How the Netflix ISP Speed Index Documents Netflix Congestion Problems

By Peter Sevcik
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As of this writing, a comedic YouTube video featuring Netflix ISP Speed Index data showing Netflix streaming quality deteriorating and then improving after Netflix and Comcast began to peer directly, has received more than 3.5 million views. This is a powerful example of media and public response to the Netflix ISP Speed Index data. But what does the data really mean? We thought it would be helpful to analyze Netflix service performance swings during the period under scrutiny using Netflix's own data, and place that data into context, as well as to analyze more generally how the Netflix ISP speed index works to understand all the factors that affect the index.

Important contextual information is that Netflix content delivery has undergone four evolutionary phases (shown in Figure 1), each of which has changed the critical server-to-player streaming path, thus affecting Netflix ISP Speed Index results.

In mid-2013 Netflix accelerated shifting its server-to-player content delivery system from third party Content Delivery Networks (CDNs) like Akamai (Phase 1) to its own CDN called Open Connect (Phase 2). To connect the Netflix CDN to the Internet, Netflix uses a variety of "middle-mile" ISPs, including Cogent Communications and Level 3 Communications. As the amount of traffic Netflix served from its own CDN increased, some of its "middle mile" Internet connectivity suppliers apparently lacked sufficient capacity to service the Netflix load, and video performance levels, as documented by the Netflix ISP Speed Index, dropped.

Netflix also offers to embed Netflix CDN servers (called Open Connect appliances) directly into the data centers of last-mile ISPs (Phase 3). Netflix video content delivered to users of ISPs with embedded Netflix servers is not served by "middle-mile" ISPs because it is delivered from the Netflix-supplied servers located within the ISPs' networks. Phase 4, a recently-deployed option for a last-mile ISP to connect its network directly to key points in the Netflix-operated Open Connect CDN service, also removes Netflix middle-mile ISPs from the streaming server-to-player path.

The middle-mile ISP congestion problem experienced in Phase 2 affected a dozen last-mile ISP networks. The problem did not affect last-mile Phase 3 ISPs that embedded Netflix CDN servers in their network, because the video content destined for their users did not traverse the congested middle-mile ISP networks. The adversely-affected ISP networks included:

AT&T - DSL	Frontier - DSL
AT&T-Uverse - Fiber	Mediacom - Cable
Bright House - Cable	Time Warner Cable
Centurylink - DSL	Verizon - DSL
Clearwire - Wireless	Verizon FIOS - Fiber
Comcast Cable	Windstream - DSL

In aggregate, these ISPs serve more than 70 million homes. Although not all of the homes subscribe to Netflix, the population contains a very substantial portion of Netflix customers.

A Netflix-Comcast Phase 4 arrangement directly connected the Comcast and Netflix networks, thus bypassing the Netflix middle-mile ISPs. As far as NetForecast knows, no other changes were made in either the Netflix server-to-player system, or the Comcast network. The only change that resulted from this arrangement was to remove the middle-mile ISP bottleneck between Comcast subscribers and the Netflix

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datacenters. Since Comcast has the largest user population among the dozen impacted networks, direct connection between Comcast and Netflix removed about 30% of the total Netflix traffic from the middle-mile ISP networks used by Netflix.

This caused Netflix ISP Speed Index improvements for all 12 adversely-affected last-mile ISP networks. Video quality for users at 7 of the 12 ISPs returned to Phase 1 levels, before middle-mile ISPs were used extensively by Netflix. As a result, the Comcast-Netflix interconnection arrangement also improved performance for the other 70% of the Netflix user population that used last-mile ISPs other than Comcast.

