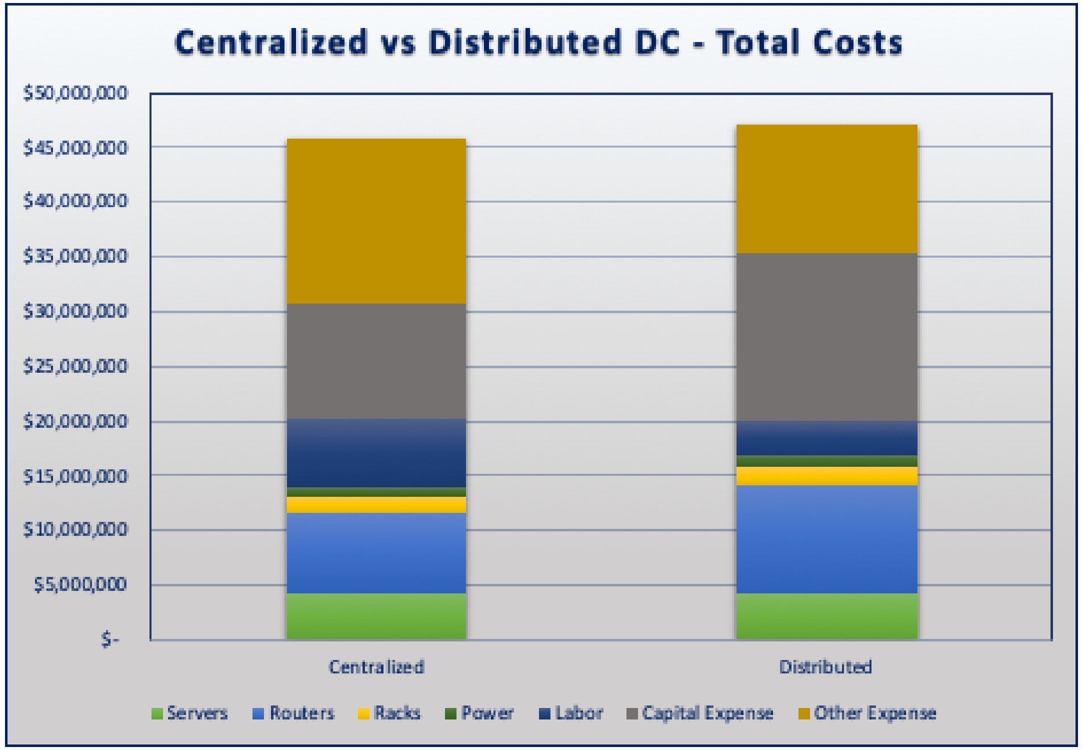
- Equivalent Peak Hours: 7.55

BOTTOM LINE UP FRONT (BLUF)

Musify



	Centralized	Distributed
Racks	252	334
Router Shelves	37	56
Router Cards	1,098	1,490
Servers	1,357	1,782



- The distributed architecture
  - Provides substantially more resources (capacity) for similar cost to the centralized architecture
  - Reduces latency by providing request services closer to user populations, and
  - Improves overall system availability and resiliency through geographically dispersed, redundant capability

PROJECT 2 ASSUMPTIONS

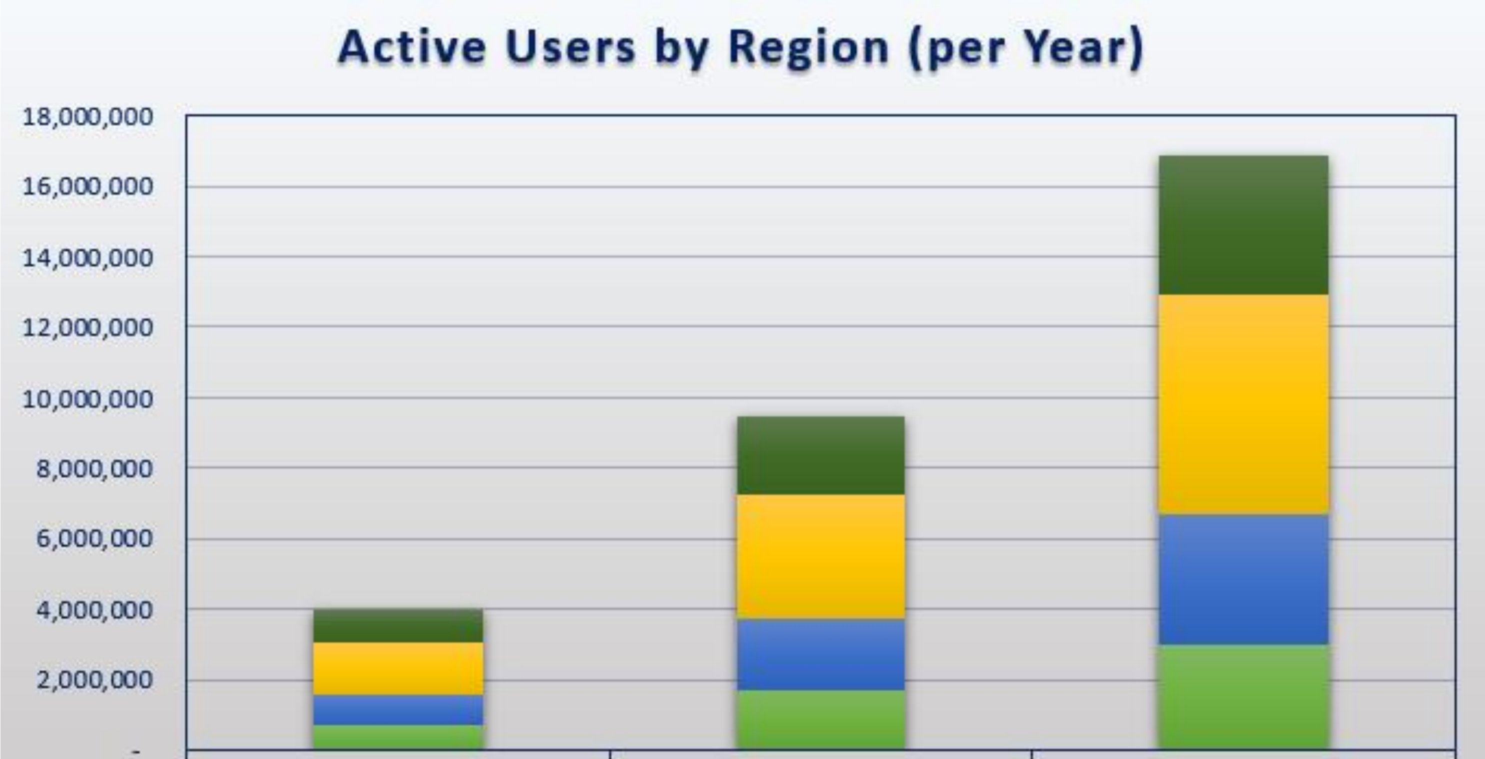
Musify

- Distributed Data Center Architecture
- Annual Capacity Upgrades
  - Start-of-Year capacity supports end-of-year forecast (same as Project 1)
- Prices and rates are static throughout the 3-year assessment period (no inflation or reductions in cost due to technological advances)
- Bandwidth needs between Data Centers (e.g., routing of song requests from Midwest and South regions to Northeast and West region Data Centers) were not estimated
  - Considered a small fraction of actual user request bandwidth capacity needs
- Load-balancing within and between Data Centers is "perfect" (precisely aligned with the percentages specified for the project)
- Usage patterns (quantities and types of requests per user) are consistent within and among regions (e.g., a given MW region user requests as many song streams as a W region user)

REGIONAL USER DISTRIBUTION

- Northeast
  - 17.92% of users
  - 3.02M active users*
- Midwest
  - 21.68% of users
  - 3.65M active users*
- South
  - 37.10% of users
  - 6.25M active users*
- West
  - 23.30% of users
  - 3.93M active users*

