SECOND EDITION

The DevOps Handbook

HOW TO CREATE WORLD-CLASS AGILITY, RELIABILITY, & SECURITY IN TECHNOLOGY ORGANIZATIONS

GENE KIM, JEZ HUMBLE, PATRICK DEBOIS, & JOHN WILLIS

FEATURING NEW FOREWORD AND UPDATED MATERIALS FROM NICOLE FORSGREN, PhD

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Table 0.1: The Ever-Accelerating Trend toward Faster, Cheaper, Lower Risk Delivery of Software

	1970s–1980s	1990s	2000s–Present
Era	Mainframes	Client/Server	Commoditization and Cloud
Representative technology of era	COBOL, DB2 on MVS, etc.	C++, Oracle, Solaris, etc.	Java, MySQL, Red Hat, Ruby on Rails, PHP, etc.
Cycle time	1–5 years	3–12 months	2–12 weeks
Cost	$1M–$100M	$100k–$10M	$10k–$1M
At risk	The whole company	A product line or division	A product feature
Cost of failure	Bankruptcy, sell the company, massive layoffs	Revenue miss, CIO's job	Negligible

Source: Adrian Cockcroft, "Velocity and Volume (or Speed Wins)," presentation at FlowCon, San Francisco, CA, November 2013.

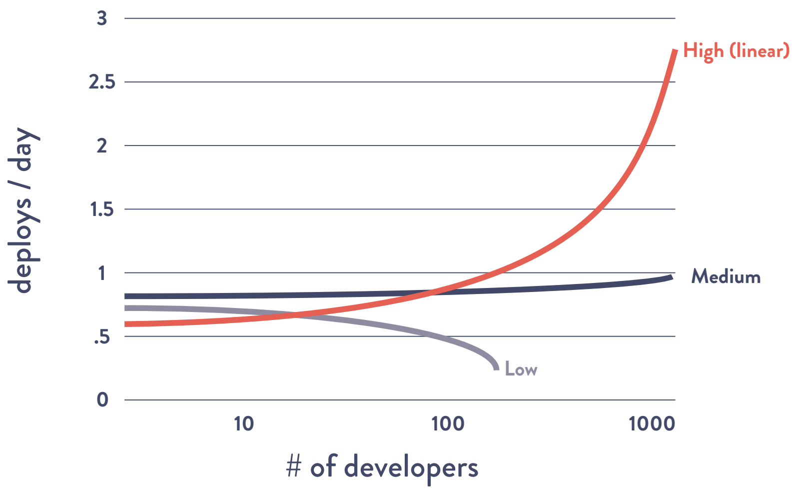


Figure 0.1: Deployments per Day vs. Number of Developers

Only organizations that are deploying at least once per day are shown.
Source: Puppet Labs, *2015 State Of DevOps Report*.

