

An Empirical Analysis of HTTPS Configuration Security

Camelia Simoiu*
 Stanford University
 csimoiu@stanford.edu

Wilson Nguyen*
 Stanford University
 wdnguyen@cs.stanford.edu

Zakir Durumeric
 Stanford University
 zakir@cs.stanford.edu

ABSTRACT

It is notoriously difficult to securely configure HTTPS, and poor server configurations have contributed to several attacks including the FREAK, Logjam, and POODLE attacks. In this work, we empirically evaluate the TLS security posture of popular websites and endeavor to understand the configuration decisions that operators make. We correlate several sources of influence on sites' security postures, including software defaults, cloud providers, and online recommendations. We find a fragmented web ecosystem: while most websites have secure configurations, this is largely due to major cloud providers that offer secure defaults. Individually configured servers are more often insecure than not. This may be in part because common resources available to individual operators—server software defaults and online configuration guides—are frequently insecure. Our findings highlight the importance of considering SaaS services separately from individually-configured sites in measurement studies, and the need for server software to ship with secure defaults.

KEYWORDS

security, tls, https, tls configuration, defaults, recommendations

1 INTRODUCTION

HTTPS provides the foundation for secure web communication, however, configuring HTTPS securely has proven to be notoriously difficult [56]. This is largely due to the complexity of the underlying TLS transport protocol, which requires server operators to make a wide range of configuration decisions. Most web servers do not ship with optimal TLS settings, and many come with insecure options configured by default. To make matters worse, there are hundreds of options to select from. As of early 2020, there are over 360 cryptographic ciphers, 44 elliptic curves, 40 protocol extensions, and 6 protocol versions [27]. Seemingly benign settings like session ticket lifetime have nuanced security implications [29, 70], and recommendations continually change as vulnerabilities (e.g., [9, 29, 29, 34, 35, 41]) are discovered.

The security community has released hundreds of configuration guides [4, 18], online tools for verifying configuration correctness [67], and third-party software to automatically configure servers [7]. Despite these solutions, large swaths of the web have been vulnerable to attacks because they continue to use insecure configurations. For example, when the FREAK attack was disclosed in 2015, 10% of popular websites and 37% of browser-trusted websites still supported export-grade ciphers, which had been deprecated decades earlier [41]. In this paper, we try to better understand whether servers remain misconfigured today, and if so, why.

We start by empirically evaluating the security posture of the Tranco Top Million sites [63]. We reverse-engineer the configuration of each website by performing a series of TLS handshakes with varying cryptographic parameters and grade the user-configurable components of each configuration. We find that approximately 40% of sites have optimal settings and 90% of sites have secure settings. While this initially appears promising, these aggregate statistics mask the coexistence of two distinct ecosystems with dramatically different security postures. One ecosystem consists of optimal configurations defined by SaaS (Software as a Service) providers that use secure-by-default options for all hosted sites. The other consists of individual operators who are likely manually configuring servers and struggling to do so securely. Unfortunately, the adoption of SaaS masks that operators still cannot achieve secure configurations, despite aggregate ecosystem health improving.

To better understand why individually configured sites are much less likely to be secure, we quantify the influence of several factors on configuration security that operators make decisions about when manually setting up TLS: provider, web server software, and online recommendations. We investigate the default security of the two most popular web servers, Apache and Nginx, as well as online recommendations for configuring them on Ubuntu. We find that most online recommendations are incomplete and insecure: 89% recommend TLS 1.0, 55% deprecated ciphers, 28% insecure ciphers, and 8% are vulnerable to known attacks. Similarly, defaults provided by Nginx and Apache provide sub-optimal security. Our work suggests that the current approach of sub-optimal defaults along with online recommendations that guide operators to fix those settings, is fundamentally broken. We echo previous studies' calls for fixing systems to be secure by default [36, 57]. We also encourage future studies to consider SaaS services separately from individually-configured services since aggregate statistics can otherwise be misleading.

2 RELATED WORK

The HTTPS ecosystem and Web PKI has been subject to much attention and there is a large body of prior work analyzing server usability and misconfiguration [36, 57], TLS clients and interception [40, 46, 51, 54], server configuration [42, 43, 56, 60, 70], TLS attacks [10, 29–31, 34, 35, 37, 38, 45, 50, 71, 72], and Web PKI [32, 39, 44, 52, 74]. We highlight relevant prior work below.

HTTPS Deployment Difficulty. In 2014, Fahl et al. investigated common reasons that websites have certificate errors [48]. Later, in 2017, Krombholz et al. [57] showed that technically proficient users encounter challenges deploying TLS correctly. In 2019, Bernhard et al. [36] analyzed how 10 operators deployed HTTPS on Apache 2 with and without Let's Encrypt [28]. Both Krombholz and Bernhard use Qualys SSL Labs server test [67] to grade deployments. Bernhard did not find significant evidence to suggest that Let's Encrypt led to more secure HTTPS deployments. Our study is complimentary and

*Both authors contributed equally to this research.

focuses on real-world deployment difficulties rather than analyzing laboratory participants.

TLS Measurements. Felt et al. [49] track the evolution of HTTPS adoption on the Web from 2016-2017 from both a user perspective (via aggregate user metrics from Google Chrome and Mozilla Firefox), as well as server support for HTTPS among top and long-tail websites. Kotzias et al. [56] fingerprint TLS clients connecting to servers at several academic institutions in North America from 2012-2017 and document trends in support for cipher suites, protocol versions, and vulnerabilities over time. They similarly find a long tail in TLS deployment that suggests the demand for backwards compatibility. Their results provide insights into popular client configurations incoming into servers in a certain geographical area, such as browsers and OS-provided libraries, but provides limited visibility into the server ecosystem, which is the focus of our study. More recently, Holz et al. [53] track the deployment of TLS 1.3 from 2017-2019—a small subset of our measurements. ICSI SSL Notary [33] similarly provided high level statistics of TLS sessions from 10 participating organizations. SSL Pulse [65] is a dashboard for monitoring the quality of TLS support over time across 150K HTTPS websites sample from the Alexa Top Million. For this subset of sites, they present the distribution of grades as well as support for a number of individual directives (e.g., protocol support, ciphers, key exchange strength, etc.) and the number of sites being vulnerable to various attacks (e.g., DROWN, ROBOT, POODLE, etc.) Most recently, Lee et al. investigate the spatial differences in TLS configurations and security of 7M domains hosted on content delivery networks (CDNs) and other web hosting services. They find that it is possible to redirect TLS handshake messages to weak TLS servers of which both the origin server and the client may not be aware of [59].

While measuring the support for directives is helpful in assisting operators in understanding the deprecation of specific features, they do not provide insight into the higher level decisions made by operators (e.g., to keep system defaults, to follow recommendations, or to migrate to a cloud provider). Rather than focus on individual components Qualys’ SSL Labs Test and SSL Pulse [65] do, we consider a site’s configuration as our unit of analysis. Our focus is on the various sources of influence on the security of the HTTPS ecosystem (defaults, providers, and online recommendations). While we analyze specific configuration choices in order to determine whether a server is set up securely, this is a first step in understanding how operators arrive at a configuration, rather than the end result of our analysis. As far as we are aware, no prior work has analyzed server operator decisions at scale or with this intent. As we will show, analyzing individual directives provides a misleading picture of the security posture of the HTTPS ecosystem, as it masks many notable differences among web server software and provider.

SSL Grading. Qualys’ SSL Server Test [67] provides numeric and letter grades for SSL servers. Qualys’ scheme [64, 66] grades sites on their protocol support, cipher suite support and strength, key exchange support and strength, and TLS vulnerabilities. Our grading scheme is based on SSL Lab’s, but differs in a few ways. First, Qualys rates servers on their certificate and HTTP configuration in

addition to TLS configuration. We do not grade servers on these categories as our focus is on TLS directives that are user-configurable for servers like Nginx and Apache. Certificate values are not configured by server operators, and the introduction of the CA/Browser Forum Baseline Requirements has resulted in certificates being consistently issued by authorities [58]. Our grading schemes are comparable in leniency: Qualys’ A+ and A grades roughly correspond with our A grade, their A and B grades with our Bs, their Cs and Ds with our Cs, and their Fs with our Fs.

3 BACKGROUND

TLS Handshake. In HTTPS, communication is encrypted using the Transport Layer Security (TLS) protocol [25]. TLS handshakes are initiated when the client sends a `ClientHello` message, which specifies the TLS version, cipher suites, and extensions that the client supports. Each cipher suite consists of four components: authentication algorithm, key exchange method, symmetric cipher, and message authentication code (MAC). The client may choose to list these cipher suites in its preferred order. The server replies to the client with a `ServerHello` message that contains the server’s selection of TLS options (e.g., protocol version, cipher suite, extensions) from the client’s presented list of support. For a more detailed reference, we refer the readers to RFC 5246.

Web Server Configuration. Server operators are faced with several decisions when configuring a web server. While some operators choose to host websites on cloud providers like Cloudflare, which leave a limited amount of configuration options for users, others use popular open source software such as Apache [2], Nginx [19], and Lighttpd [16], which come equipped with a default configuration. Beyond acquiring and installing a certificate, operators often choose to manually configure the default settings, by enabling more secure features such as server cipher preference and disabling insecure ones like RC4 ciphers. Operators can draw on several sources for guidance in this process: official server specific documentation [8, 20], online recommendations such as the Mozilla SSL Configuration Generator [18], personal blogs by security experts, and automatic tools that configure servers [7]. Online tests such as SSL Labs’ SSL Server Test [67] provide a means of testing the security of TLS configurations and identifying security issues.

4 METHODOLOGY AND DATA COLLECTION

We start our analysis by collecting and grading the HTTPS configurations of the Tranco Top Million websites. In this section, we describe our HTTPS scanner and grading methodology. To note, we build a scanner instead of using SSL Labs’ due to the scale of our study—we scan several million sites, which would not have been possible in a reasonable time frame using SSL Labs’ API.