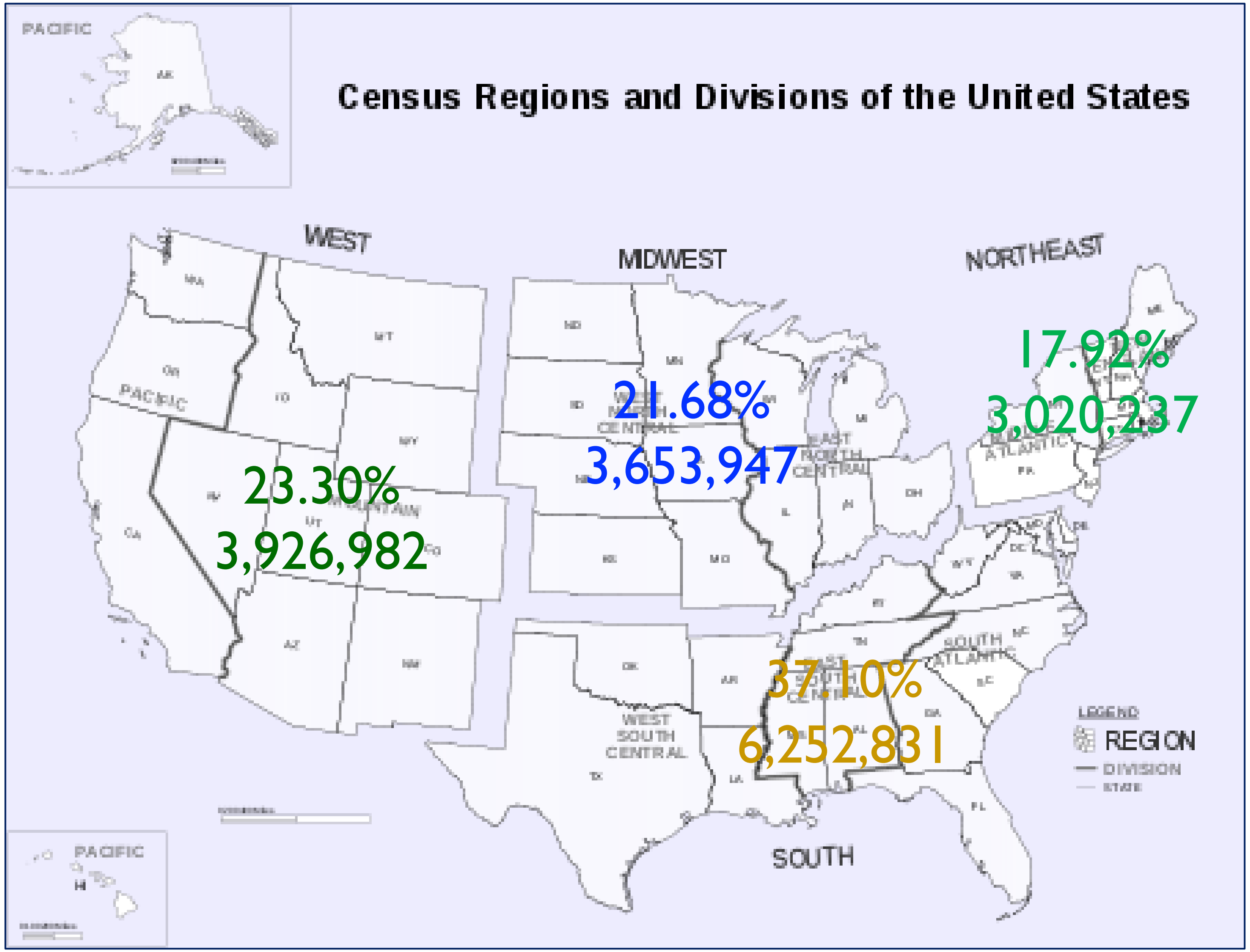
* by year 3



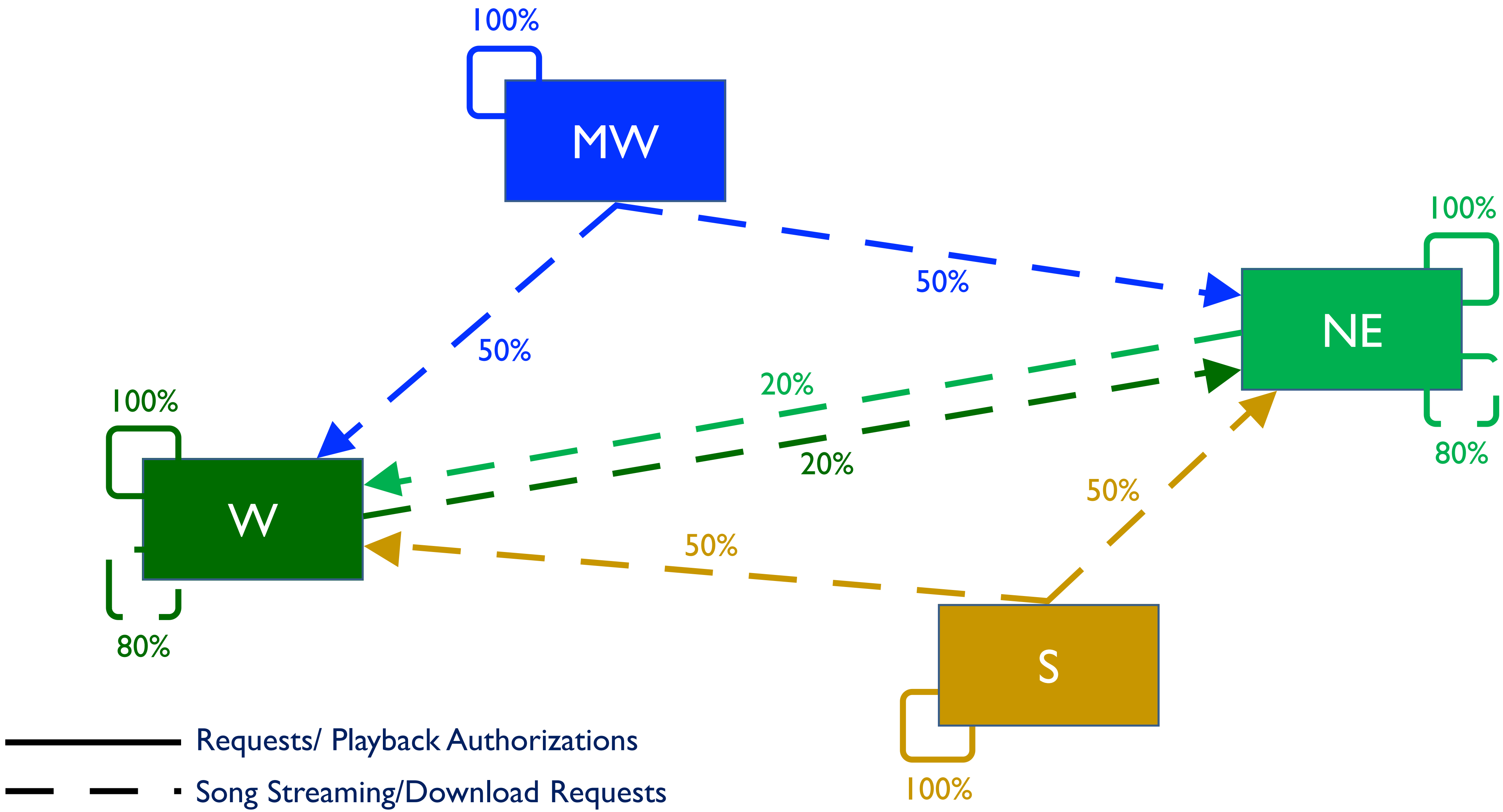
	Year 1	Year 2	Year 3
W	932,117	2,208,840	3,926,982
S	1,484,186	3,517,080	6,252,834
MW	867,308	2,055,264	3,653,947
NE	716,890	1,698,816	3,020,237

ACTIVE USER DISTRIBUTION MAP

Musify



NORMAL TRANSACTION DISTRIBUTION



REDUNDANCY/FAILOVER APPROACH

Musify

- Assume only one DC failure at any given time
- DC Failure Scenarios:
  - Northeast: All local transactions route to South; all system streaming/downloads routed to West
  - Midwest: All local transactions route to West; streaming/download routing unchanged (50/50 between West and Northeast)
  - South: All local transactions route to Northeast; streaming/download routing unchanged (50/50 between West and Northeast)
  - West: All local transactions route to Midwest; all system streaming/downloads routed to Northeast
- Conclusions
  - Loss of a data host DC (NE or W) requires the other content DC to process all streams and downloads
  - Make NE and W DCs same size (to cover loss of other) and fact that population distribution is only different by ~5% users; largest is W
  - Make all DCs support 55% of user transaction/authorization (for configuration consistency); not a significant cost driver

DATA CENTER LOCATION ASSESSMENT

Musify

- What we considered:
  - Quantified: Industrial Space Lease Costs, Effective Property Tax Rates, Labor Costs and Supply, Power Rates
  - Qualified: Environment/Climate (including Force Majeur risk), State/Local Gov't policies (taxes, bureaucracy, "business-friendly"), growth trends (expanding/contracting), access to internet hubs and bandwidth