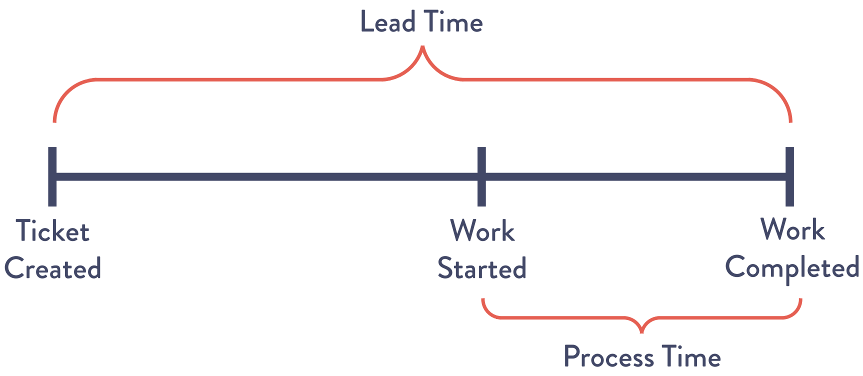


Figure 1.1: Lead Time vs. Process Time of a Deployment Operation

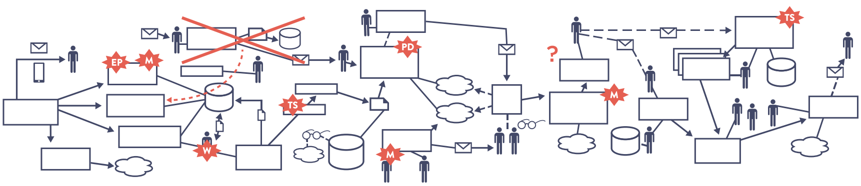
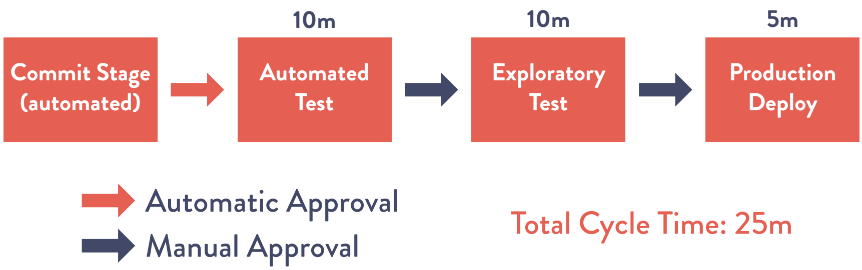


Figure 1.2: A Technology Value Stream with a Deployment Lead Time of Three Months
Source: Damon Edwards, "DevOps Kaizen," 2015.



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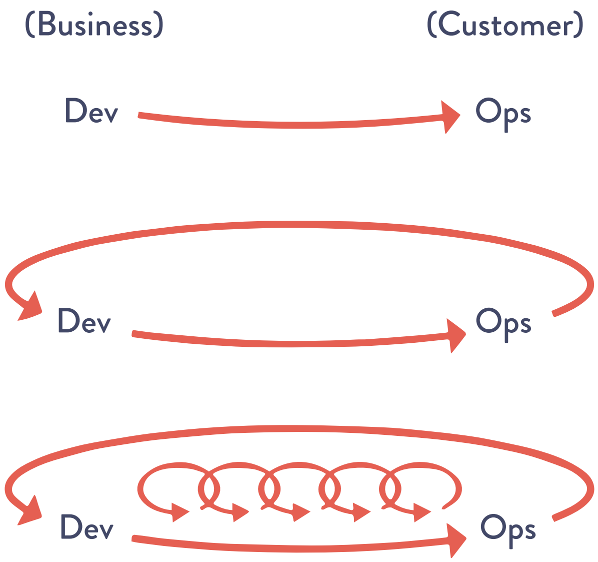
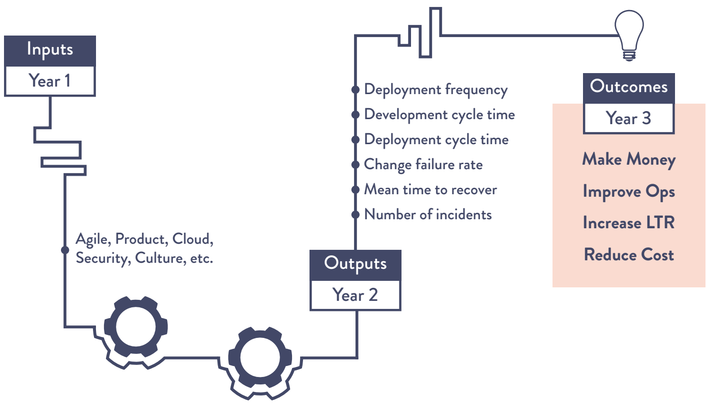


Figure 1.4: The Three Ways
Source: Gene Kim, "The Three Ways: The Principles Underpinning DevOps," ITRevolution.com (blog), August 22, 2012, http://itrevolution.com/the-three-ways-principles-underpinning-devops/.