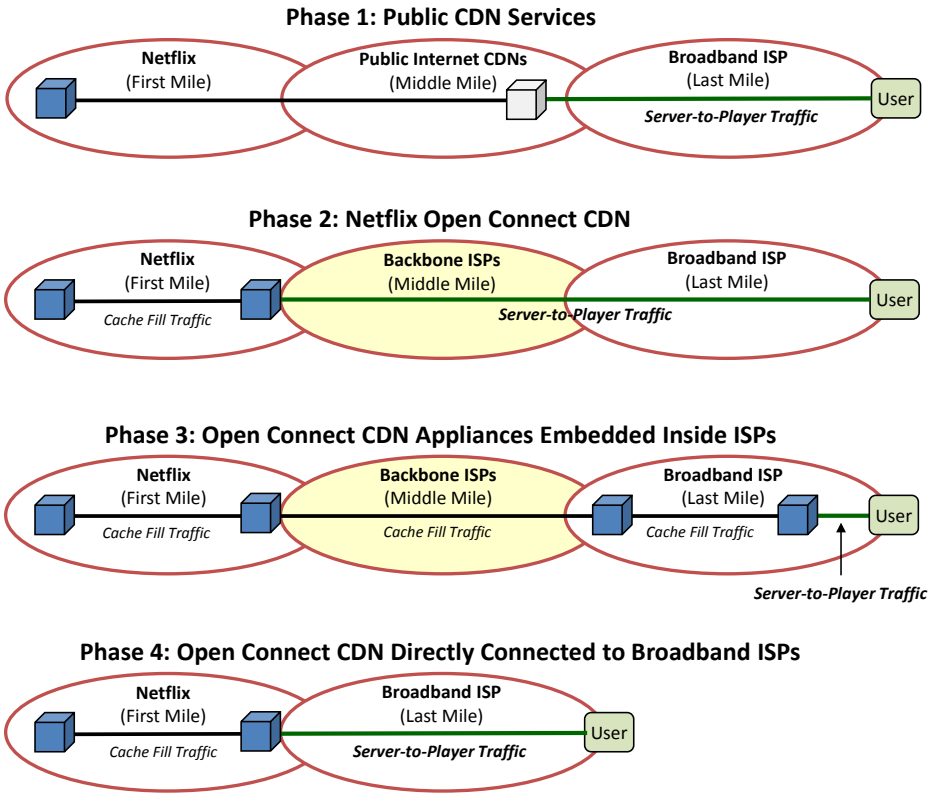

Figure 1 – Netflix Video Delivery Architectures

NetForecast Analysis Methodology

Congestion in Netflix's middle-mile ISP-supplier networks (Phase 2) peaked in January 2014. NetForecast gathered data from the Netflix website for all US ISPs reported in the Netflix Index. We studied a 9-month period (September 2013 to May 2014), that included 4 months leading up to and 4 months after congestion peaked. ISPs in this analysis met the following criteria:

- The Netflix Index was available for the 9-month analysis time span.
- The ISP had a January value below its September starting point (deterioration occurred).
- The ISP had a May value above its January value (improvement occurred).

The complete Netflix Index results for the 12 ISPs that matched these criteria are shown in Figure 2 (screen shot from the Netflix website).