4.1 Defining a Configuration

We define a configuration in terms of the TLS options that are configurable in the four most common user-configurable web sites: Nginx, Apache, Lighttpd, and IIS. This includes TLS version, cipher suites, session ID resumption, extension session ticket, ticket lifetime hint, compression support, server cipher preference, Diffie-Hellman (DH) group size, and Diffie-Hellman group, but excludes library-controlled settings like TLS Heartbeat support. To avoid the

exponential explosion of variable space and because cipher suites are typically introduced by cipher, we analyze cipher components (e.g., ECDHE, 3DES, RC4, MD5) rather than individual TLS cipher suites. All features are binary indicators, with the exception of DH group size and ticket lifetime hint, which we discretize.

4.2 Collecting Server Configurations

To collect configurations, we introduce a scanner that reverse engineers the HTTPS settings of websites by performing a series of HTTPS handshakes that present varying sets of cryptographic parameters. We detail the scanner and handshakes below:

HTTP(S) Support. We first attempt a TLS handshake that emulates a modern browser by offering TLS 1.2 support and the union of ciphers present in the recent versions of Chrome, Safari, Firefox, and Edge.¹ If this handshake succeeds, we attempt an HTTP GET / over TLS. We exclude hosts that do not complete these two handshakes from our study as they would not be accessible to normal users. We also note the certificate signature algorithm to decide whether to offer ECDSA or RSA ciphers in future handshakes.

TLS Version. We check SSLv3–TLSv1.2 protocol support by iteratively sending TLS *Client Hello* messages that indicate support for progressively older TLS versions. For every message, we present the set of versions older than the server’s last indicated support. For example, if a server selects TLSv1.1 in response to our TLS1.2 handshake, we would present TLSv1, and if successful, SSLv3. We offer commonly supported cipher suites and curves in each handshake. We test support for SSLv2 and TLSv1.3 separately because they use different handshakes or mechanisms for indicating version support.

Cipher Suite Support. We test support for DES, 3DES, RC4, IDEA, SEED, Camellia, ARIA, ChaCha, and AES symmetric ciphers, MD5, SHA-1, SHA-256, and SHA-384 MACs, and NULL or EXPORT components. We do not test for widespread support of PSK, SRP, ECCPWD, KRB, DSS, DH, or ECDH-based key exchange methods, MD2 MACs, or Anon signature algorithms, because we find that less than 0.1% of sites in the Tranco Top Million support these algorithms.² To measure cipher suite support, we send a Client Hello that indicates support for all cipher suites compatible with the presented certificate (i.e., ECDSA or RSA) and iteratively remove the server selected cipher until the handshake fails. Although browsers typically present fewer than 30 cipher suites, we find that including 97 cipher suites (the maximum we offer in our first handshake) does not preclude any server from completing a handshake.

Extensions. We test support for TLS extensions by sending a single handshake that indicates support for the following extensions: server name, heartbeat, session ticket, ALPN, OCSP stapling, secure renegotiation, extended master secret, and signed certificate timestamp, and checking for selection in the *Server Hello*. If the server indicates support for heartbeat, we also test for the Heartbleed vulnerability.

TLS Compression. We attempt a handshake with TLS compression methods deflate and LZS [55].

¹We specifically use the TLS 1.2-compatible cipher suites specified by Chrome 65, Safari 13.0.1, Firefox 66, and Microsoft Edge 18.18363.

²Prior to doing our large-scale scan of Tranco and CT, we scanned Tranco for support of the comprehensive set of ciphers supported by IANA.

Session Resumption. We test support for session ID resumption and session tickets by sending two handshakes each, to establish and attempt to resume sessions.

We implemented our scanner in Go, using the ZCrypto TLS library [26]. We have released our scanner at <https://github.com/stanford-esrg/tls-webserver-configuration-scanner> under the Apache 2.0 license. In total, our algorithm completes 14–93 handshakes per server. The large range is primarily due to the large number of cipher suites that a server can theoretically support. On average, we perform 40–43 handshakes per site.

4.3 Grading Configurations

Inspired by Qualys’ SSL Server Test [67], we define a grading scheme to quantitatively compare the security provided by different configurations (see Section 2 for a comparison between our algorithm with Qualys’ SSL Server Test). We assign a grade of A (optimal), B (non-optimal but safe), C (weak, vulnerable to academic attacks), and F (severely broken, simple MITM possible) grades to websites. We grade sites based on 7 categories and assign the minimum score across the categories:

Protocol Support. To receive an A, sites must support TLSv1.2 or 1.3 and must not support SSLv2 or 3. Sites that support SSLv2 receive an F; sites that do not support TLSv1.2 or 1.3 receive a C.

Key Exchange. Sites must only support ECDHE key exchange for an A; sites must support a minimum 2048-bit DHE group or an uncommon 1024-bit group for a B. Sites with 768-bit DHE groups receive a C, and sites with smaller DHE groups receive an F.

Symmetric Ciphers & MAC Algorithm. To receive an A, sites must support AEAD ciphers, and not support any of: Camellia, ARIA, IDEA, SEED, RC4, or DES ciphers, MD5, NULL or EXPORT ciphers. For a B, sites must not support any of: RC4 or DES ciphers, MD5 MACs, NULL or EXPORT components. To receive a C, sites must not support DES ciphers or any NULL or EXPORT components. Otherwise, sites will receive an F for supporting DES ciphers or any NULL or EXPORT components.

Preferred Cipher. Sites must support server cipher preference and must prefer an AEAD cipher and Perfect Forward Secrecy (PFS) to receive an A. All other sites receive a B.

Compression. Sites that support TLS compression receive a C, otherwise, they receive an A.

Ticket Lifetimes. Sites with session ticket hints longer than a week receive a C; 1–7 days, B; and under 24 hours, A. While a session ticket hint can differ from the ticket lifetime, Springall et al. showed that they are nearly always the same in practice [70].

Vulnerabilities. Sites vulnerable to CRIME[10], POODLE[35], or FREAK[71] receive a C. Sites vulnerable to Heartbleed receive an F. Sites not vulnerable to any TLS attacks to receive an A.³

4.4 Data Collection and Annotation

We analyze 1.16M websites that appeared in the Tranco Top Million [63] in August 2019. We performed our scan between September 4–8, 2019 from 3 servers at Stanford University. We completed

³We do not consider elliptic curve support in our definition of a configuration as there are no known curve-based vulnerabilities (despite downgrade attacks [73]) and there have been bugs in Nginx related to curve selection, where even if specific curves are specified, they may not end up being used [61] [62].

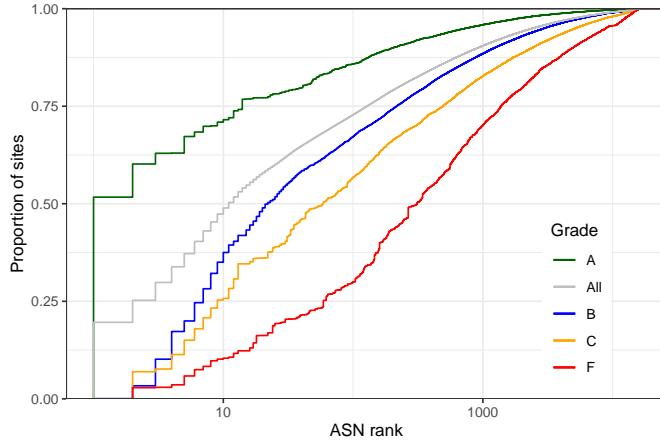


Figure 1: CDF of site count by grade and ASN rank.—Cloudflare’s dominance and its small set of A-grade configuration is responsible for approximately 50% of As, lifting the average grade for all sites.

handshakes over a 102 hour period and waited a random 0–2400 second period between each handshake in order to prevent overloading sites. Of the 1.16M candidate sites, we were able to resolve 1.06M names and successfully complete a TCP handshake on port 443 with 890K. Of those, 678K sites presented a browser-trusted certificate that matched the name on the website and responded to an HTTPS GET / request. In the event of a non-TLS related error, our scanner attempts another handshake before proceeding. This extra attempt accounts for potential network loss. We followed the best practices set forth by Durumeric et al. [47], configuring the HTTP page on scan hosts to redirect to a website that explained our study. We received only one exclusion request.

We extract the server software from the HTTP Server header [24] and use MaxMind GeoIP2 GeoLite [13] to geolocate sites at the country-level. We identify Content Delivery Networks (CDNs) and Software as a Service (SaaS) providers from their Autonomous System (AS) number and name.

Finally, to understand whether different types of sites have differing security profiles, we map a random sample of 100K sites to the Alexa Top Sites [1] 17 categories.⁴ We were able to successfully map approximately 67% of our sample to categories.

5 HTTPS ECOSYSTEM SECURITY

Across the 678K sites in our study, we find 7.7K unique configurations in over 16K ASes. The most popular configuration accounts for 14% of sites and belongs to Cloudflare. The long tail begins thereafter, with the next most popular configuration being adopted by only 3.3% of sites and hosted across 1,421 ASes. Nearly 90% of all sites have secure HTTPS settings (A or B). Nearly 40% receive an optimal A grade, 10% receive Cs, and only 1% Fs. While this initially appears very promising, the aggregate number masks notable

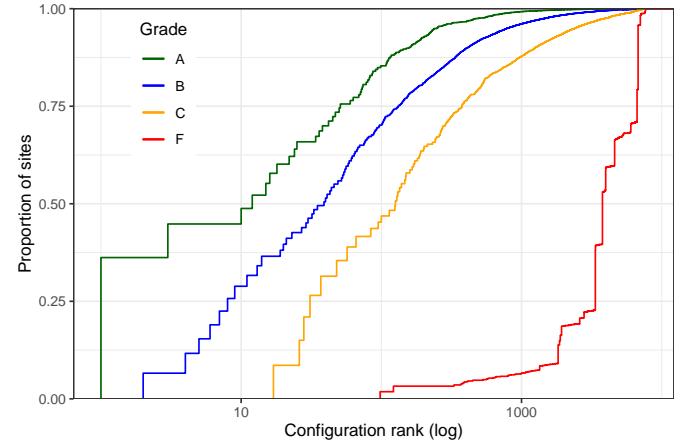


Figure 2: CDF of site count by grade and configuration rank.—Sites receiving As concentrate in higher-ranking configurations, whereas configurations that are less commonly used are more insecure.

differences in the distribution of grades across server software and provider, which we detail in the remainder of this section.