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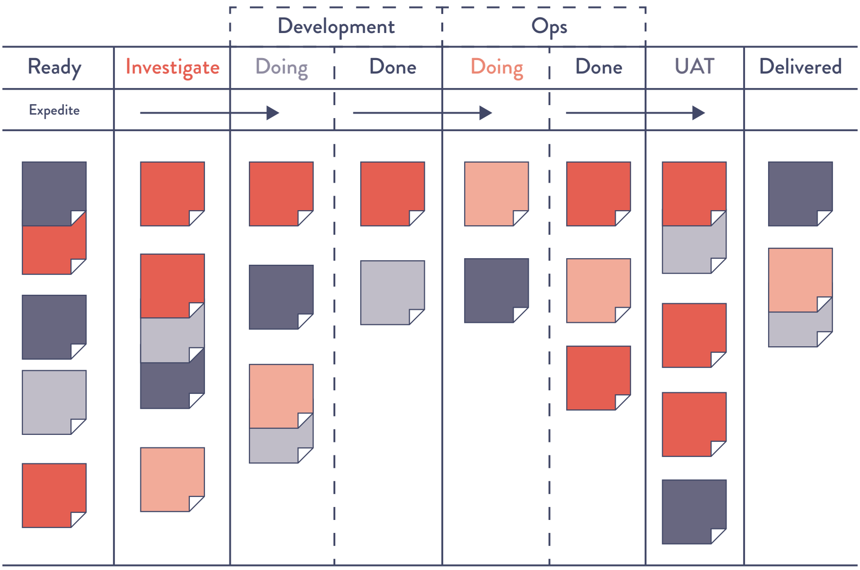
Source: With permission of Ross Clanton



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Source: David J. Andersen and Dominica DeGrandis, *Kanban for IT Ops*, training materials for workshop, 2012.

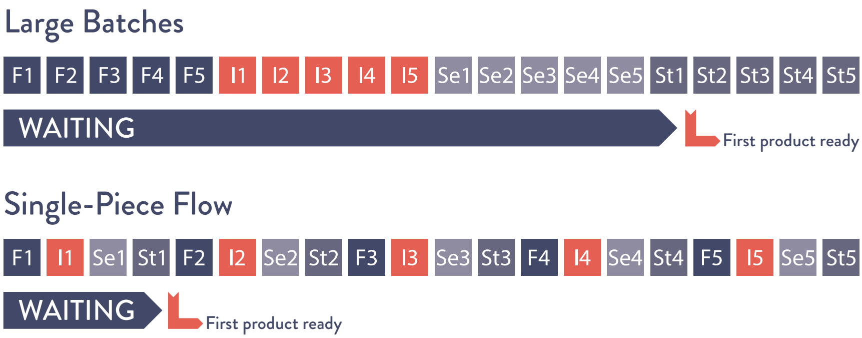


Figure 2.2: Simulation of "Envelope Game"

(Fold, insert, seal, and stamp the envelope.)
Source: Stefan Luyten, "Single Piece Flow," Medium.com, August 8, 2014, https://medium.com/@stefanluyten/single-piece-flow-5d2c2bec845b.

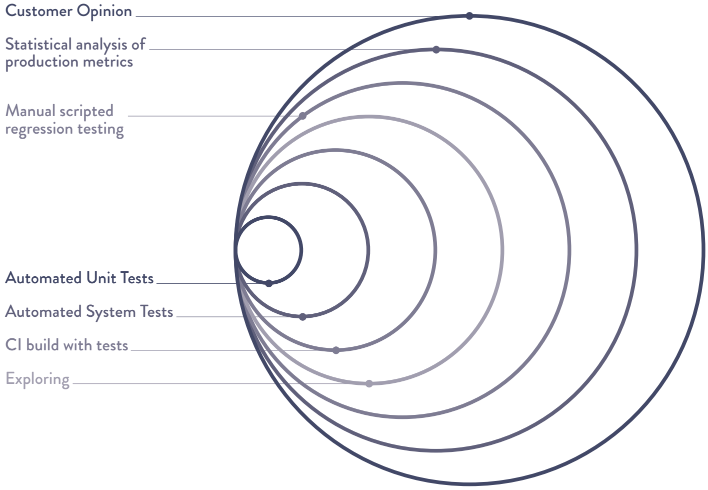
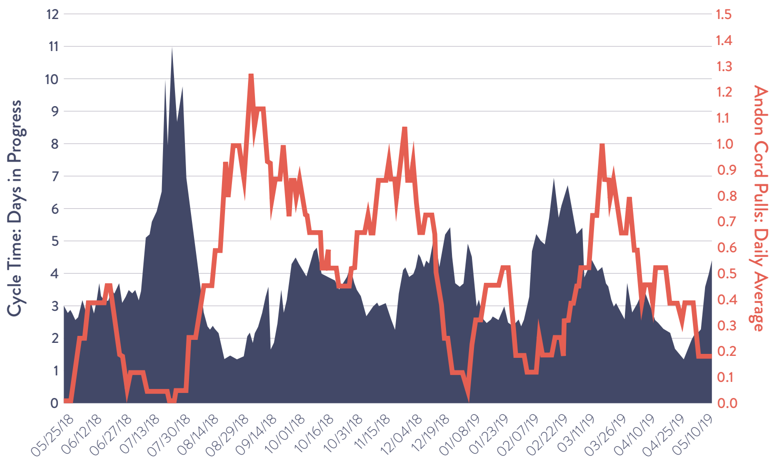