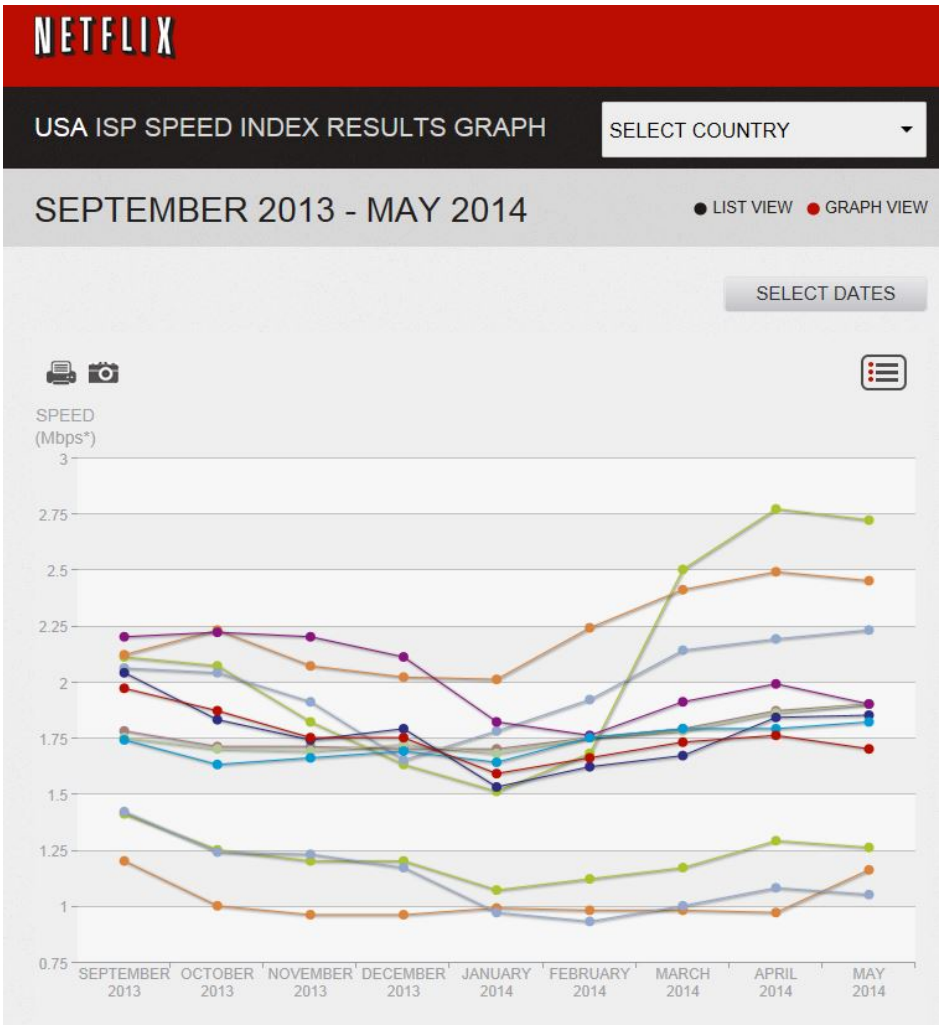

Figure 2 – The Netflix Index for the Dozen ISPs Over the Incident Period

Figure 3 below generated by NetForecast shows the same data as in Figure 2, with each ISP's Netflix effective bandwidth normalized to the September starting point. Normalizing removes the distraction that each ISP started in September at a different speed. Figure 3 also adds the legend for each curve.

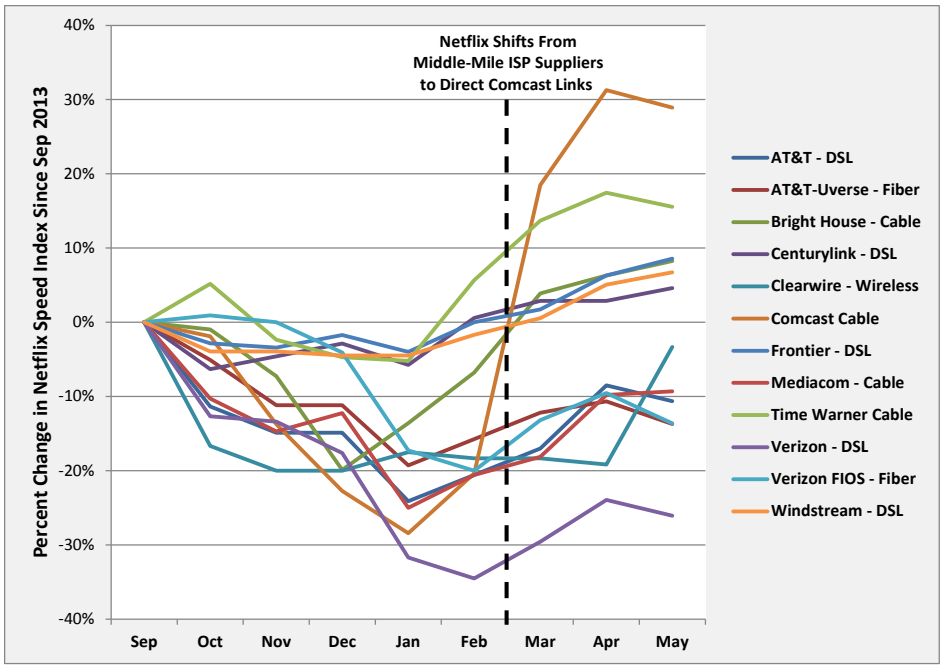

Figure 3 – Netflix Index Normalized for the Dozen ISPs Over the Incident Period

The analysis is a simple interpretation of the curves in Figure 3 as follows:

- All ISPs began with the same performance value in September (0% change in September from September).
- By January, all ISPs had dropped in performance relative to September (all values show a negative change).
- In late February and March, the Comcast-Netflix interconnections were implemented, thus removing about 30% of the Netflix real-time server-to-player traffic from middle-mile ISP networks.
- By May, all ISPs had improved relative to their values in the January peak congestion month.