- Selected four candidate locations in each region
  - Large Population Centers or close to them (user access, available workforce)
  - Established Data Center presence
  - Opportunities for Growth

DATA CENTER LOCATIONS – NORTHEAST/SOUTH

Musify

Northeast Region							
Candidate Location	(1) Industrial Space Lease Costs ($/sf/mo)	(2) Effective Property Tax Rate (%)	(3) Labor Cost ($/yr)	(4) Labor Supply	(5) Power Rates ($/kwH)	(6) Other Factors	(7) Yr 3 Cost Comparison
New York, NY	$ 9.44	2.342%	$ 187,610	42,080	$ 0.1060	E, G-, T-, I+	$1,709,817.39
Northern NJ	$ 8.56	1.582%	$ 187,610	42,080	$ 0.0474	E, G-, T, I+	$1,317,206.90
Boston, MA	$ 8.17	1.104%	$ 177,490	11,290	$ 0.1257	E, G-, T-, I	$1,568,598.87
Northern VA	$ 11.36	0.495%	$ 181,310	27,430	$ 0.0624	E, G+, T++, I++	$1,553,542.80

South Region							
Candidate Location	(1) Industrial Space Lease Costs ($/sf/mo)	(2) Effective Property Tax Rate (%)	(3) Labor Cost ($/yr)	(4) Labor Supply	(5) Power Rates ($/kwH)	(6) Other Factors	(7) Yr 3 Cost Comparison
Atlanta, GA	$ 4.47	1.471%	$ 161,790	13,650	$ 0.0572	E+, G+, T, I	$ 179,647.53
Nashville, TN	$ 5.09	2.583%	$ 150,460	5,610	$ 0.0661	E+, G+, T, I	$ 171,906.37
DFW Area, TX	$ 5.06	2.526%	$ 171,060	18,520	$ 0.0557	E+, G+, T++, I+	$ 191,912.46
Houston, TX	$ 6.44	2.526%	$ 184,391	11,070	$ 0.0557	E-, G-, T+, I+	$ 209,482.82

DATA CENTER LOCATIONS – MIDWEST/WEST

Musify

Midwest Region							
Candidate Location	(1) Industrial Space Lease Costs ($/sf/mo)	(2) Effective Property Tax Rate (%)	(3) Labor Cost ($/yr)	(4) Labor Supply	(5) Power Rates ($/kwH)	(6) Other Factors	(7) Yr 3 Cost Comparison
Chicago, IL	$ 5.08	2.266%	$ 155,030	17,940	$ 0.0139	E, G-, T+, I+	$ 173,890.80
Madison, WI	$ 4.64	1.513%	$ 158,790	2,360	$ 0.0786	E, G+, T+, I+	$ 178,113.35
Indianapolis, IN	$ 3.80	1.997%	$ 149,990	3,670	$ 0.0736	E, G+, T, I-	$ 167,095.21
Minneapolis, MN	$ 4.88	1.800%	$ 151,460	9,280	$ 0.0683	E, G-, T+, I	$ 171,429.05

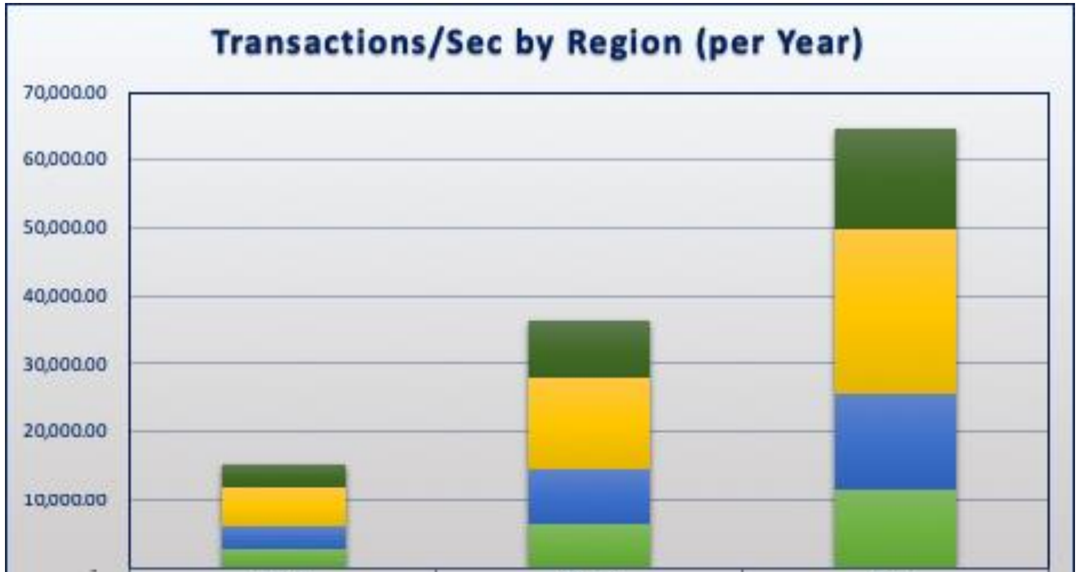
West Region							
Candidate Location	(1) Industrial Space Lease Costs ($/sf/mo)	(2) Effective Property Tax Rate (%)	(3) Labor Cost ($/yr)	(4) Labor Supply	(5) Power Rates ($/kwH)	(6) Other Factors	(7) Yr 3 Cost Comparison
Southern CA	$ 9.36	0.954%	$ 164,880	19,210	$ 0.1173	E-, G-, T, I++	$1,620,089.33
Northern CA	$ 13.20	0.954%	$ 200,040	8,010	$ 0.0517	E-, G-, T+, I+	$1,734,882.48
Seattle, WA	$ 7.61	0.692%	$ 182,590	9,890	$ 0.0595	E, G-, T+, I+	$1,205,635.64
Phoenix, AZ	$ 6.70	2.000%	$ 149,300	10,740	$ 0.0787	E-, G+, T++, I	$1,270,776.97

LOCATION SELECTIONS

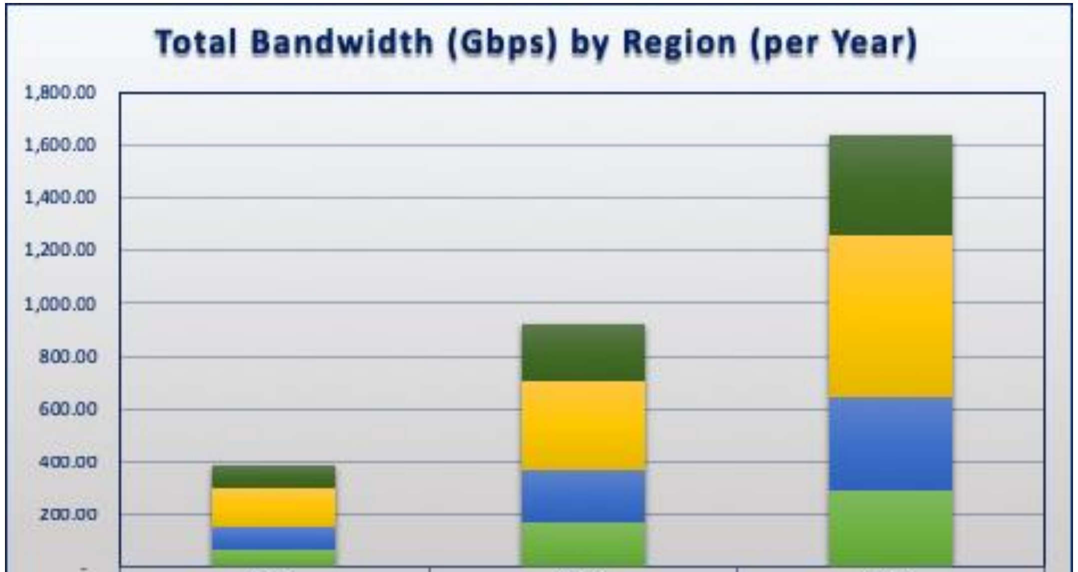
Musify

- Northeast: Northern Virginia
  - PROs: Lower property taxes, sizeable workforce, low power rates, significant market absorption and access to 70% of global internet traffic, proximity to both Northeast and South population centers
  - CONs: High space lease and labor costs
- South: Dallas/Fort Worth Area
  - PROs: Sizeable workforce, lower power rates, favorable climate, pro-business gov't policies, significant data center presence and sizeable bandwidth access, no income taxes
  - CONs: High property taxes and labor costs (for the region)
- Midwest: Madison, WI
  - PROs: Low lease and property tax rates; access to Chicago-area workforce and bandwidth, growing market absorption, favorable government policies
  - CONs: Smaller local workforce, higher labor costs, high power costs
- West: Phoenix, AZ
  - PROs: Low lease and labor rates, sizeable workforce, significant growth trends
  - CONs: High property taxes, hot/dry climate (power/cooling costs)