5.1 CDN Providers

A small number of CDNs and unique configurations account for the majority of secure sites (A or B grade). Ten ASes account for approximately 72% of sites with As and 38% of Bs; 100 ASes account for 86% of As and 67% of Bs. At first glance, this concentration may not appear surprising. Infrastructure providers host a large number of *all* sites. The top 10 and vast majority of the top 100 ASes belong to SaaS companies, cloud providers, and CDNs. Indeed nearly 73% of all websites—regardless of grade—are hosted in 100 ASes and 33% of sites are hosted in 10 ASes. However, as can be seen in Figure 1, sites with poor security do not see this concentration, and are widely spread across a large number of ASes: 100 ASes account for only 57% of Cs and 30% of Fs.

We investigate the sites in the top 100 ASes and find that in many cases, there is a single or small handful of configurations in popular SaaS/CDN/cloud networks that account for a significant fraction of sites. This suggests that providers exert influence on operators’ choice of configuration options, whether it be via a default configuration, limiting configuration options, or providing clear recommendations that operators use in practice. Within the top ten ASes, the most popular configuration in each AS is used by a significant proportion of sites, and in each case, it is secure (i.e., receives either an A or B grade). At the extreme, a single Cloudflare configuration accounts for 52% of *all* sites in our study that receive an A grade. The top 100 configurations that receive an A grade account for 97% of all A websites. In contrast, the top 100 configurations that receive an F grade account for only 18% of sites with Fs.

In some cases, this is due to the provider offering their own SaaS service, even when the top configuration does not account for the majority of sites on the provider. For example, the most popular configuration in Amazon ASes belongs to Cloudfront, which offers

⁴We limit our analysis to 100K sites instead of the complete list due to resource constraints. Alexa Top Sites categorizes websites into the following categories: Adult, Arts, Business, Computers, Games, Health, Home, Kids and Teens, News, Recreation, Reference, Regional, Science, Shopping, Society, Sports, and World.

	→ B	→ C	→ F
Preferred Ciphers	12	13	20
KEY Ciphers	40	44	0
Protocol Ciphers	29	5	29
Vulns			5

Table 1: Primary reasons for grade downgrades—Primary factors contributing to downgrades from each grade to the next lower one. Each value represents the proportion of sites downgraded to each grade (from better grades) by reason.

clients six possible security policies to choose from [21]. The dominant configuration accounts for 14% of Amazon sites and 5.6% of all sites in Tranco. We also see evidence of smaller SaaS providers operating within the cloud providers. For example, Google’s most dominant configuration is used in 39% of its sites and belongs to a hosted third-party provider, WP Engine [22, 23]. We empirically infer the default configurations for providers, and provide the five most popular configurations within each of the top 10 ASes in Tranco in Table 4. The default TLS settings are typically not advertised online and we found it intractable to create accounts for each provider, especially as each provider typically offers multiple plans, including enterprise policies. Some CDNs may provide more or less than five default configurations, however, as can be seen in Table 4, any defaults we have missed are only used by a small proportion of sites in the tail of the distribution and are thus less impactful on the ecosystem as a whole. We find that all of the dominant configurations are secure, receiving either an A or B grade.

While we cannot exactly quantify the improvement in security that SaaS providers are responsible for due to the tremendous number of providers globally, we observe an unambiguous positive contribution to improving the security of the overall HTTPS ecosystem from even the ten most popular. There is a clear disparity in the security profile for sites hosted on large, well-known SaaS providers versus individually-configured sites, which are likely manually configured servers by operators. We confirm this finding more generally by considering the top configurations independent of the AS they are in. A pairwise T-test with a Bonferroni adjustment for multiple comparisons confirms that configuration dominance (i.e., the proportion of sites that use a configuration) is correlated with grade: the unique configurations that receive higher grades are used by a larger number of sites than configurations that are insecure. Figure 2 shows the complete distributions of configuration rank in terms of the proportion of sites using each configuration. At the other extreme, we find that for uniquely configured sites, the odds of the configuration being insecure (receiving a grade of C or F) is 1.30 times higher than being secure—57% versus 43% of uniquely configured sites are insecure. The same qualitative result holds even if we relax this threshold and consider configurations used in more than one site, although the effect is attenuated. For example if considering configurations used in at least 10 sites, the odds of having an insecure configuration is 1.09 times that of having a secure configuration.

5.2 Drivers of Insecurity

Next, we investigate the main reasons why sites are insecure, which are summarized in Table 1. Of sites that received a B, the primary reasons why servers were downgraded was a lack of cipher preference (12% of sites) and support for at least one suboptimal cipher (13%). Sites were downgraded to a C for key exchange (20% of sites used 1024 bit common DH parameters and are susceptible to Logjam) and support for ciphers (40% of sites supported RC4 and 32% supported MD5 MACs). To prevent a majority of downgrades to C, servers can generate fresh 2048 bit DH parameters with OpenSSL or use Mozilla’s predefined ffdhe2048 parameter [18] and remove support for RC4 and MD5 macs. Last, of sites that were downgraded to an F, 44% were downgraded due to support for SSLv2, 29% were downgraded due to a weak key exchange strength, 29% were downgraded due to supporting insecure ciphers (80–89% of these supported export grade ciphers, NULL cipher components, and DES ciphers), and 5% were due to having vulnerabilities (all sites receiving an F were vulnerable to Heartbleed, 90% supported compression and CBC ciphers). Patching Heartbleed requires an update of the cryptographic library. A comprehensive description of individual directive support is included in the Appendix. We caution that our analysis only captures a snapshot of the current state of the HTTPS ecosystem, and results may be volatile over time.

Of sites that were downgraded to B because of their cipher preference, 74% did not have server cipher preference and 56% first negotiated with non-AEAD ciphers. Of servers that were downgraded to B because of their cipher suite support, over 74–99% supported older, uncommon, and non-AEAD ciphers: ARIA, Camellia, SEED, or IDEA. This suggests that enabling server cipher preference and removing support for uncommon ciphers are simple changes that could upgrade servers to optimal security without affecting client compatibility. While we cannot confirm for certain whether an insecure site is left so intentionally, for example, in order to support legacy clients, previous work has documented the difficulties that operators face when configuring servers [36, 48, 57], so it is likely that a significant portion, if not all, of these issues are attributable to configuration mistakes or are configurations that have become outdated over time. Further, many of the misconfigurations made do not improve compatibility with any version of mainstream browsers.

5.3 Ordinal model

To more quantitatively confirm our finding that cloud providers are primarily responsible for secure configurations, we model the relationship between server security and several variables related to the provider, server software, geographic location, site content, and site popularity in Tranco. For example, it could be that popular sites are more secure than unpopular ones, and popular sites use SaaS providers. We exclude Cloudflare sites as there are few configuration choices left to the user and little variance in the grade—virtually all sites obtain an A.

We treat the set of sites measured as a random sample of the most popular sites. We fit a generalized ordered logistic regression model using R’s oglmx package [11] to understand the relationship between a server’s grade and several variables related to the server

	F/C	B	A		F/C	B	A
Nginx	0.94	0.99	1.07	.org	0.99	1.00	1.01
IIS	1.10	1.01	0.90	.net	1.01	1.00	0.99
LiteSpeed	0.73	0.81	1.71	.de	0.98	1.00	1.03
OpenResty	0.88	0.95	1.20	.uk	0.99	1.00	1.02
cPanel	1.10	1.00	0.90	.jp	1.05	1.01	0.94
BigIP	0.87	0.95	1.20	.ae	1.02	1.00	0.98
Cloudfront	0.72	0.79	1.77	.au	0.97	0.99	1.03
Varnish	0.83	0.92	1.32	.ir	1.03	1.00	0.97
ATS	0.92	0.98	1.11	.it	1.03	1.00	0.97
AWSelb/2.0	0.73	0.79	1.72	.co	0.97	0.99	1.04
SquareSpace	0.98	1.00	1.03	.ua	0.96	0.99	1.05
Akamai	0.75	0.82	1.64	.io	0.94	0.98	1.09
GHS	0.97	0.99	1.03	.es	1.02	1.00	0.98
Other	0.87	0.96	1.20	.vn	1.05	1.01	0.95

Table 2: Marginal effect sizes in terms of odds for ordinal logistic regression. Only significant predictors, with an absolute effect size greater than 1% are shown. The baseline categories for server is Apache, and “.com”. All coefficient are significant at the 0.05 confidence level.

software, geographic location, site content, and site popularity in Tranco. As is usual in these contexts, we assume that, underlying the observed discrete grade categories of a site i , Y_i , there is a continuous latent variable \tilde{Y}_i that captures the security posture of a site. We assume that the mean of the underlying latent variable may be modeled as a linear combination of explanatory variables:

$$\tilde{Y}_i = \beta_0 + \beta_{\text{server}} s_i + \beta_{\text{tld}} t_i + \beta_{\text{median}} m_i + \beta_{\text{sd}} d_i + \epsilon_i \quad (1)$$

where β_0 is an intercept term, s_i represents the server software, t_i represents the top level domain of the site; m_i and d_i represent the median and standard deviation of the site rank across the one month period, respectively; and ϵ_i is a mean zero error assumed to be logically distributed across observations.