Once the new Netflix-Comcast interconnection arrangement was implemented, users at all 12 ISPs began to experience better Netflix video performance as documented by the Netflix Index.

Not surprisingly, Comcast users saw the greatest improvement. However, Netflix video experiences for users of all 11 other IPSs also improved. The average benefit to the 11 ISPs from January to May was 12%, which nearly overcomes the 15% overall performance decline their users suffered from September to January.

By May, performance at 6 of the 12 ISPs exceeded the September baseline performance.

NetForecast believes the Netflix ISP Speed Index can be a useful tool for tracking Netflix users' experiences over time. Others will likely find new insights in the historic data Netflix supplies. Unfortunately, Netflix does not disclose details of its measurement methodology. To fully realize the full potential of the Netflix ISP Speed Index data, it is important to understand how the Index works and what it measures. The rest of this report aims to contribute to that understanding.

How the Netflix ISP Speed Index Works

In December 2012, Netflix began publishing its ISP Speed Index, which it describes as a "monthly update on which Internet Service Providers (ISPs) provide the best Netflix streaming experience." The name "Speed Index" implies that it reflects the actual "speed" that an ISP can deliver. NetForecast set out to understand what the Netflix ISP ratings mean, and to test and assess if the Index reflects the bandwidth (i.e., speed) that ISPs deliver to their subscribers. Figure 4 shows an example summary Netflix Speed Index screen shot (http://ispspeedindex.netflix.com/usa).

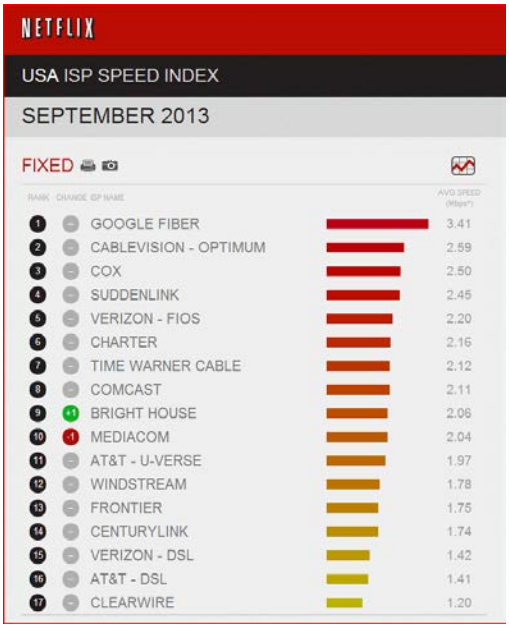

Figure 4 – Netflix ISP Speed Index

NetForecast found that rather than reflecting actual ISP last-mile bandwidth delivered, the Netflix ISP Speed Index reflects five other factors:

- ability of the user's device to process highly or less highly encoded video
- video quality decisions made by users
- behavior of the Netflix adaptive streaming algorithms
- available capacity or performance of the Netflix CDN servers
- performance of interconnections between the Netflix CDN and ISP networks.

Netflix acknowledges that these factors play a role in the Index results, but states that they "cancel out when comparing across ISPs." Based on our analysis, NetForecast questions that conclusion.

NetForecast Test Methodology

NetForecast measured the performance of streaming Netflix movies under a wide range of conditions, using five representative ISPs; one providing DSL service (CenturyLink), two cable service providers (Comcast and Time Warner Cable), and two fiber service providers (Verizon FIOS and Google Fiber). Actual speeds were measured and recorded. A range of movie players from slow legacy PCs to very high-end TVs were used, and the Netflix video quality settings were carefully controlled. NetForecast ran more than 100 tests, each lasting five minutes—and all packets associated with each test were captured using a Wireshark open-source packet analyzer.