VOLUMETRICS



	Year 1	Year 2	Year 3
W	3,581.53	8,487.16	15,088.88
S	5,702.78	13,513.89	24,025.65
MW	3,332.51	7,897.07	14,039.78
NE	2,754.55	6,527.46	11,604.84



	Year 1	Year 2	Year 3
W	90.45	214.35	381.08
S	144.03	341.30	606.78
MW	84.16	199.44	354.58
NE	69.57	164.85	293.09

- Regional DCs process 100% of their "local" user requests
  - Process all playback authorization requests
- Northeast and West DCs combine to process 100% of streaming and download requests
  - Including streaming rate adaptation and digital rights management (DRM) encryption

VOLUMETRICS – APPROACHES

- Web/App Server architectures in all DCs are identical in capacity and configuration
  - Maintenance best practice, facilitates DC loss/failover flexibility, provides additional built-in capacity

- Song library and rate/adaptation and encryption architectures in Northeast and West region DCs are identical in capacity and configuration
  - Maintenance best practice,
  - Each must be capable of processing 100% of streaming / download requests if the other DC fails

- Given DC failover and resiliency of distributed architecture, redundancy within DCs was relaxed
  - Centralized DC in Project 1 had 2N or greater redundancy in servers, storage, NICs, routers, power/cooling, etc.
  - Followed N+1 or 1-for-2 redundancy patterns in distributed architecture

VOLUMETRICS – APPROACHES

Musify

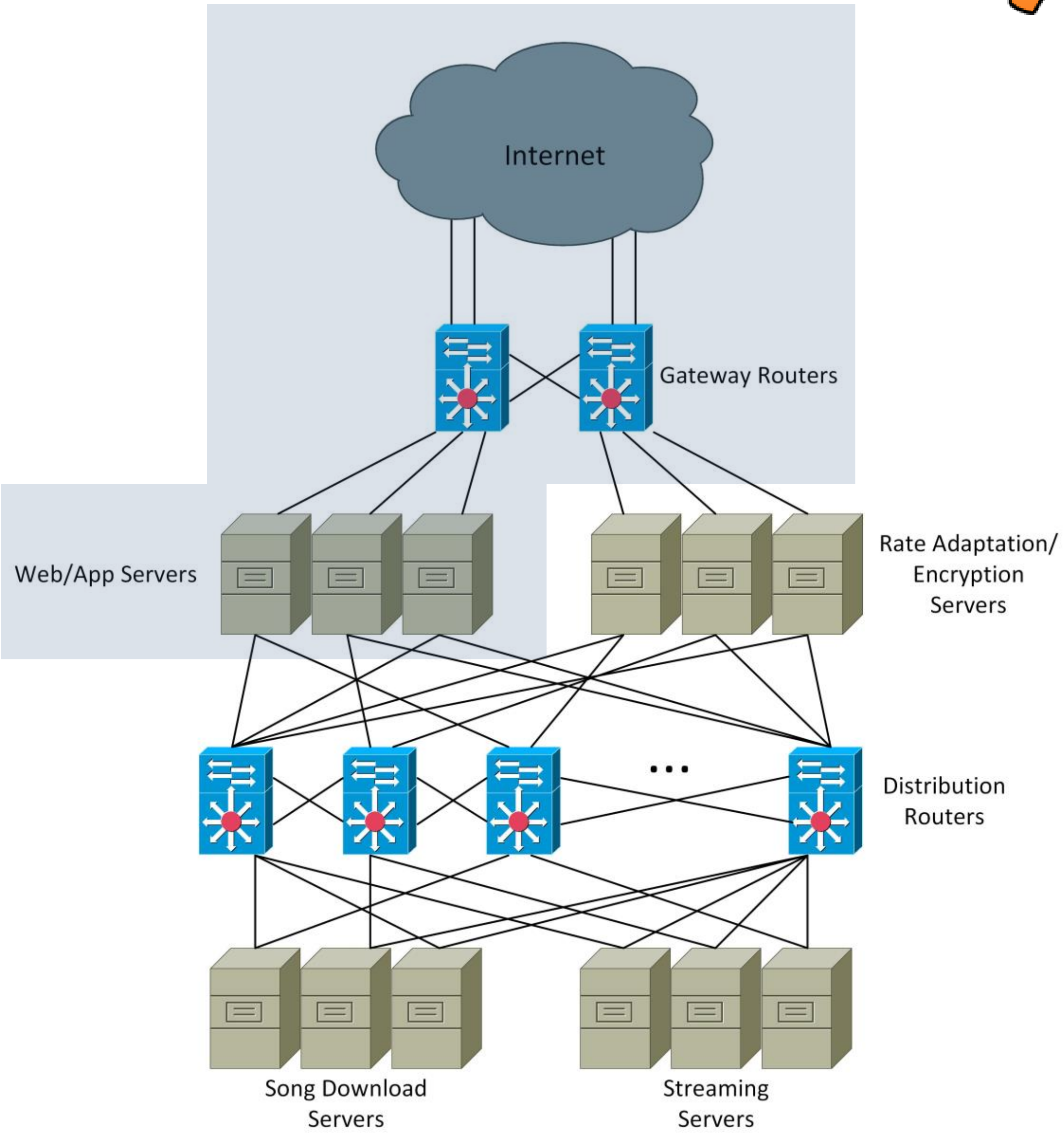
- For the Song Processing Data Centers (NE and W), elected to lease conditioned data center space rather than build two fixed, custom data centers
  - Fixed, custom DCs would have each approached the cost of the centralized data center in Project 1
    - Cost of both NE and W leased data centers roughly equivalent to the centralized DC cost in Project 1, but with more resources
  - Leased space allows for opportunity for modular year-on-year build out of data center, rather than having to build to 3-year size in year 1 and maintain it.

- Transaction-Only Data Centers (MW and S), require minimal resources, so elected to go with deployable, pre-fab DC container
  - Used 20’ HP Performance-Optimized Datacenter (POD) as basis for cost and sizing

ARCHITECTURE

Musify

- Song Processing Data Centers (NE and W) are similar to the centralized data center in Project 1
  - Process local transactions and process all song requests
- Transaction Only Data Centers (MW and S) are limited to receipt and processing of user requests and playback authorizations (shaded area)
  - They route streaming and download requests to the NE and W DCs for processing



INTER-DATACENTER BANDWIDTH

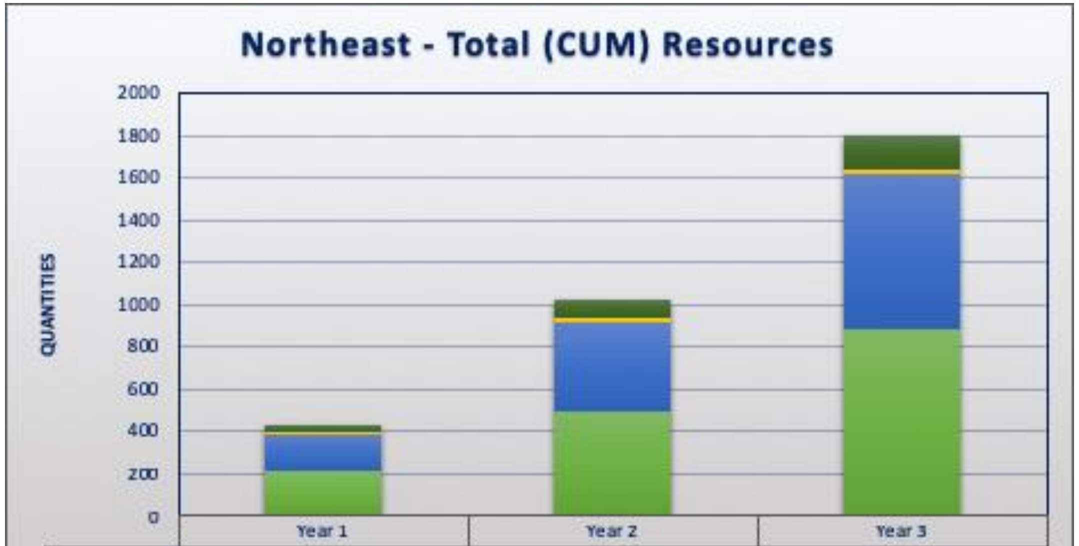
Musify

- User streaming and song download requests are routed between DCs per the distributions specified by the project and illustrated earlier
- Data Centers only exchange requests for songs, not the songs themselves
  - We assumed a stream or download request API message (sent from a local DC Web/App Server to a Song Processing Server was a total of 1.5KB (1KB request, 0.5KB response)
- Based on user and transaction distributions, we calculated the inter-DC bandwidth needs