We find that server software and TLDs (especially country-level TLDs) are highly correlated with grade, while the other covariates have minimal effect. Microsoft-IIS and cPanel in particular stand out. The odds of obtaining a high grade decrease, from 1.10 times greater for a F/C, to 0.88 lower for an A. There is some evidence that top level domain and geographical location of the site matters. Sites with Japanese and Vietnamese TLDs are more likely to obtain a low grade. The odds of obtaining an F/C is 1.05 times higher for Japan and Vietnam, and the odds of obtaining an A is 0.94 lower for Japan, and 0.95 lower for Vietnam. In contrast, sites with .io, .co, and .ua are more likely to get an A, with odds of 1.09, 1.05, and 1.04 respectively. The popularity of the site does not seem to matter. The median rank was not found to be significant, and the effect sizes for standard deviation of rank were small, even when significant. In contrast, sites hosted on LiteSpeed, BigIP, Varnish, as well as several cloud providers: Amazon CloudFront, AWS elb/2.0, and Akamai increase the odds of obtaining an A. The effects are large and significant. For example, the odds of obtaining an A (as opposed to a lower grade) is 1.77 times higher for a site hosted on Cloudfront, than for one hosted on Apache. The complete model output including significance results are given in Table 6.

5.4 Ubuntu Defaults

To better understand why so many individually configured sites receive B, C, and F grades, we investigate the default settings and online recommendation guides for the two most popular web servers, Apache and Nginx. Together, Apache and Nginx account for 70% of non-Cloudflare Tranco sites. We primarily investigate Ubuntu defaults as Ubuntu is the most commonly identifiable OS, accounting for 48% of sites that identify an OS in their server string in Tranco.⁵ To identify default Ubuntu settings, we installed the last four Ubuntu LTS releases (12.04–18.04) with all compatible combinations of packaged OpenSSL (1.0.1–1.1.1) and Nginx (1.1.19–1.14.0) or Apache (2.2.22–2.4.29) packages. In total, we analyze 2,069 combinations and extract 11 unique configurations (Table 3) consistent with our definition of a configuration.

We find that no default receives an A grade; the majority (5/11) receive a B.⁶ All Ubuntu defaults support TLS 1.0–1.2, session tickets valid for 300 seconds, AES-128, AES-256, and AES-GCM ciphers, AEAD, CBC, Camellia and ARIA ciphers, RSA key exchange, as well as SHA-1 MACs. Five defaults on older Ubuntu versions support SSL 3.0 and two on the most recent version (18.04) support TLS 1.3. Two Apache on Ubuntu configurations support RC4 and three support 3DES ciphers; no defaults support DES or IDEA ciphers, MD5 MACs, or NULL or EXPORT components. We note that default security has improved over time, with the most recent versions obtaining B-grades. Nevertheless—they still lag behind cloud providers and servers that offer secure TLS settings by default like Caddy [5] of which 99% of sites receive an A grade.

Both Nginx and Apache on Ubuntu fall short of an A because they support uncommon ciphers (e.g., CAMELLIA). Additionally, Apache configurations are capped at a B because they do not have server cipher preference. Encouragingly, the latest versions of Apache on 18.04 have TLSv1.3 support by default. Nginx on 18.04 has intermittent support for TLSv1.3. Only a small number of sites in Tranco use these exact default values—1.7% of sites. Of sites that identify as using Nginx, 1.8% support an Nginx default; of sites that identify as using Apache, 4% support an Apache default. It is unclear why operators change settings that do not improve site security. It may be a misguided attempt to improve security, or an attempt to fix unrelated problems.

The Ubuntu configurations of Nginx and Apache differ in several ways. Nginx on Ubuntu by default has server cipher preference in 16.04 onward. We note that this is a Ubuntu specific choice rather than an Nginx default [17], which has server cipher preference turned off. Other OSes such as Fedora [12] and Centos [6] do not set server cipher preference. Apache on Ubuntu does not use server preference in its defaults [3]. Additionally, Apache on Ubuntu by default supports session ID resumption [3] whereas Nginx on Ubuntu does not [17]. Starting with version 18.04, Nginx on Ubuntu also removed support for finite-field-based Diffie-Hellman key exchange.

⁵We are able to identify the OS from the server string on only 10% of sites in Tranco

⁶A server supports a TLS feature by default if: (1) the server software implements the feature, (2) the feature is enabled through compilation, and (3) the feature is turned on in the configuration file.

Server	Ubuntu ver	OpenSSL	Grade	% Tranco	TSLv1.3	TSLv1.2	TSLv1.1	TSLv1.0	SSLv3.0	SSLv2.0	Server pref	Session ID	Session Ticket	RC4	DES	3DES	Export	ARIA	Camellia	IDEA	SEED	CHACHA	AEAD	AES-GCM	DH Group	KE:DHE	KE:ECDHE	KE:RSA	MD5	SHA
Nginx	14.04	1.0.1f	C	8	○	●	●	●	○	○	○	●	○	○	○	○	○	○	●	○	○	○	●	●	1024	●	●	●	○	●
Nginx	16.04	1.0.2g	C	28	○	●	●	●	○	○	●	○	●	○	○	○	○	○	●	○	○	○	●	●	1024	●	●	●	○	●
Nginx	18.04	1.1.0g ²	B	0	○	●	●	●	○	○	●	○	●	○	○	○	○	○	●	●	●	●	●	-	○	●	●	○	●	
Nginx	18.04	1.1.0g ²	B	0	●	●	●	●	○	○	●	○	●	○	○	○	○	○	●	●	●	●	●	-	○	●	●	○	●	
Apache	12.04	1.0.1	F	2	○	●	●	●	●	○	○	●	●	●	○	●	○	○	●	○	●	●	●	●	1024	●	○	●	○	●
Apache	12.04 ¹	1.0.1 ³	C/F	24	○	●	●	●	●	○	○	●	●	●	○	●	○	○	●	○	●	●	●	●	2048	●	●	●	○	●
Apache	14.04	1.0.1f	C	1	○	●	●	●	●	○	○	●	●	●	○	○	○	○	●	○	○	○	●	●	2048	●	●	●	○	●
Apache	16.04	1.0.2g	B	78	○	●	●	●	○	○	○	●	●	●	○	○	○	○	●	○	○	○	●	●	2048	●	●	●	○	●
Apache	18.04	1.1.0g ²	B	15	○	●	●	●	○	○	○	●	●	●	○	○	○	○	●	●	●	●	●	2048	●	●	●	○	●	
Apache	18.04	1.1.0g ²	B	4	●	●	●	●	●	○	○	●	●	●	○	○	○	○	●	●	●	●	●	2048	●	●	●	○	●	

Table 3: Default configurations for Ubuntu and OpenSSL on Nginx and Apache. A circle represents support, an empty circle indicates no support. Values represent the proportion of domains supporting each default out of the subset of sites running Ubuntu and each server in Tranco and CT (n=15K Apache and n=9.6K Nginx in Tranco; n=13K Apache and n=9.4K Nginx in CT). Several defaults had multiple server types as indicated by the footnotes: [1] includes Ubuntu versions 12.04, 14.04; [2] includes OpenSSL versions 1.1.0g, 1.1.1; [3] includes OpenSSL versions 1.0.1, 1.0.1f.

5.5 Online Recommendations

With only a fraction of sites matching defaults and with defaults receiving Bs or lower, we turn our attention to HTTPS configuration guides to understand how operators try to securely configure sites. We collect a sample of likely-found recommendations by having four researchers independently compile a list of relevant search terms for Nginx and Apache, and then analyze the configuration guides from the first three pages of Google results for each search. In total, the team generated 16 unique search terms for Nginx and 9 for Apache e.g., “secure SSL configuration apache”, “secure nginx ssl settings”). In cases where websites recommended multiple configurations (e.g., for modern and legacy, or wide compatibility), we extracted all recommendations. To ensure our results are not biased towards English recommendations, we also searched for Nginx TLS recommendations in the next top three languages (after English): German, Russian, and French. These languages correspond to the countries where the highest number of non-Cloudflare sites geolocated. We performed our searches over ExpressVPN using the country-specific Google search engine for each. Another concern is that the exact recommendations on each site may have changed over time and what we observe today may not be reflective of what server operators may have seen when they were setting up web servers, potentially several years ago. For this reason, we also compiled a list of historical recommendations. Specifically, we selected a random sample of 50 unique URLs for which we inspected historical snapshots from WayBack Machine [14]—a free online service that stores snapshots of websites over time.

In total, we collected 1,162 search results, from which we extracted 466 unique recommendation sites, including 57 URLs in French, 76 URLs in German, and 58 URLs in Russian. About 40% of sites do not contain a recommendation. These sites tend to be websites related to SSL configurations but do not contain a specific, ready-to-use recommendation. For example, a large number of sites

cover topics related to installing SSL certificate or setting up an SSL proxy. Usable recommendations typically specify a handful of settings (e.g., version, ciphers, and server cipher preference), but most do not account for all configurable options. About 26% of recommendations are from commercial sites (e.g., official documentation and cloud tutorials), 63% are blogs (73% of which are personal and 27% corporate), and 12% are forum posts on sites like Stack Overflow. The highest ranked URLs tend to be official sources. The SSL Mozilla configuration generator and an official Nginx documentation page show up most frequently in search results, followed by posts from TechRepublic, DigitalOcean, CyberCiti, Apache, Linode, TechMint, and GeekFlare. The first non-official URL is “hayden-james.io”, which appears in results from 6 of the 38 search terms.