How the Netflix Delivery System Works

Netflix uses an adaptive video algorithm that chooses a video rate to optimize several factors, including: the processing power of the viewing device (e.g., slow and fast PCs); the amount of traffic being served by the video server; and the video quality setting at the viewing device.

Netflix lets the user choose video quality. This helps users control their bandwidth consumption to avoid exceeding ISP usage caps. The Netflix viewing choices (see Figure 5) are: "good quality" (up to 0.3 GB per hour); "better quality" (up to 0.7 GB per hour); and "best quality" (up to 1 GB per hour, or up to 2.3 GB per hour for HD). The quality setting is accessible three clicks from the Netflix ordering screen. The existence of this setting is not intuitively obvious to less savvy consumers.

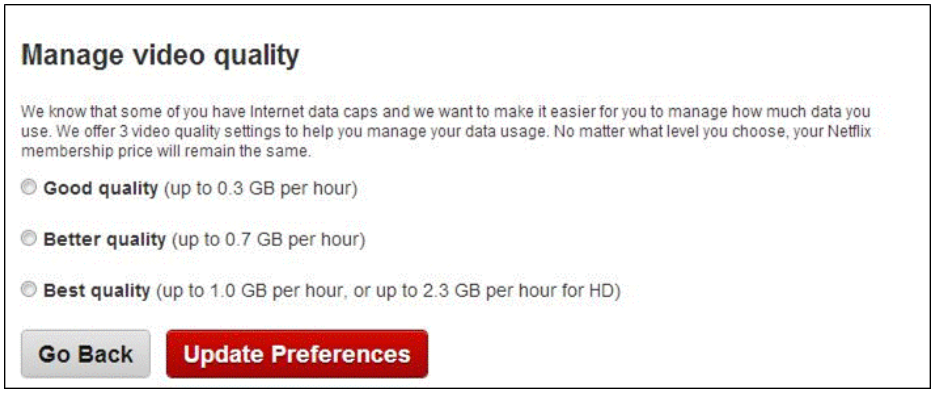

Figure 5 – Netflix Movie Quality Settings

The delivery of Netflix content can be categorized into four phases—initialization, start, play, and restart.

Initialization Phase: When a user requests video content, the system selects a file to stream based on many factors, including knowledge of the processing capability of the client. The file includes a decompression algorithm for the client. The algorithm includes the size of the buffer that will be needed to properly play the movie. This becomes the traffic that must be transferred in the start phase. NetForecast observed a range of file sizes, but they clustered around 25 MB for a "good" video quality selection, and 50 MB for a "best" video quality selection.

Start Phase: The start process loads the buffer with the file. This transfer is not performed with streaming in mind; rather, to load the buffer "as fast as you can get it

there" mode. The data rates we measured were likely the maximum performance of a single TCP connection from the Netflix server to the client.

At this point in the content delivery process, and only at this point, did the speed provided by the ISP matter. The start process typically takes less than one minute.

Play Phase: Once the buffer is loaded, the true streaming algorithm and protocol operate, and the Netflix system enters the play phase. The play data rate is defined by the pre-set video compression algorithm, device processing capability, and user preferences.

Restart Phase: If the streaming protocol can't keep the buffer full enough (small adjustments to catch up occur), then the movie freezes and the start process is performed again for a short time. The Netflix client tells the user that it is "loading" again. Once the buffer is sufficiently re-loaded, play mode resumes.

Bandwidth Consumed by Netflix

The different modes of the start and play phases generate strikingly different traffic patterns. To understand the basic Netflix Index inputs, it is important to quantify the actual data rate of each phase.

Start Phase Bandwidth

Bandwidth consumption in the start phase varies. The transfer rate is partially governed by the last mile speed. Figure 6 shows a typical high-speed transfer burst in the start phase, followed by the long slow-speed play phase.