Year	Bandwidth Between DCs (Gbps)				
	NE-MW	NE-W	NE-S	W-MW	W-S
Year 1	0.0127	0.0097	0.0218	0.0127	0.0218
Year 2	0.0302	0.0229	0.0516	0.0302	0.0516
Year 3	0.0536	0.0408	0.0917	0.0536	0.0917

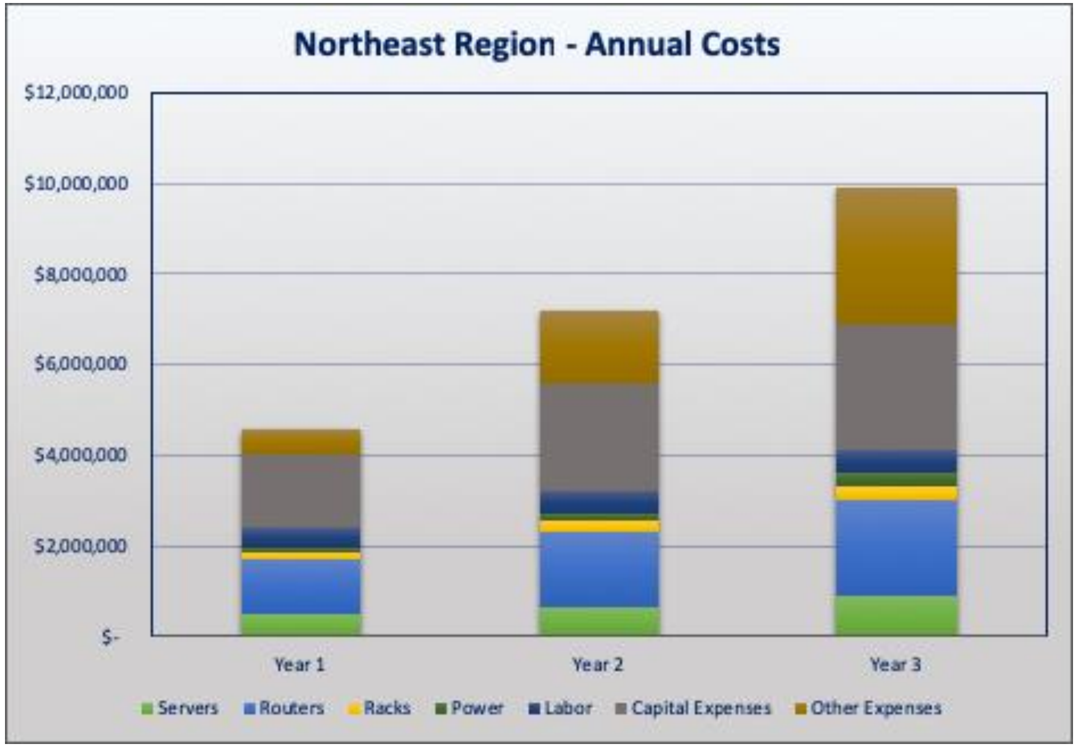
- These bandwidths are insignificant to overall bandwidth requirements and do not influence the recommendation of centralized vs distributed architecture
  - Example: The additional bandwidth to the W region for song requests from NE, MW and S combined total just 186.1 Mbps (less than a single server NIC card)

NORTHEAST DATA CENTER



	Year 1	Year 2	Year 3
Racks	39	93	163
Router Shelves	7	16	27
Router Cards	178	419	735
Servers	210	497	881

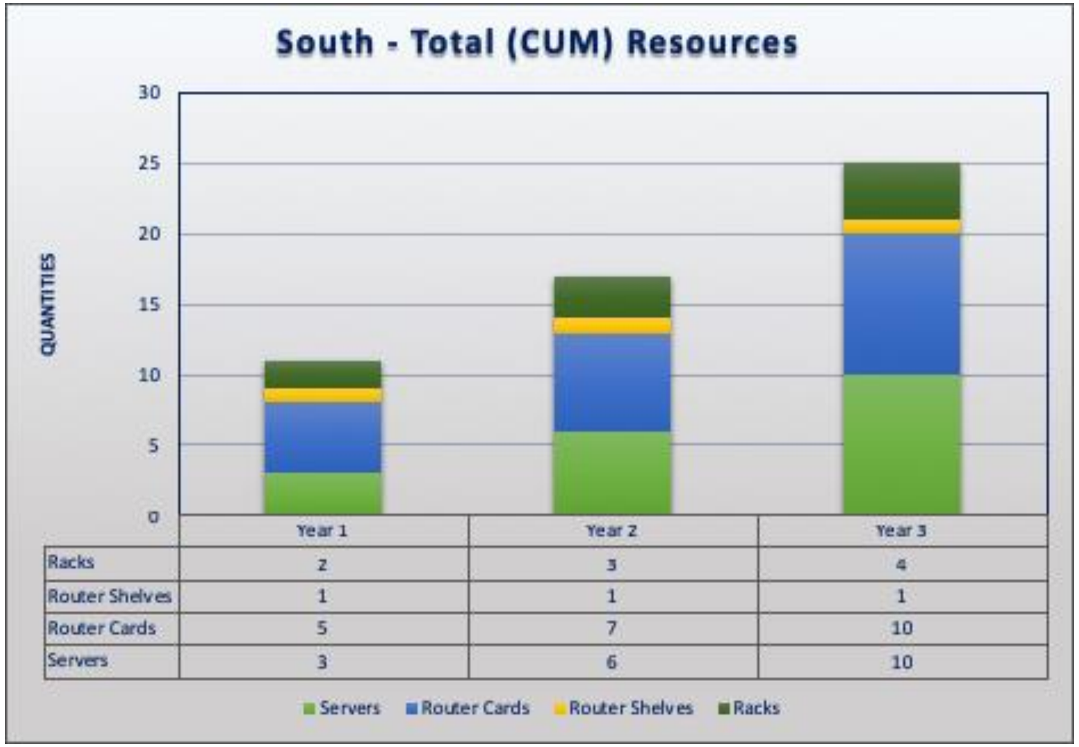
Servers Router Cards Router Shelves Racks



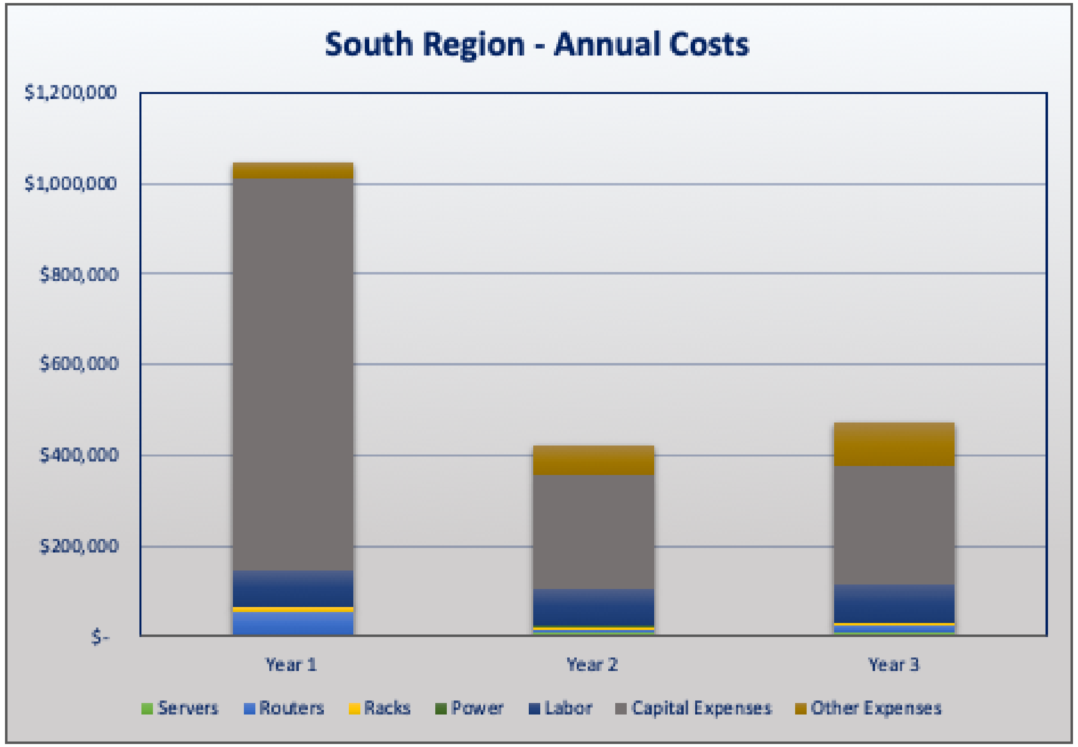
- Provides 48% of total song streaming and download capacity under normal operations; 100% with loss of West Region DC
- Provides 18% of all transaction processing and authorization requests nominally; up to 55% under DC failure