Figure 3.1: Feedback Cycle Times

Source: Hendrickson, Elisabeth. "DOES15—Elisabeth Hendrickson—Its All About Feedback." Posted by DevOps Enterprise Summit, November 5, 2015. YouTube video, 34:47. https://www.youtube.com/watch?v=r2BFTXBundQ.



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Source: Zach Ayers and Joshua Cohen. "Andon Cords in Development Teams—Driving Continuous Learning," presentation at the DevOps Enterprise Summit Las Vegas, 2019. https://videolibrary.doesvirtual.com/?video=504281981.

Table 4.1: The Westrum Organizational Typology Model

How organizations process information.

Pathological Organization	Bureaucratic Organization	Generative Organization
Information is hidden	Information may be ignored	Information is actively sought
Messengers are “shot”	Messengers are tolerated	Messengers are trained
Responsibilities are shirked	Responsibilities are compartmented	Responsibilities are shared
Bridging between teams is discouraged	Bridging between teams allowed but discouraged	Bridging between teams is rewarded
Failure is covered up	Organization is just; merciful	Failure causes injury
New ideas are crushed	New ideas create problems	New ideas are welcomed

Source: Ron Westrum, “A typology of organisation culture,” *BMJ Quality & Safety* 13, no. 2 (2004), doi:10.1136/qshc.2003.009522.

he *innovators* and *early adopters* (see Figure 5.1).[30]

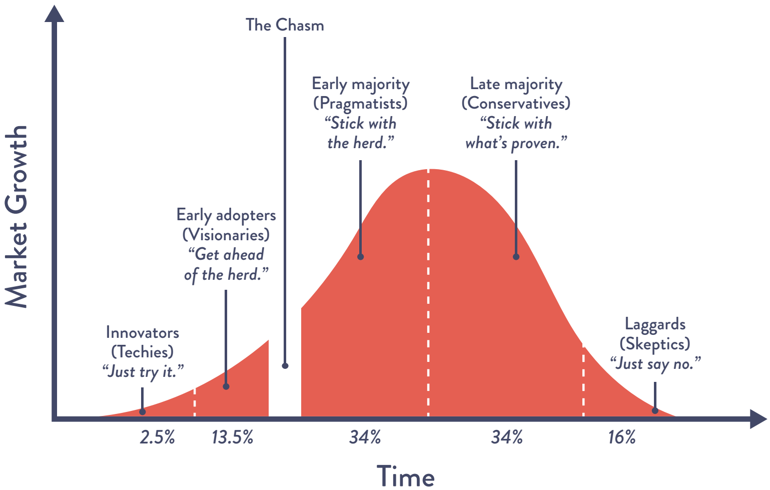


Figure 5.1: The Technology Adoption Curve
Source: Moore and McKenna, *Crossing the Chasm*, 15.