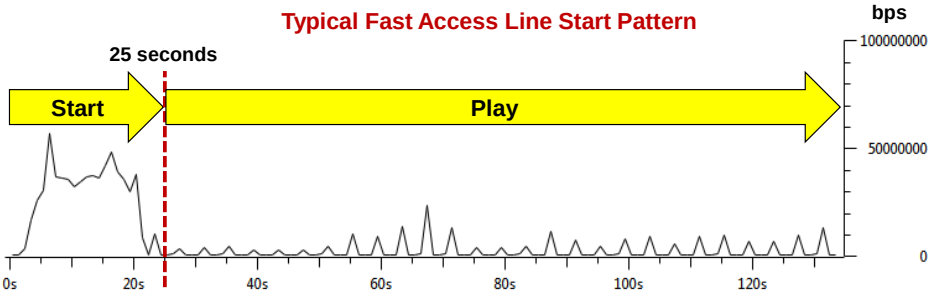

Figure 6 – Typical Netflix Delivery Pattern over a Fast Broadband Connection

If an access line is slow, or limited by a slow Wi-Fi connection, the Netflix start process takes longer. In the example shown in Figure 7, the start process took 230 seconds.

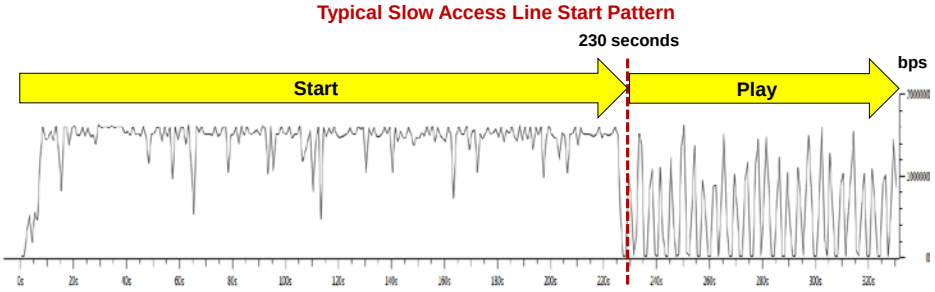

Figure 7 – Example of Netflix Delivery Pattern over a DSL Connection

Play Phase Bandwidth

Play phase bandwidth is generally fixed for each movie viewing session. The NetForecast data show that play phase video streaming rates depend upon the Netflix quality setting as well as the PC speed. The average streaming rates we measured for four scenarios are shown in the following table.

Table 1 – Play Phase Data Rates

Streaming Rates for Netflix Play Period			
Best Quality Video		**Good Quality Video**	
Fast PC	Slow PC	Fast PC	Slow PC
2.5Mbps	2.0Mbps	1.3Mbps	1.0Mbps

Figure 8 shows the bandwidth consumed by the two phases across all of the ISPs measured. The start phase uses more bandwidth if more is available. But that usage is not proportional to the available line rate. Even though the start phase is trying to load the buffer "as fast as it can go," the endpoints cannot take advantage of the available bandwidth at higher speeds.

The play phase is nearly flat, even though the horizontal axis shows 3-order-of-magnitude speed differences among the ISPs tested. Figure 5 confirms the fixed play values shown in the Table 1.