Total 3-Year Cost: $21.68M

SOUTH DATA CENTER



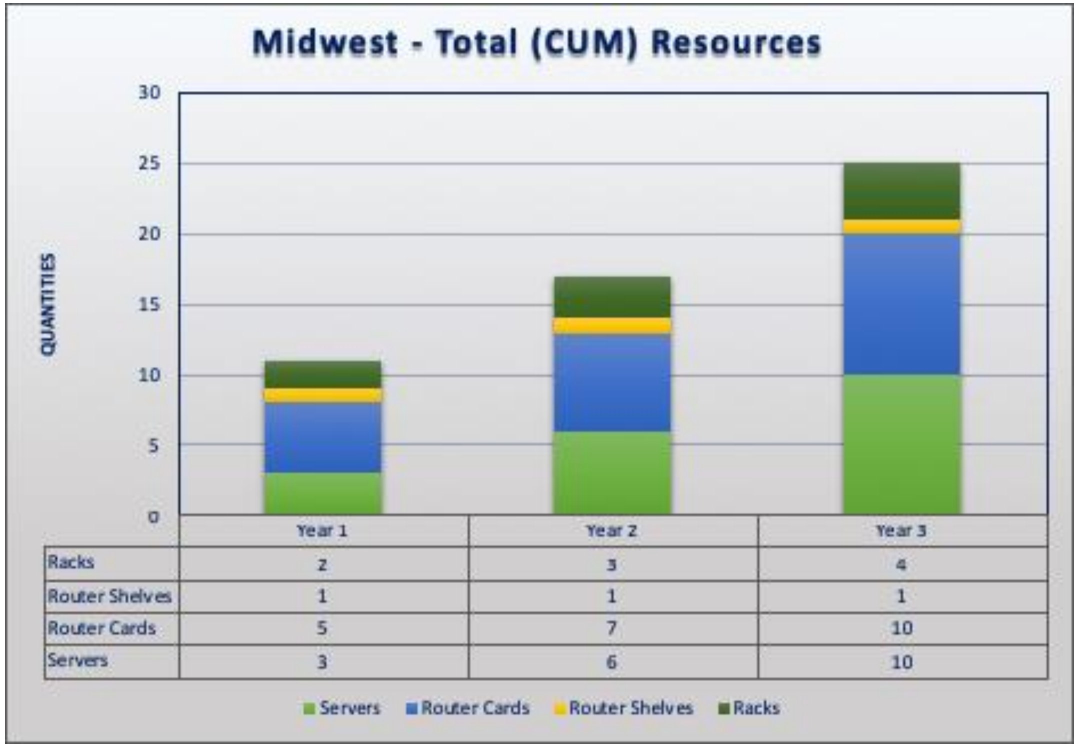
	Year 1	Year 2	Year 3
Racks	2	3	4
Router Shelves	1	1	1
Router Cards	5	7	10
Servers	3	6	10



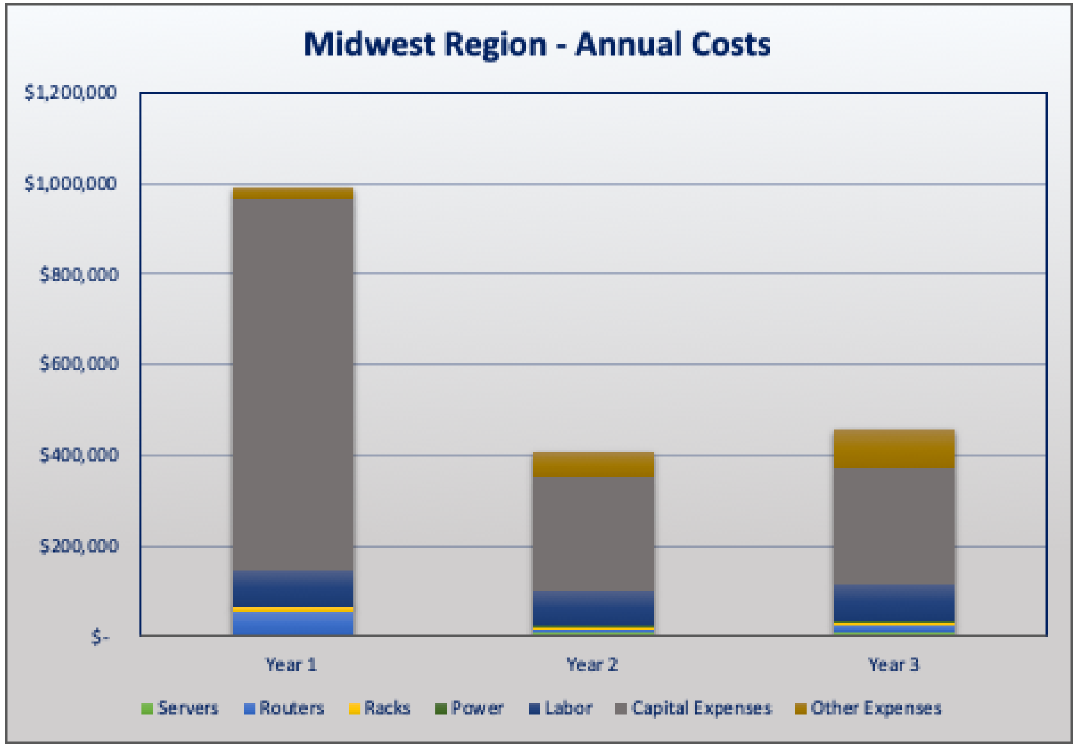
- Provides 37.1% of all transaction processing and playback authorizations under normal operations; capacity for up to 55% with loss of another region's DC
- Non-recurring and recurring Capital Expenses (container and internet connectivity) FAR outpace equipment and other operational costs

Total 3-Year Cost: $1.86M

MIDWEST DATA CENTER



	Year 1	Year 2	Year 3
Racks	2	3	4
Router Shelves	1	1	1
Router Cards	5	7	10
Servers	3	6	10