Measuring which websites follow a specific recommendation is complicated by the fact that applying recommendations to different versions of Apache, Nginx, and OpenSSL can lead to different TLS feature support. First, different versions of OpenSSL support different TLS versions, cipher suites, and extensions. Second, recommendations of SSL protocol versions and ciphers are often stated in terms of exclusions (e.g., All -SSLv2) and components (e.g., ECDHE+AESGCM). For this reason, we check *consistency* with recommendations and check for support of allowed or disallowed options and cipher components instead of the exact cipher strings. For example, given the recommendation ECDHE+AESGCM: !RC4, a configuration would be consistent with it if at least one ECDHE+AESGCM cipher suite is supported, no non-ECDHE+AESGCM cipher suite is supported, including no RC4 cipher suites. We thus offer an upper bound estimate on the number of sites that follow a recommendation. We limit our analysis to non-Cloudflare sites hosted on Apache and Nginx. We find that 4% of Apache sites and 20% of Nginx sites in Tranco are consistent with a recommendation. Of sites that identify themselves as running on Ubuntu, 18% of Apache sites are consistent with a recommendation and 7.3% of Nginx sites

are consistent. Because we know the default values of Ubuntu, we can calculate the exact options for each recommendation by applying them to the defaults from all versions of Apache, Nginx, and OpenSSL on Ubuntu 14.04–18.04. In the case of a recommendation that is missing directives, we substitute the default setting. We find almost no matches when searching for exact recommendations in our data—under 1% of both Tranco and CT sites. While many sites running Ubuntu likely do not include the OS in the Server header, the result confirms that our *consistent* metric significantly overestimates the number of sites that follow a recommendation and should only be treated as a high upper bound.

Security of online recommendations. We apply our grading scheme to the recommendations we collect to understand how they would affect server security. Interestingly, only 7.3% of unique recommendations receive a grade of A. The large majority—88%, receive either a grade of B or C, and 4.0% receive an F. We find that secure recommendations rank higher than insecure recommendations. The average rank for recommendations receiving an A is 9.8, versus 14.4 for B and 12.6 for C (differences are statistically significant using an ANOVA test with a significance level 0.05, $p < 0.001$).

In terms of individual TLS parameter support, several findings stand out. First, only a small proportion of recommendations would result in a modern, A-grade configuration with only the most up-to-date security parameters (only 22% recommend TLSv1.3, 30% recommend ChaCha ciphers). If applied to the default configuration of a server, many would not exclude insecure options. Specifically, 8% of recommendations support SSLv3, 3% support DES, 18% support 3DES, 13% support RC4, and 8% support MD5. More recommendations still allow ciphers that are not widely used (38% Camellia, 16% SEED and ARIA ciphers).

There are several options that are consistently recommended across the majority of sources. Just under a third of recommendations mention session tickets (31%). Where mentioned, few recommendations suggest that session tickets be turned on (11% of current). This is contrary to the wide support that we observe empirically—74% of non-Cloudflare domains support session tickets in Tranco. Another option where recommendations are generally unanimous is `ss1_prefer_server_ciphers`. This directive is mentioned in 75% of recommendations, 91% of which recommend that it be turned on. This is higher than the level of support we empirically observe in Tranco (63%). Historical recommendations follow a qualitatively similar patterns and are omitted for brevity. We do not find significant differences between current and historical recommendations in terms of security posture, and they do not result in a higher proportion of matches.

One possible explanation for observing such a larger number of insecure recommendations may be that they are outdated. The majority of sites display the publication date (77%), and we investigate whether the publication date has any impact on the security posture of the recommendation. Despite a long tail of publication years dating back to 2010, we find that 39% of recommendations are “current”, meaning that they were published on or after January 1, 2019. Of sites that are current, 46% are secure, versus 56% of secure sites published prior to 2019. A Chi-square test confirms that there is no statistically significant relationship between the

security posture of a recommendation (secure versus not) and publication date (current versus not), ($d.f.=1$, $p = 3.0112$, $p = 0.0827$). This result points to a worrying trend that the security posture of recommendations is not improving over time. This may be in part due to the fundamental nature of the TLS protocol, which makes it such that servers wishing to support older clients need to adopt legacy recommendations that are inevitably less secure.

These results highlight a surprising amount of variance and a high degree of inconsistency across recommendations—a pattern that has been observed in other areas of security as well [68, 69]. Moreover, they do not consistently point users to the most secure configurations. This may be in part, because server operators must also consider backwards compatibility. Nevertheless, approximately 10% of recommendations still allow MD5 MACs and RC4 ciphers, neither of which are needed to support the modern browsers (Chrome, Safari, Edge, Firefox).

6 DISCUSSION

We initially expected to find large clusters of sites using the same configurations. We hoped that we would be able to match these common configurations to online recommendation guides, Stack Overflow posts, blogs, server defaults, and administration tools like Certbot [7]. Instead, we find a complex and fragmented ecosystem of HTTPS configurations with a long tail of individually configured sites. Our attempts to cluster configurations and find commonalities were largely unsuccessful—there are simply a large number of unique, seemingly unrelated configurations deployed. In nearly all cases, when a large number of sites use the same configuration, it is due to SaaS providers deploying the same configuration on all sites. Despite the complexity of the ecosystem, there are several important high-level takeaways for the security community.

Our results highlight the importance of doing analysis at the configuration-level, as opposed to adopting a uni-dimensional view that considers support for an individual directive at a time. Adopting such a uni-dimensional view may mask patterns that only emerge at the configuration-level, such as the influence of geography, cloud providers, provider defaults, and online recommendations. We find that using a cloud provider is one of the strongest predictors for a site being configured correctly. Most individually managed servers struggle to achieve secure configurations. It is an important distinction that operators are not getting better at configuring servers, but are instead migrating to platforms where they can sidestep the process. Although we cannot quantify exactly how much SaaS providers pull up the overall security of the internet, we provide a lower bound by manually labeling configurations from the largest and most well-known SaaS providers, and show that it is significant enough in order for security researchers to distinguish it when evaluating the security posture of the overall internet. This may be relevant for a number of research directions: when the aim is to understand the decision-making process of server operators, when evaluating the adoption of new security features or technologies, as well as the overall security posture of the internet.

It is unclear why we find such little evidence of online recommendations being used in practice. It may be because very few server operators use online recommendations exactly as specified, or another component of the ecosystem that we do not observe

is contributing to the process. For example, server operators may individually remove cipher suites over time as vulnerabilities are announced, they may use online grading tools such as SSL Labs and edit their recommendations to obtain good grades, or they may use additional software that automatically configures TLS (e.g., Certbot). Our results may also add important context to endeavors to invest in tools and resources to improve online recommendations, such as a recent effort from the Internet Society (ISOC), who is actively investing in and developing recommendations for a variety of server software [15].

Lastly, our results point to the importance of secure defaults that do not require operators to seek out trustworthy sources for how to securely configure sites post-installation—a system which appears to be fundamentally broken. Echoing previous studies [36, 57], we encourage the security community to build future systems that prioritize being secure “out of the box”.

7 CONCLUSION

We find a complex and fragmented ecosystem of HTTPS configurations with a long tail of individually configured websites. While the majority of sites are securely configured, this is primarily due to cloud providers, which provide secure configurations for all hosted websites. Using a cloud provider is one of the strongest predictors for a site being configured correctly. Most individually managed servers, however, continue to struggle to achieve secure configurations. Few operators use server defaults for Nginx and Apache, and there is a lack of adherence to online recommendations, which may be in part because these are often incomplete and insecure. Our findings point to the need for future analysis of HTTPS security to take into account these two disparate ecosystems, and for the security community to invest in solutions that bridge the security gap between the two.