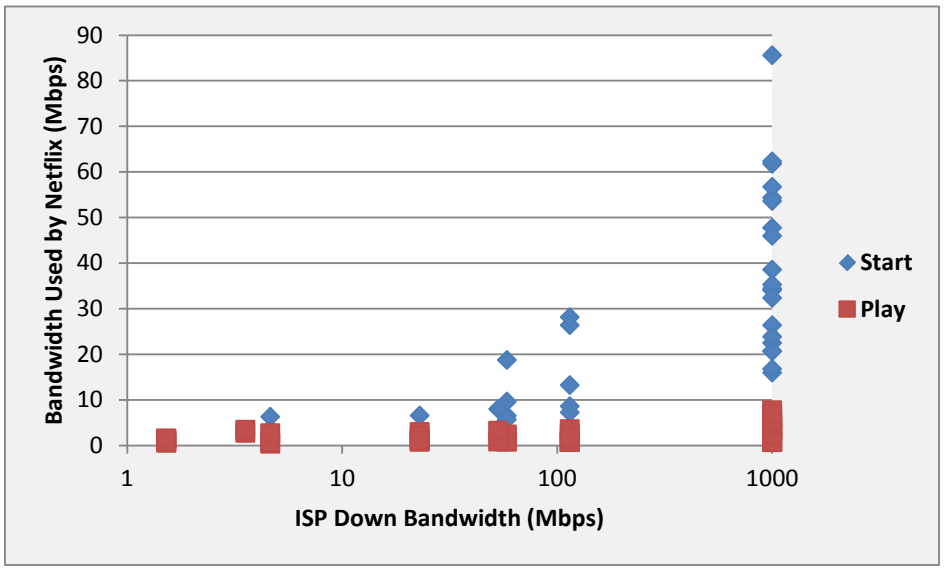

Figure 8 – Netflix Bandwidth Used During Start and Play Phases

How the Netflix Index Works

The Netflix ISP Speed Index is based on the overall average speed with which Netflix plays movies. The total number of bytes sent is divided by the movie run time to obtain the speed calculation for each Netflix session.

NetForecast has modeled the playing of a typical movie. Using the Netflix Index rating data, NetForecast calculated that the average movie viewing experience lasts 30 minutes. Although this may sound surprisingly short, a large number of movies are started and subsequently abandoned, resulting in the 30 minute average.

The Netflix Speed Index is a time-weighted average of the start and play phases. Since the start phase is very short (less than 1 minute), it has a small effect on the final score (less than one-thirtieth in a 30-minute movie play time).

The overwhelming factors that influence the outcome of the Netflix Speed Index calculation are the consumer choices of device processing speed and video quality selection.

Other user choices, such as the average length of time people watch a movie, also affect the index. Households that typically jump from movie to movie within a few minutes of viewing incur many starts that will be averaged over short play times. This raises the Netflix Index. Conversely, households that typically play complete movies lower the Netflix Index. *The index is, therefore, also a window into viewing habits.*

What the Netflix Index Really Reports

NetForecast's analysis shows five primary factors at play behind the Netflix index. Rather than reporting on an ISP's ability to deliver a quality streaming experience, the index mostly reports on:

1. The ability of the user's device to process highly and less-highly encoded video (e.g., the relative processing capabilities of a fast versus slow viewing device).
2. The video quality choice made by the user—or the default choice that Netflix makes for the user if the user does not change it (see Figure 5).
3. The behavior of the Netflix adaptive streaming algorithms that automatically downgrade the user's quality choice if he or she has a slow connection (e.g., a slow Wi-Fi connection). In those scenarios, Netflix throttles back to whatever speed will still deliver the movie.
4. The available capacity or performance of the Netflix servers.
5. The performance of the network path between the Netflix CDN and last-mile ISPs, either via multiple middle-mile ISPs or directly to last-mile ISPs. This is the many versions of the server-to-player path shown in Figure 1.

Netflix does not tell users that they should give up trying to watch a movie because they have a slow device or a slow connection. That choice is left to the user—and as long as users tolerate a poor quality viewing experience (e.g., teenagers with iPhones watching a movie in the basement, two floors away from the Wi-Fi access point), that experience will be reflected in the Netflix Index rating for that ISP.

In summary, the Netflix Index largely documents user and Netflix choices, not ISP performance—and many of the user choices are economic. Users who spring for high-end home entertainment systems and who choose "best quality" via the Netflix interface, experience a higher streaming rate. In contrast, users who watch a movie or old sitcom on an iPhone, and do not actively select "best quality," experience lower streaming rates. Our analysis indicates that this explains the minute rating differences among essentially identical service offerings from ISPs using the same technology (copper, cable, or fiber).

The Netflix Index is NOT reporting on the provisioned or delivered bandwidth of the ISP's last mile. NetForecast's analysis shows that the Netflix position that the five factors cited here "cancel out when comparing across ISPs" is incorrect.

About the Author

Peter Sevcik is President of NetForecast and is a leading authority on Internet traffic and performance. Peter has contributed to the design of more than 100 networks, including the Internet, and is the co-inventor of two patents on application response-time prediction and congestion management. He works extensively with the SamKnows system in support of the FCC Measuring Broadband America project, analyzing operational integrity and performing deep data analysis. He can be reached at peter@netforecast.com.

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