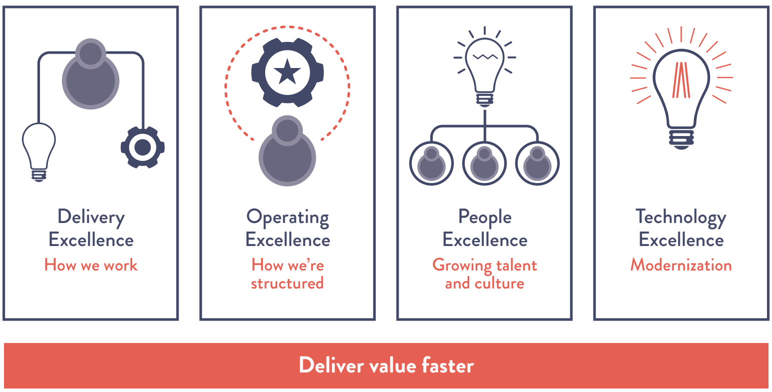


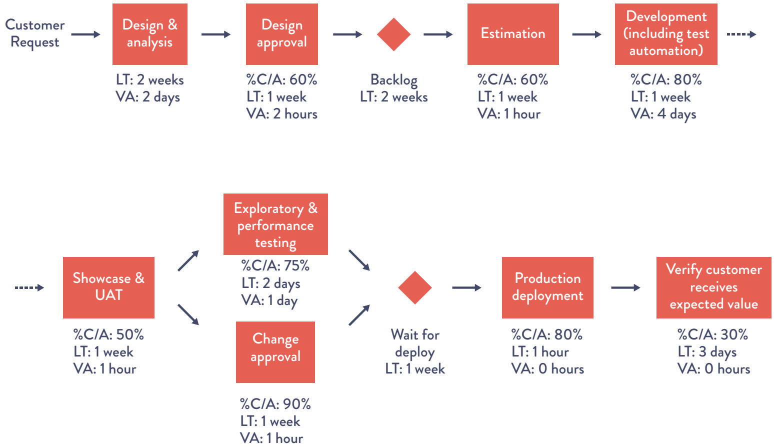
Figure 5.2: American Airlines' Delivery Transformation

Source: Maya Leibman and Ross Clanton, "DevOps: Approaching Cruising Altitude," presentation at DevOps Enterprise Summit-Virtual Las Vegas 2020, videolibrary.doesvirtual.com/?video=467488959.

Table 5.1: American Airlines' New Vocabulary

Before	After
I want to create a pop-up to incentivize people to download the mobile app.	Fragile applications are prone to failure.
What did our competitors do?	What do our customers value?
When will this project be done?	When do we start seeing value?
What went wrong?	What did we learn and how can I help?
I want a completely new website.	What's the first thing we can try to experiment with this idea?

Source: Maya Leibman and Ross Clanton, "DevOps: Approaching Cruising Altitude," presentation at DevOps Enterprise Summit-Virtual Las Vegas 2020, ideolibrary.doesvirtual.com/?video=467488959.



Aggregate values:
Total lead time: 10 weeks
Value added time: 7.5 days
Percent complete and accurate: 8.6%

Figure 6.1: An Example of a Value Stream Map
Source: Humble, Molesky, and O'Reilly, *Lean Enterprise*, 139.

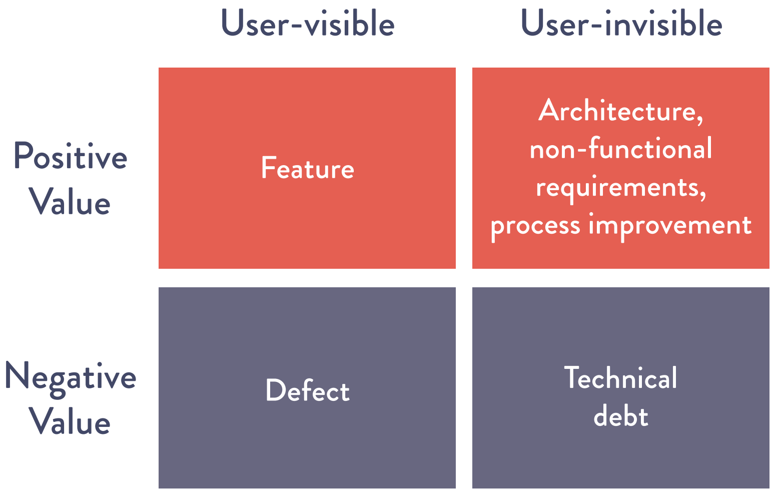


Figure 6.2: Invest 20% of Capacity in those Who Create Positive, User-Invisible Value

Source: "Machine Learning and Technical Debt with D. Sculley," Software Engineering Daily podcast, November 17, 2015, http://softwareengineeringdaily.com/2015/11/17/machine-learning-and-technical-debt-with-d-sculley/.