REFERENCES

- [1] Alexa top sites. <https://aws.amazon.com/alexa-top-sites/>.
- [2] Apache http server project. <https://httpd.apache.org/>.
- [3] Apache module mod_ssl. https://httpd.apache.org/docs/current/mod/mod_ssl.html#sslhonorcipherorder.
- [4] Applied crypto hardening. <https://bettercrypto.org/>.
- [5] Caddy - the ultimate server. <https://caddyserver.com/>.
- [6] Centos nginx rpm. https://centos.pkgs.org/7/nginx-x86_64/nginx-1.18.0-1.el7.ngx.x86_64.rpm.html.
- [7] certbot. <https://certbot.eff.org/>.
- [8] Configuring https servers. http://nginx.org/en/docs/http/configuring_https_servers.html.
- [9] Cve-2009-3555. <https://nvd.nist.gov/vuln/detail/CVE-2009-3555>.
- [10] Cve-2012-4929. <https://nvd.nist.gov/vuln/detail/CVE-2012-4929>.
- [11] Estimation of ordered generalized linear models. <https://www.rdocumentation.org/packages/oglmx/versions/3.0.0.0>.
- [12] Fedora nginx rpm. <https://src.fedoraproject.org/rpms/nginx/blob/master/f/nginx.conf>.
- [13] Geolite2. <https://dev.maxmind.com/geoip/geoip2/geolite2/>.
- [14] Internet archive wayback machine. <https://web.archive.org/>.
- [15] Introducing our open standards everywhere project – securing web servers in 2020. <https://www.internetsociety.org/blog/2020/01/introducing-our-open-standards-everywhere-project-securing-web-servers-in-2020/>.
- [16] Lighttpd. <https://www.lighttpd.net/>.
- [17] Module ngx_http_ssl_module. http://nginx.org/en/docs/http/ngx_http_ssl_module.html.
- [18] Mozilla SSL configuration generator. <https://ssl-config.mozilla.org/>.
- [19] Nginx. <https://www.nginx.com/>.
- [20] SSL/TLS strong encryption: How-to. <https://httpd.apache.org/docs/2.4/ssl/howto.html>.
- [21] Supported protocols and ciphers between viewers and cloudfront. <https://docs.aws.amazon.com/AmazonCloudFront/latest/DeveloperGuide/secure-connections-supported-viewer-protocols-ciphers.html>.
- [22] Wordpress hosting options on google cloud. <https://cloud.google.com/wordpress>.
- [23] Wpengine. <https://wpengine.com/>.
- [24] Hypertext transfer protocol – http/1.1, 1999. <https://tools.ietf.org/html/rfc2616#section-14.38>.
- [25] The transport layer security (tls) protocol version 1.2, 2008. <https://tools.ietf.org/html/rfc5246>.
- [26] Liberal go tls + x.509 library for research. Technical report, 2020. <https://github.com/zmap/zcrypto>.
- [27] Transport layer security (tls) parameters, 2020. <https://www.iana.org/assignments/tls-parameters/tls-parameters.xhtml>.
- [28] J. Aas, R. Barnes, B. Case, Z. Durumeric, P. Eckersley, A. Flores-López, J. A. Halderman, J. Hoffman-Andrews, J. Kasten, E. Rescorla, et al. Let’s Encrypt: An automated certificate authority to encrypt the entire web. In *ACM Conference on Computer and Communications Security*, 2019.
- [29] D. Adrian, K. Bhargavan, Z. Durumeric, P. Gaudry, M. Green, J. A. Halderman, N. Heninger, D. Springall, E. Thomé, L. Valenta, B. VanderSloot, E. Wustrow, S. Zanella-Béguelin, and P. Zimmermann. Imperfect forward secrecy: How diffie-hellman fails in practice. In *22nd ACM Conference on Computer and Communications Security*, 2015.
- [30] N. J. Al Fardan and K. G. Paterson. Lucky thirteen: Breaking the tls and dtls record protocols. In *2013 IEEE Symposium on Security and Privacy*, 2013.
- [31] N. AlFardan, D. J. Bernstein, K. G. Paterson, B. Poettering, and J. C. N. Schuldt. On the security of RC4 in TLS. In *22nd USENIX Security Symposium*, 2013.
- [32] B. Amann, R. Sommer, M. Vallenlin, and S. Hall. No attack necessary: The surprising dynamics of ssl trust relationships. In *29th Annual Computer Security Applications Conference*, 2013.
- [33] B. Amann, M. Vallenlin, S. Hall, and R. Sommer. Extracting certificates from live traffic: A near real-time SSL notary service. Technical report, Citeseer, 2012.
- [34] N. Aviram, S. Schinzel, J. Somorovsky, N. Heninger, M. Dankel, J. Steube, L. Valenta, D. Adrian, J. A. Halderman, V. Dukhovni, E. Kasper, S. Cohney, S. Engels, C. Paar, and Y. Shavitt. DROWN: Breaking TLS with SSLv2. In *25th USENIX Security Symposium*, Aug. 2016.
- [35] T. D. B. Moller and K. Kotowicz. This POODLE bites: exploiting the SSL 3.0 fallback. Technical report, 2014. <https://www.openssl.org/~bodo/ssl-poodle.pdf>.
- [36] M. Bernhard, J. Sharman, C. Z. Acemyan, P. Kortum, D. S. Wallach, and J. A. Halderman. On the usability of HTTPS deployment. In *CHI Conference on Human Factors in Computing Systems*, 2019.
- [37] B. Beurdouche, K. Bhargavan, A. Delignat-Lavaud, C. Fournet, M. Kohlweiss, A. Pironi, P. Strub, and J. Zinzindohoue. A messy state of the union: Taming the composite state machines of TLS. In *IEEE Symposium on Security/Privacy*, 2015.
- [38] K. Bhargavan and G. Leurent. Transcript collision attacks: Breaking authentication in tls, icas and ssh. In *NDSS*, 2016.
- [39] J. Clark and P. C. van Oorschot. Sok: Ssl and https: Revisiting past challenges and evaluating certificate trust model enhancements. In *IEEE Symposium on Security and Privacy*, 2013.
- [40] X. de Carné de Carnavalet and M. Mannan. Killed by proxy: Analyzing client-end tls interception software. 01/2016.
- [41] Z. Durumeric, D. Adrian, A. Mirian, M. Bailey, and A. Halderman. The freak attack. <https://censys.io/blog/freak>.
- [42] Z. Durumeric, D. Adrian, A. Mirian, M. Bailey, and J. A. Halderman. A search engine backed by Internet-wide scanning. In *22nd ACM Conference on Computer and Communications Security*, 2015.
- [43] Z. Durumeric, D. Adrian, A. Mirian, J. Kasten, E. Bursztein, N. Lidzborski, K. Thomas, V. Eranti, M. Bailey, and J. A. Halderman. Neither snow nor rain nor MITM...: An empirical analysis of email delivery security. In *ACM Internet Measurement Conference*, 2015.
- [44] Z. Durumeric, J. Kasten, M. Bailey, and J. A. Halderman. Analysis of the HTTPS certificate ecosystem. In *ACM Internet measurement conference*, 2013.
- [45] Z. Durumeric, F. Li, J. Kasten, J. Amann, J. Beekman, M. Payer, N. Weaver, D. Adrian, V. Paxson, M. Bailey, and J. A. Halderman. The matter of heartbleed. In *ACM Internet Measurement Conference*, 2014.
- [46] Z. Durumeric, Z. Ma, D. Springall, R. Barnes, N. Sullivan, E. Bursztein, M. Bailey, J. A. Halderman, and V. Paxson. The security impact of HTTPS interception.
- [47] Z. Durumeric, E. Wustrow, and J. A. Halderman. ZMap: Fast Internet-wide scanning and its security applications. In *22nd USENIX Security Symposium*, 2013.
- [48] S. Fahl, Y. Acar, H. Perl, and M. Smith. Why eve and mallory (also) love webmasters: a study on the root causes of SSL misconfigurations. In *9th ACM symposium on computer and communications security*, 2014.
- [49] A. P. Felt, R. Barnes, A. King, C. Palmer, C. Bentzel, and P. Tabriz. Measuring HTTPS adoption on the web. In *26th USENIX Security Symposium (USENIX Security 17)*, pages 1323–1338, Vancouver, BC, Aug. 2017. USENIX Association.
- [50] C. Garman, K. G. Paterson, and T. V. der Merwe. Attacks only get better: Password recovery attacks against RC4 in TLS. In *24th USENIX Security Symposium*, 2015.
- [51] M. Georgiev, S. Iyengar, S. Jana, R. Anubhai, D. Boneh, and V. Shmatikov. The most dangerous code in the world: Validating ssl certificates in non-browser software. In *ACM Conference on Computer and Communications Security*, 2012.

[52] R. Holz, L. Braun, N. Kammenhuber, and G. Carle. The ssl landscape: a thorough analysis of the x. 509 pki using active and passive measurements. In *ACM conference on Internet measurement*, pages 427–444, 2011.

[53] R. Holz, J. Hiller, J. Amann, A. Razaghpanah, T. Jost, N. Vallina-Rodriguez, and O. Hohlfeld. Tracking the deployment of tls 1.3 on the web: A story of experimentation and centralization. *ACM SIGCOMM Computer Communication Review*, 50(3):3–15, 2020.

[54] M. Husák, M. Cermak, T. Jirsik, and P. Celeda. Network-based https client identification using ssl/tls fingerprinting. 08 2015.

[55] IANA. Transport layer security (tls) compression method identifiers. Technical report, 2020. <https://www.iana.org/assignments/comp-meth-ids/comp-meth-ids.xhtml>.

[56] P. Kotzias, A. Razaghpanah, J. Amann, K. G. Paterson, N. Vallina-Rodriguez, and J. Caballero. Coming of age: A longitudinal study of tls deployment. In *Proceedings of the Internet Measurement Conference 2018*, IMC ’18, page 415–428, New York, NY, USA, 2018. Association for Computing Machinery.

[57] K. Krombholz, W. Mayer, M. Schmiedecker, and E. Weippl. “i have no idea what i’m doing”: On the usability of deploying HTTPS. In *26th USENIX Security*, 2017.

[58] D. Kumar, Z. Wang, M. Hyder, J. Dickinson, G. Beck, D. Adrian, J. Mason, Z. Durumeric, J. A. Halderman, and M. Bailey. Tracking certificate misissuance in the wild. In *IEEE Symposium on Security and Privacy*, 2018.

[59] J. Lee, H. Lee, J. Jeong, D. Kim, and T. T. Kwon. Analyzing spatial differences in the tls security of delegated web services. In *Proceedings of the 2021 ACM Asia Conference on Computer and Communications Security*, ASIA CCS ’21, page 475–487, New York, NY, USA, 2021. Association for Computing Machinery.

[60] W. Mayer, A. Zauner, M. Schmiedecker, and M. Huber. No need for black chambers: Testing tls in the e-mail ecosystem at large. In *2016 11th International Conference on Availability, Reliability and Security (ARES)*, pages 10–20, 2016.

[61] Mozilla. Set ssl_ecdh_curve parameter in nginx config. Technical report, 2017. <https://github.com/mozilla/server-side-tls/issues/189>.

[62] Mozilla. Set ecdh curves in nginx and apache configuration. Technical report, 2020. <https://github.com/mozilla/ssl-config-generator/issues/76>.

[63] V. L. Pochat, T. Van Goethem, S. Tajalizadehkhoob, M. Korczyński, and W. Joosen. Tranco: A research-oriented top sites ranking hardened against manipulation. *arXiv preprint arXiv:1806.01156*, 2018.

[64] Qualys. Ssl labs grading 2018. Technical report, 2018. <https://qualys-secure.force.com/discussions/s/article/000005828>.

[65] Qualys. Ssl pulse. Technical report, 2020. <https://www.ssllabs.com/ssl-pulse/>.

[66] Qualys. Ssl server rating guide. Technical report, 2020. <https://github.com/ssllabs/research/wiki/SSL-Server-Rating-Guide>.

[67] Qualys. Ssl server test. Technical report, 2020. <https://www.ssllabs.com/ssltest/>.

[68] E. M. Redmiles, N. Warford, A. Jayanti, A. Koneru, S. Kross, M. Morales, R. Stevens, and M. L. Mazurek. A comprehensive quality evaluation of security and privacy advice on the web. In *29th USENIX Security Symposium*, 2020.

[69] R. W. Reeder, I. Ion, and S. Consolvo. 152 simple steps to stay safe online: Security advice for non-tech-savvy users. *IEEE Security & Privacy*, 15(5):55–64, 2017.