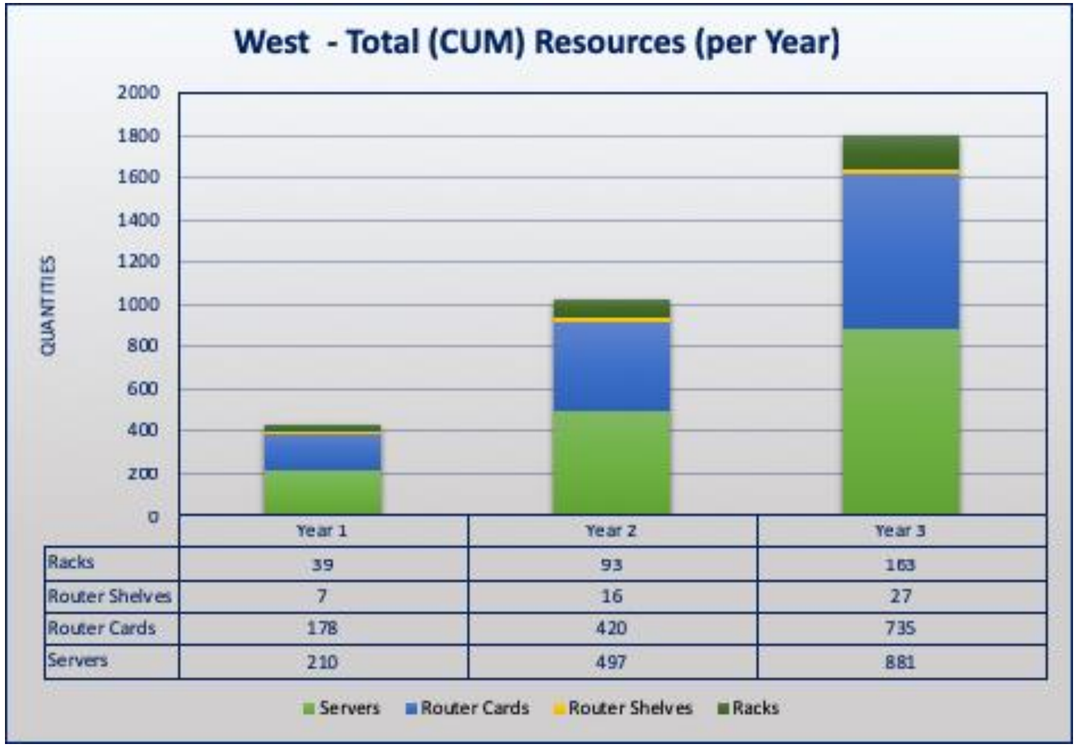


- Provides 21.7% of all transaction processing and playback authorizations under normal operations; capacity for up to 55% with loss of another region's DC
- Non-recurring and recurring Capital Expenses (Container and internet connectivity) FAR outpace equipment costs and other operational costs

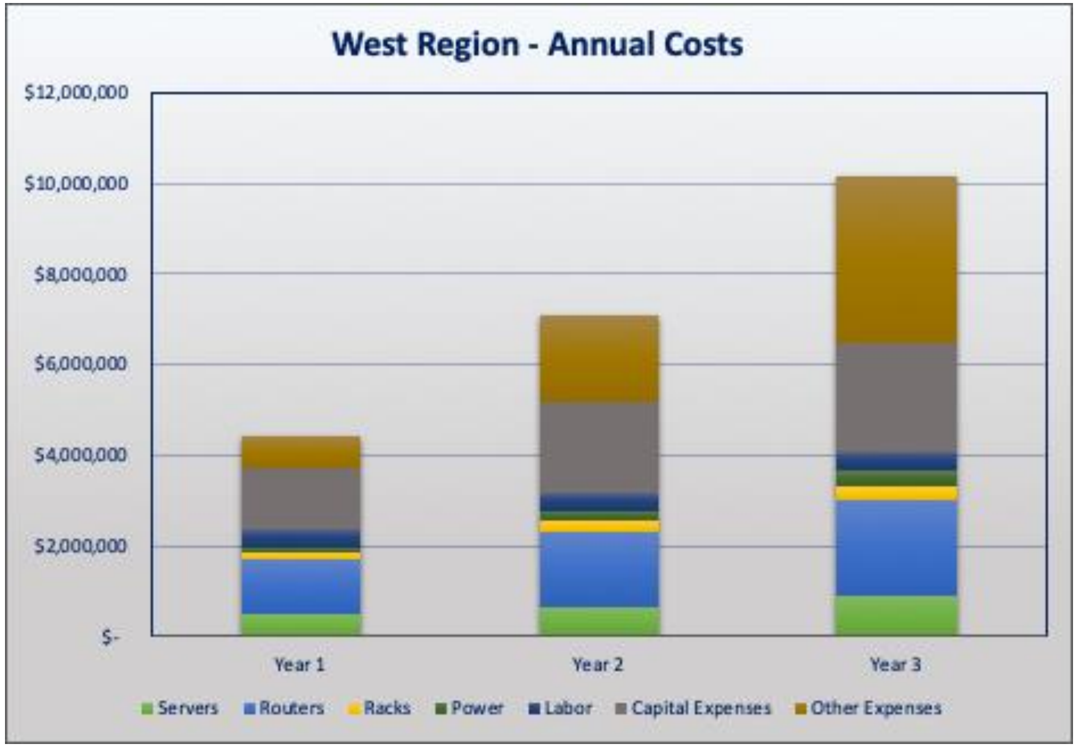
Total 3-Year Cost: $1.86M

WEST DATA CENTER

Musify



	Year 1	Year 2	Year 3
Racks	39	93	163
Router Shelves	7	16	27
Router Cards	178	420	735
Servers	210	497	881



- Provides 52% of total song streaming and download capacity under normal operations; 100% with loss of Northeast Region DC
- Provides 23.3% of all transaction processing and authorization requests nominally; up to 55% under DC failure

Total 3-Year Cost: $21.66M

DISTRIBUTED DC COST SUMMARY

Musify

Region	Measure	Year 1	Year 2	Year 3	Total
Midwest	$ 1,857,943				
	Equipment Costs	$ 66,050	$ 22,191	$ 29,780	$ 118,021
	Servers	$ 7,050	$ 7,191	$ 9,780	$ 24,021
	Routers (Shelves	$ 49,000	$ 10,000	$ 15,000	$ 74,000
	Racks	$ 10,000	$ 5,000	$ 5,000	$ 20,000
	CAPEX & OPEX	$ 927,157	$ 385,400	$ 427,365	$ 1,739,922
	Power	$ 1,345	$ 2,179	$ 3,284	$ 6,809
	Labor	$ 75,950	$ 78,229	$ 80,575	$ 234,754
	Capital Expense	$ 823,613	$ 248,549	$ 258,090	$ 1,330,252
	Other Expense	$ 26,249	$ 56,444	$ 85,415	$ 168,108
West	$ 21,661,684				
	Equipment Costs	$ 1,881,100	$ 2,559,557	$ 3,331,187	$ 7,771,844
	Servers	$ 484,100	$ 673,557	$ 924,187	$ 2,081,844
	Routers (Shelves	$ 1,212,000	$ 1,636,000	$ 2,077,000	$ 4,925,000
	Racks	$ 185,000	$ 250,000	$ 330,000	$ 765,000
	CAPEX & OPEX	$ 2,539,727	$ 4,539,915	$ 6,810,198	$ 13,889,840
	Power	$ 81,268	$ 192,445	$ 336,990	$ 610,704
	Labor	$ 404,428	$ 416,561	$ 429,058	$ 1,250,047
	Capital Expense	$ 1,379,309	$ 1,993,416	$ 2,405,033	$ 5,777,758
	Other Expense	$ 674,721	$ 1,937,493	$ 3,639,117	$ 6,251,331

Region	Measure	Year 1	Year 2	Year 3	Total
Northeast	$ 21,681,450				
	Equipment Costs	$ 1,881,100	$ 2,554,557	$ 3,336,187	$ 7,771,844
	Servers	$ 484,100	$ 673,557	$ 924,187	$ 2,081,844
	Routers (Shelves	$ 1,212,000	$ 1,631,000	$ 2,082,000	$ 4,925,000
	Racks	$ 185,000	$ 250,000	$ 330,000	$ 765,000
	CAPEX & OPEX	$ 2,676,645	$ 4,632,870	$ 6,600,091	$ 13,909,605
	Power	$ 64,436	$ 152,476	$ 267,194	$ 484,107
	Labor	$ 486,196	$ 500,782	$ 515,805	$ 1,502,783
	Capital Expense	$ 1,595,974	$ 2,384,543	$ 2,785,063	$ 6,765,581
	Other Expense	$ 530,038	$ 1,595,069	$ 3,032,028	$ 5,157,134
South	$ 1,936,526				
	Equipment Costs	$ 66,050	$ 22,191	$ 29,780	$ 118,021
	Servers	$ 7,050	$ 7,191	$ 9,780	$ 24,021
	Routers (Shelves	$ 49,000	$ 10,000	$ 15,000	$ 74,000
	Racks	$ 10,000	$ 5,000	$ 5,000	$ 20,000
	CAPEX & OPEX	$ 978,269	$ 398,653	$ 441,584	$ 1,818,506
	Power	$ 953	$ 1,544	$ 2,327	$ 4,825
	Labor	$ 79,370	$ 81,751	$ 84,204	$ 245,325
	Capital Expense	$ 863,013	$ 249,700	$ 259,719	$ 1,372,432
	Other Expense	$ 34,932	$ 65,658	$ 95,334	$ 195,924

Total 3-Year Cost: $47.14M

ARCHITECTURE SENSITIVITY

Musify

- Up-Front Architecture Decision -- Song Processing DCs (NE and W) distribute songs directly to users rather than route the songs back through the users' regional DCs
  - This avoids sizeable inter-DC bandwidth traffic that would otherwise increase costs by 67% while reducing or eliminating the intended latency benefits due to the "extra" hop