[70] D. Springall, Z. Durumeric, and J. A. Halderman. Measuring the security harm of tls crypto shortcuts. In *ACM Internet Measurement Conference*, 2016.

[71] L. Valenta, S. Cohnen, A. Liao, J. Fried, S. Bodduluri, and N. Heninger. Factoring as a service. *Cryptology ePrint Archive*, Report 2015/1000, 2015. <https://eprint.iacr.org/2015/1000>.

[72] L. Valenta, N. Sullivan, A. Sanso, and N. Heninger. In search of curveswap: Measuring elliptic curve implementations in the wild. In *2018 IEEE European Symposium on Security and Privacy (EuroS&P)*, pages 384–398. IEEE, 2018.

[73] L. Valenta, N. Sullivan, A. Sanso, and N. Heninger. In search of CurveSwap: Measuring elliptic curve implementations in the wild. In *2018 IEEE European Symposium on Security and Privacy*, 2018.

[74] B. VanderSloot, J. Amann, M. Bernhard, Z. Durumeric, M. Bailey, and J. A. Halderman. Towards a complete view of the certificate ecosystem. In *ACM Internet Measurement Conference*, 2016.

AS Name	Num Sites	% AS	Grade	TSLv1.3	TSLv1.2	TSLv1.1	TSLv1.0	SSLv3.0	Server pref	Session ID	Session Ticket	RC4	DES	3DES	Export	ARIA	Camellia	IDEA	SEED	CHACHA	AEAD	AES-GCM	DH Group	KE-DHE	KE-ECDHE	KERSA	MD5	SHA
Cloudflare	93,083	70	A	●	●	●	●	○	●	●	○	○	○	○	○	○	○	○	●	●	-	○	●	○	○	●		
Cloudflare	22,123	16.6	A	●	●	●	●	○	○	○	○	○	○	○	○	○	○	○	●	●	-	○	●	●	○	●		
Cloudflare	8,771	6.6	A	●	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	●	-	○	●	●	○	●		
Cloudflare	2,276	1.7	A	○	●	●	●	○	○	○	○	○	○	○	○	○	○	○	●	●	-	○	●	●	●	●		
Cloudflare	1,588	1.2	A	●	●	●	○	○	○	●	●	○	○	○	○	○	○	○	●	●	-	○	●	○	○	●		
Amazon-02	5,441	14.2	A	○	●	●	○	○	●	○	●	○	○	○	○	○	○	○	○	●	●	-	○	●	●	○	●	
Amazon-02	4,563	11.9	A	○	●	●	●	○	●	●	○	○	○	○	○	○	○	○	○	●	●	-	○	●	●	●	●	
Amazon-02	3,074	8.0	A	○	●	●	●	○	●	○	●	○	●	●	○	●	●	○	●	●	●	-	○	●	●	●	●	
Amazon-02	1,696	4.4	A	○	●	●	●	○	●	●	○	○	○	○	○	○	○	○	●	●	●	-	○	●	●	●	○	
Amazon-02	1,100	2.9	B	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	2048	●	●	●	●	○	
Google	11,978	38.6	B	○	●	●	○	●	●	●	●	○	○	○	○	○	○	○	○	●	●	2048	●	●	●	●	○	
Google	2,461	7.9	A	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	-	○	●	●	●	●	
Google	2,028	6.5	B	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	-	○	●	●	●	●	
Google	1,790	5.8	B	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	-	○	●	●	●	●	
Google	1,742	5.6	A	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	●	-	○	●	●	●	●	
Unified Layer	15,519	57.1	B	○	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	2048	●	●	○	○	●	
Unified Layer	5,008	18.4	B	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	-	○	●	●	○	●	
Unified Layer	958	3.5	B	○	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	-	○	●	○	○	●	
Unified Layer	764	2.8	C	○	●	●	●	●	○	○	○	○	○	○	○	○	●	●	●	●	●	-	○	●	●	●	●	
Unified Layer	500	1.8	B	○	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	2048	●	●	●	○	●	
Amazon AES	3,270	14.2	A	○	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	-	○	●	●	●	○	
Amazon AES	1,522	6.6	A	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	-	○	●	●	●	●	
Amazon AES	1,494	6.5	B	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	2048	●	●	●	●	●	
Amazon AES	1,022	4.4	A	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	-	○	●	●	●	●	
Amazon AES	791	3.4	A	○	●	●	○	○	○	●	●	●	●	●	●	●	●	●	●	●	●	-	○	●	●	●	●	
OVH	2,943	13.9	B	○	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	2048	●	●	●	●	○	
OVH	2,034	9.6	B	○	●	●	○	○	○	○	○	○	○	○	○	●	●	●	●	●	●	-	○	●	●	●	●	
OVH	749	3.5	B	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	-	○	●	●	●	●	
OVH	705	3.3	B	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	2048	●	●	●	●	●	
OVH	690	3.3	B	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	2048	●	●	●	●	●	
Hetzner	1,712	9.4	B	○	●	●	○	○	○	●	●	●	●	●	●	●	●	●	●	●	●	-	○	●	●	○	●	
Hetzner	1,017	5.6	B	○	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	2048	●	●	●	●	●	
Hetzner	640	3.5	A	○	●	●	○	○	○	●	●	●	●	●	●	●	●	●	●	●	●	-	○	●	●	○	●	
Hetzner	546	3.0	B	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	2048	●	●	●	●	●	
Hetzner	539	3.0	B	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	-	○	●	●	●	●	
GoDaddy	8,101	51.7	B	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	2048	●	●	●	●	○	
GoDaddy	2,359	15.0	B	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	2048	●	●	●	●	●	
GoDaddy	968	6.2	B	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	2048	●	●	●	●	●	
GoDaddy	884	5.6	C	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	-	○	●	●	●	●	
GoDaddy	630	4.0	B	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	2048	●	●	●	●	●	
Digital Ocean	1,570	11.4	B	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	2048	●	●	●	●	●	
Digital Ocean	1,166	8.5	B	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	2048	●	●	●	●	●	
Digital Ocean	995	7.2	B	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	2048	●	●	●	●	●	
Digital Ocean	603	4.4	A	●	●	●	○	○	○	●	●	●	●	●	●	●	●	●	●	●	●	-	○	●	●	○	●	
Digital Ocean	496	3.6	A	●	●	●	○	○	○	●	●	●	●	●	●	●	●	●	●	●	●	-	○	●	●	●	●	
SingleHop	7,446	70.9	B	●	●	●	●	○	○	●	●	●	●	●	●	●	●	●	●	●	●	2048	●	●	●	●	●	
SingleHop	363	3.5	B	○	●	●	○	○	○	●	●	●	●	●	●	●	●	●	●	●	●	-	○	●	●	○	●	
SingleHop	341	3.2	A	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	-	○	●	●	●	●	
SingleHop	196	1.9	B	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	2048	●	●	●	●	●	
SingleHop	149	1.4	A	○	●	●	○	○	○	●	●	●	●	●	●	●	●	●	●	●	●	-	○	●	●	○	●	

Table 4: The five most dominant configuration from the top 10 most popular ASs in terms of the proportion of sites hosted on the AS (% AS).

TLS Configuration	Tranco Top 1 Million					Certificate Transparency Sample				
	All	Apache	Nginx	IIS	Other	All	Apache	Nginx	IIS	Other
Version Support										
TLS v13	0.28	0.04	0.15	0.01	0.23	0.12	0.02	0.11	0.01	0.21
TLS v12	0.99	0.99	0.99	0.91	0.99	0.99	1	1	0.86	1
TLS v11	0.81	0.78	0.85	0.75	0.7	0.75	0.74	0.87	0.78	0.69
TLS v10	0.68	0.64	0.64	0.76	0.53	0.68	0.67	0.71	0.88	0.62
SSL v30	0.04	0.01	0.03	0.21	0.02	0.02	0.01	0.01	0.29	0.01
SSL v20	0.01	0	0	0.06	0	0	0	0	0.11	0
HTTP/2	0.57	0.26	0.66	0.23	0.63	0.56	0.42	0.75	0.24	0.64
Compression										
TLS compression	0	0	0	0	0	0	0	0	0	0
HTTPS compression gzip	0.42	0.38	0.48	0.29	0.36	0.5	0.47	0.51	0.36	0.57
HTTP2 compression gzip	0.28	0.14	0.32	0.06	0.27	0.3	0.23	0.38	0.08	0.37
Extensions										
server name	0.61	0.89	0.86	0.45	0.52	0.75	0.97	0.88	0.47	0.44
status request	0.41	0.30	0.19	0.45	0.36	0.42	0.42	0.13	0.4	0.53
signed certificate timestamp	0	0	0	0	0	0	0	0	0	0
heartbeat	0.45	0.84	0.6	0.03	0.24	0.65	0.93	0.57	0.03	0.38
extended master secret	0.45	0.09	0.32	0.84	0.51	0.28	0.05	0.39	0.85	0.47
session ticket	0.83	0.89	0.87	0.06	0.73	0.88	0.94	0.83	0.06	0.87
renegotiation info	0.99	0.99	1	0.99	0.99	0.99	0.99	1	0.99	0.99
server preference support	0.63	0.59	0.91	0.99	0.9	0.67	0.54	0.93	0.98	0.77
session id resumption	0.82	0.91	0.68	0.86	0.64	0.83	0.95	0.73	0.9	0.69
alpn	0.77	0.07	0.81	0.26	0.78	0.88	0.89	0.9	0.27	0.88
Ciphers										
RC4	0.08	0.14	0.01	0.41	0.06	0.08	0.08	0.01	0.57	0.09
DES	0	0.01	0	0.01	0	0	0	0	0.01	0
3DES	0.30	0.43	0.24	0.67	0.35	0.32	0.31	0.26	0.78	0.37
EXPORT	0	0	0	0	0	0	0	0	0	0
SEED	0.07	0.15	0.03	0.01	0.05	0.07	0.1	0.02	0.01	0.07
CAMELLIA	0.29	0.43	0.46	0.04	0.25	0.27	0.26	0.41	0.03	0.24
ARIA	0.05	0.02	0.15	0	0.01	0.05	0.01	0.24	0	0.01
IDEA	0.04	0.11	0.01	0	0.04	0.06	0.08	0.01	0.01	0.06
AES	1	1	1	1	1	1	1	1	1	1
MD5	0.07	0.11	0.01	0.4	0.06	0.07	0.07	0.01	0.56	0.06
SHA1	0.94	0.86	0.96	0.99	0.96	0.87	0.79	0.96	0.99	0.87
SHA2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Curves										
sect283k1/r1/s	0.25	0.51	0.26	0.02	0.16	0.53	0.8	0.29	0.01	0.33
sect409k1/r1/s	0.25	0.51	0.26	0.02	0.16	0.53	0.8	0.29	0.01	0.33
sect571k1/r1/s	0.25	0.51	0.26	0.02	0.16	0.53	0.8	0.29	0.01	0.33
quad secp224r1/s	0.21	0.01	0.01	0.02	0.03	0.03	0	0	0.01	0.01
secp256k1	0.31	0.59	0.38	0.03	0.19	0.56	0.82	0.39	0.02	0.34
secp256r1	0.96	0.97	0.9	0.97	0.98	0.97	0.99	0.91	0.98	0.98
secp256s	0.31	0.59	0.38	0.03	0.19	0.56	0.82	0.39	0.02	0.34
secp384r1	0.80	0.71	0.75	0.93	0.8	0.86	0.87	0.82	0.9	0.86
secp521r1	0.66	0.68	0.63	0.26	0.43	0.73	0.86	0.71	0.17	0.54
brainpool 256r1, 384r1, 512r1	0.25	0.51	0.26	0.02	0.16	0.53	0.8	0.3	0.01	0.33
x25519	0.39	0.08	0.28	0.21	0.47	0.27	0.04	0.35	0.21	0.52
x448	0.08	0.05	0.16	0.01	0.12	0.08	0.03	0.27	0	0.06
Key Exchange										
RSA	0.68	0.71	0.78	0.95	0.81	0.56	0.48	0.65	0.96	0.64
DHE	0.44	0.71	0.54	0.49	0.31	0.55	0.7	0.58	0.54	0.35
ECDHE	0.99	0.97	0.99	0.98	0.99	0.99	0.99	1	0.98	1
Common DH group	0.32	0.66	0.23	0.46	0.18	0.46	0.68	0.25	0.51	0.29
DH group size 0-1024	0	0	0	0	0	0	0	0	0	0
DH group size 1024-2048	0.05	0.03	0.07	0.3	0.05	0.02	0.01	0.03	0.36	0.01
DH group size 2048+	0.39	0.67	0.47	0.2	0.27	0.53	0.69	0.54	0.17	0.34

Table 5: Support for select TLS configuration components by server. Each value represents the proportion of domains in each server within Tranco and CT, respectively.

	F/C			B			A					
	Marg. Odds	t value	Pr(> t)	Marg. Odds	t value	Pr(> t)	Marg. Odds	t value	Pr(> t)			
servernginx	0.94	-46.67	< 0.00	***	0.99	-35.67	< 0.00	***	1.07	45.74	< 0.00	***
serverother	0.87	-95.46	< 0.00	***	0.96	-57.49	< 0.00	***	1.2	86.55	< 0.00	***
servermicrosoft-iis	1.1	37.19	< 0.00	***	1.01	21.86	< 0.00	***	0.9	-40.93	< 0.00	***
serverlitespeed	0.73	-261.56	< 0.00	***	0.81	-243.73	< 0.00	***	1.71	295.08	< 0.00	***
serveropenresty	0.88	-41.38	< 0.00	***	0.95	-25.16	< 0.00	***	1.19	35.7	< 0.00	***
serverpanel	1.1	19.45	< 0.00	***	1	12.84	< 0.00	***	0.9	-21.56	< 0.00	***
serverbigip	0.87	-39.52	< 0.00	***	0.95	-23.92	< 0.00	***	1.2	33.94	< 0.00	***
servercloudfront	0.72	-491.91	< 0.00	***	0.79	-910.96	< 0.00	***	1.77	688.48	< 0.00	***
servervarnish	0.83	-50.58	< 0.00	***	0.92	-27.87	< 0.00	***	1.32	40.46	< 0.00	***
serverrats	0.92	-15.67	< 0.00	***	0.98	-10.66	< 0.00	***	1.11	14.24	< 0.00	***
serverawselb/2.0	0.73	-236.95	< 0.00	***	0.79	-194.89	< 0.00	***	1.72	239.89	< 0.00	***
serversquarespace	0.98	-3.32	0.0009	***	1	-2.86	0.0043	**	1.03	3.24	0.0012	**
serverakamai	0.75	-131.25	< 0.00	***	0.81	-69.02	< 0.00	***	1.64	98.22	< 0.00	***
serverghs	0.97	-3.2	0.0014	**	0.99	-2.7	0.0069	**	1.03	3.11	0.0019	**
median rankQ2	1	1.16	0.2479	1	1.17	0.2437	1	-1.16	0.2473			
median rankQ3	1	0.73	0.4666	1	0.75	0.4547	1	-0.73	0.465			
median rankQ4	1	0.78	0.4373	1	0.78	0.4345	1	-0.78	0.4369			
median rankQ5	1	0.04	0.9715	1	0.04	0.9715	1	-0.04	0.9715			
sd rankQ2	1.01	4.36	< 0.00	***	1	4.49	< 0.00	***	0.99	-4.38	0	***
sd rankQ3	1.01	3.5	0.0005	***	1	3.64	0.0003	***	0.99	-3.52	0.0004	***
sd rankQ4	1	1.71	0.0881	1	1.76	0.0789	1	-1.71	0.0868			
sd rankQ5	1	1.45	0.147	1	1.47	0.1424	1	-1.45	0.1464			
tld org	0.99	-4.98	< 0.00	***	1	-4.65	< 0.00	***	1.01	4.93	0	***
tld net	1.01	4.12	< 0.00	***	1	4.55	< 0.00	***	0.99	-4.18	0	***
tld ru	1	-0.38	0.7008	1	-0.38	0.7033	1	0.38	0.7011			
tld de	0.98	-6.01	< 0.00	***	1	-5.23	< 0.00	***	1.03	5.87	0	***
tld uk	0.99	-3.11	0.0019	**	1	-2.84	0.0045	**	1.02	3.07	0.0022	**
tld jp	1.05	9.74	< 0.00	***	1.01	20.13	< 0.00	***	0.94	-10.29	< 0.00	***
tld br	1.01	1.94	0.0522	0	1	2.12	0.0341	*	0.99	-1.96	0.0497	*
tld in	1.01	2.3	0.0217	*	1	2.57	0.0102	*	0.99	-2.33	0.0199	*
tld ae	1.02	2.63	0.0087	**	1	3.02	0.0025	**	0.98	-2.67	0.0076	**
tld nl	0.97	-5.81	< 0.00	***	0.99	-4.79	< 0.00	***	1.04	5.61	< 0.00	***
tld fr	1.01	1.98	0.0481	*	1	2.19	0.0282	*	0.99	-2	0.0453	*
tld au	0.97	-4.24	< 0.00	***	0.99	-3.58	0.0004	***	1.03	4.11	< 0.00	***
tld pl	1	-0.26	0.7936	1	-0.26	0.7962	1	0.26	0.794			
tld ir	1.03	3.82	0.0001	***	1	5.2	< 0.00	***	0.97	-3.94	< 0.00	***
tld it	1.03	4.74	< 0.00	***	1	6.77	< 0.00	***	0.97	-4.9	< 0.00	***
tld info	1	-0.47	0.6362	1	-0.46	0.6447	1	0.47	0.6374			
tld ca	0.99	-1	0.318	1	-0.95	0.3432	1.01	0.99	0.3217			
tld co	0.97	-4.26	< 0.00	***	0.99	-3.53	0.0004	***	1.04	4.12	0	***
tld ua	0.96	-5.37	< 0.00	***	0.99	-4.26	< 0.00	***	1.05	5.14	< 0.00	***
tld edu	1.01	0.73	0.4635	1	0.77	0.4411	0.99	-0.74	0.4606			
tld io	0.94	-8.82	< 0.00	***	0.98	-6.31	< 0.00	***	1.09	8.16	< 0.00	***
tld es	1.02	2.51	0.012	*	1	3.11	0.0019	**	0.98	-2.57	0.0101	*
tld vn	1.05	4.95	< 0.00	***	1	10.82	< 0.00	***	0.95	-5.22	< 0.00	***
tld cz	1.01	1.44	0.151	1	1.61	0.1076	0.99	-1.46	0.1454			
tld other	1.01	4.63	< 0.00	***	1	4.85	< 0.00	***	0.99	-4.66	< 0.00	***

Table 6: Generalized ordinal model results in terms of marginal odds for each grade category (F/C, B, and A). Signif. codes: 0 *** 0.001, ** 0.01, * 0.05, . 0.1

A SEARCH TERMS FOR RECOMMENDATIONS

The search terms used to search for recommendations (n=26 English terms) are as follows: secure ssl configuration nginx*, secure ssl configuration apache, nginx set up tls, apache set up tls, secure apache ssl settings, secure nginx ssl settings*, best nginx ssl config, best apache ssl config, ssllabs a plus apache, ssllabs a plus nginx, configure SSL nginx*, nginx https, nginx https configuration, nginx conf file ssl settings*, nginx secure configuration, nginx secure ssl configuration, nginx A ssl labs, nginx secure ciphers, disable weak ciphers nginx, nginx ssl configuration, nginx configure tls, apache config tls, apache set up https, setup apache secure tls configuration, harden tls configuration apache web server. Four of the search terms were translated into French, German, and Russian, for a total of 38 search terms (asterisked terms were translated).