- With more than 97.5% of total bandwidth and 100% of storage needs tied to song library content and song streaming and downloads, there is no real opportunity to distribute the libraries across multiple, smaller data centers
  - Content Centers are storage clones and have at least overlapping bandwidth capacities
  - Requires at least 2N redundancy within each region (and then across both NE and W regions) – which translates to total storage and bandwidth capacity greater than 4x of actual demand
  - A smaller regional DC loss would result in the loss of library content and processing capacity (while costing significantly more in capital and operational expenses)
  - Additional Content Centers create exponentially complex networks and costs with minimal improvements in latency and availability/reliability

ARCHITECTURE SENSITIVITY

Musify

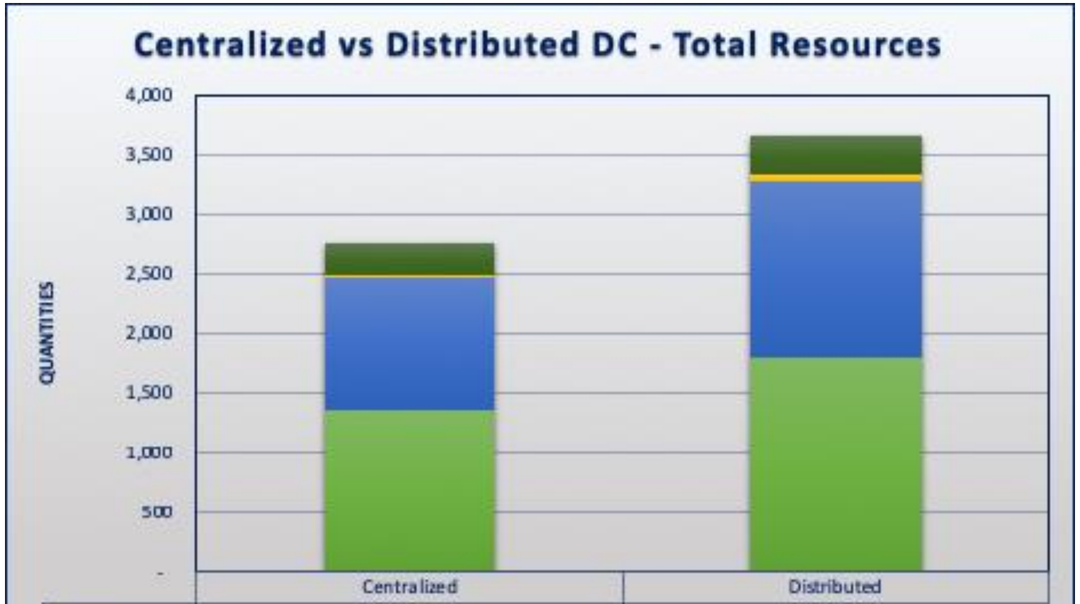
- Availability: DCs were designed to be roughly equivalent to a Tier II+ DC, with $A_0 \cong 99.741\%$ (22h 42m 12.5s downtime/year) each. NE and W DCs combine to provide > 99.9993% A_0 (3m40s downtime/year)
  - Why add a 3rd clone DC (for $Ms) to gain a couple minutes or seconds of additional annual uptime?

NOTE: Bandwidth concerns, the need for secure, available, consolidated song libraries and availability/resiliency objectives is precisely why Spotify's architecture (prior to migration to Google Cloud Platform) had only two data centers in the U.S.

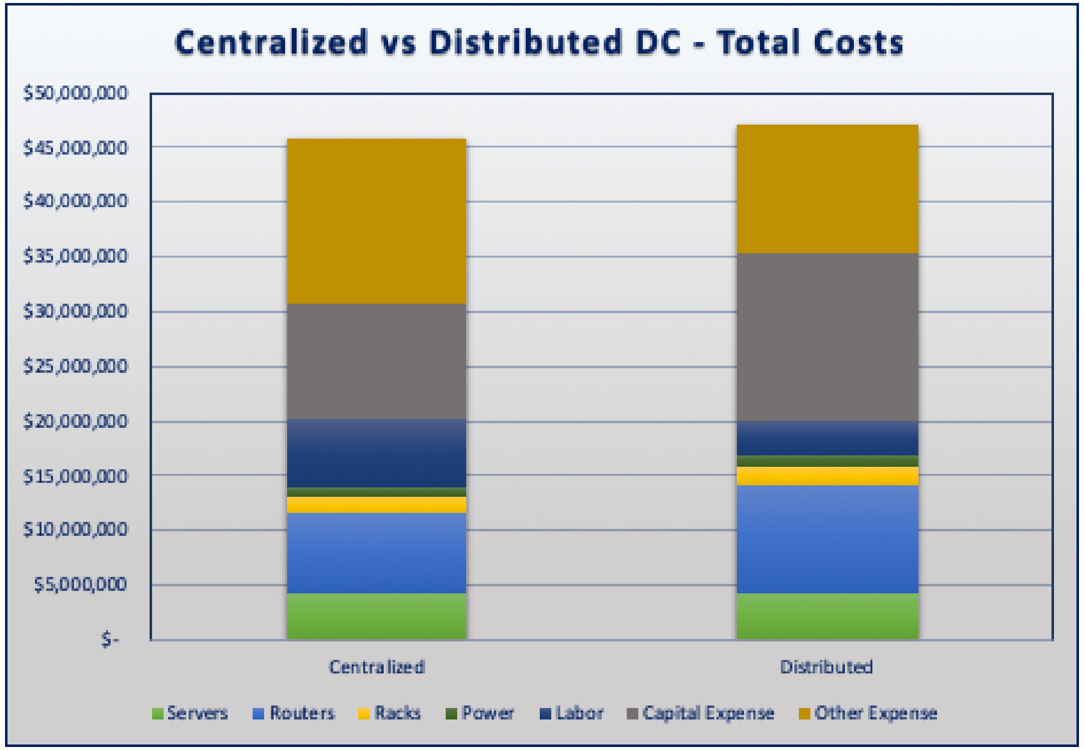
- Spotify used Client-side Peer-to-Peer (P2P) and local client caching of highly-requested for content delivery (improve latencies without incurring additional data center bandwidth-related costs)

CENTRALIZED OR DISTRIBUTED?

Musify



	Centralized	Distributed
Racks	252	334
Router Shelves	37	56
Router Cards	1,098	1,490
Servers	1,357	1,782



Total Cost: Centralized - $45.75M vs Distributed - $47.14M

$1.4M (3%) difference

CENTRALIZED VS DISTRIBUTED?

Musify

- Distributed architecture overall provides value over a centralized architecture in terms of improvements in resiliency and latency for minimal (3%) increase in 3-Year cost

- Scalability
  - Transaction-Only DCs (the PODs) scale well (horizontally and vertically)
  - Song Processing (Content Delivery) DCs scale vertically, but not horizontally
    - In fact, the architecture is largely limited to two Song Processing DCs; things get complicated and pricey with limited upside with more

Recommendation: Go with Distributed

(for the resiliency value)

FUTURE CONSIDERATIONS

Musify

Internet Transit Rates show significant year-on-year MRC reductions; this only makes Musify's distributed DC architecture more affordable

Bandwidth is THE cost driver for Musify

Move to the cloud where cloud infrastructure providers provide built-in regional resiliency, availability zones and data sharing services

Enhanced data analytics that mine user density and usage patterns and trends, and optimize the staging of content and identify regional user growth areas (to enable rapid deploy of additional modular "request handling" PODs)

BACKUP

REFERENCES

Musify

- https://www.datacentermap.com
- https://www.schneider-electric.com/en/work/solutions/system/s1/data-center-and-network-systems/trade-off-tools/data-center-capital-cost-calculator/
- https://www.electricitylocal.com/states/
- https://www.bls.gov/oes/current/oessrcma.htm
- https://www.apc.com/salestools/WTOL-8NDS37/WTOL-8NDS37_R1_EN.pdf?sdirect=true
- https://www.computerworld.com.au/article/644574/how-spotify-migrated-everything-from-on-premise-google-cloud-platform/

REFERENCES

Musify

- https://blog.telegeography.com/outlook-for-ip-transit-prices-in-2018
- https://www.landcentury.com/articles-news/average-commercial-land-prices-across-the-us
- https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a
- https://www.glassdoor.com/Salaries/index.htm
- https://en.wikipedia.org/wiki/Main_Page (multiple references)