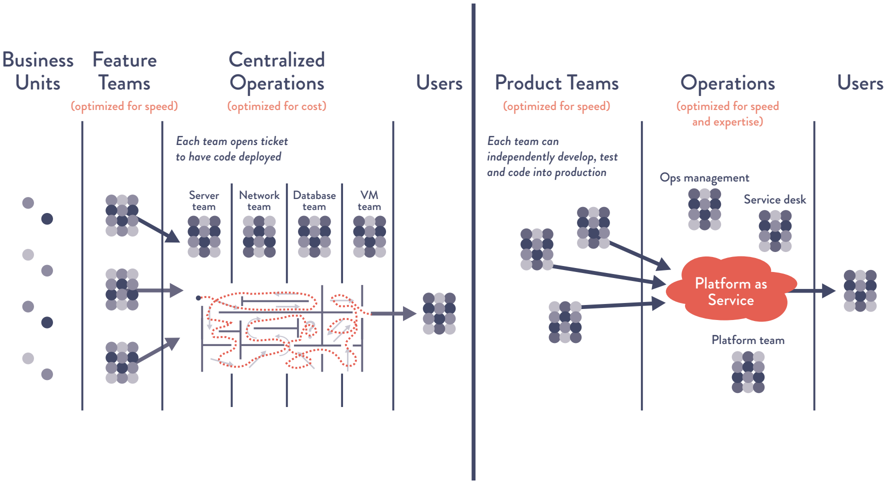


Figure 7.1: Functional vs. Market Orientation
Left: Functional orientation: all work flows through centralized IT Operations.
Right: Market orientation: all product teams can deploy their loosely coupled components self-service into production.
Source: Humble, Molesky, and O'Reilly, *Lean Enterprise*, Kindle edition, 4523 & 4592.

Table 7.1: Specialists vs. Generalists vs. "E-Shaped" Staff (experience, expertise, exploration, and execution)

"I-shaped" (Specialists)	**"T-shaped" (Generalists)**	**"E-shaped"**
Deep expertise in one area	Deep expertise in one area	Deep expertise in a few areas
Very few skills or experience in other areas	Broad skills across many areas	Experience across many areas Proven execution skills Always innovating
Creates bottlenecks quickly	Can step up to remove bottlenecks	Almost limitless potential
Insensitive to downstream waste and impact	Sensitive to downstream waste and impact	—
Prevents planning flexibility or absorption of variability	Helps make planning flexible and absorbs variability	—

Source: Scott Prugh, "Continuous Delivery," ScaledAgileFramework.com, February 14, 2013, http://scaledagileframework.com/continuous-delivery/.

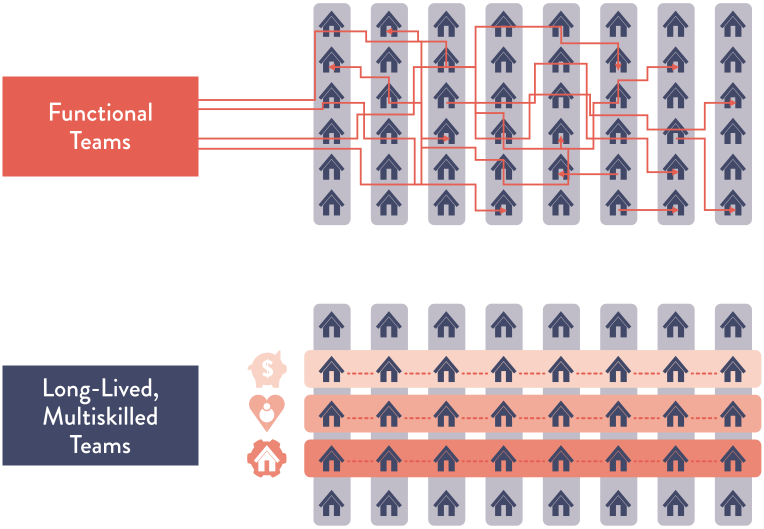


Figure 8.1: Functional Teams in Silos vs. Long-Lived, Multiskilled Teams

Source: Chapman, Janet, and Patrick Eltridge. "On A Mission: Nationwide Building Society," presentation at DevOps Enterprise Summit-Virtual London 2020. https://videolibrary.doesvirtual.com/?video=432109857.

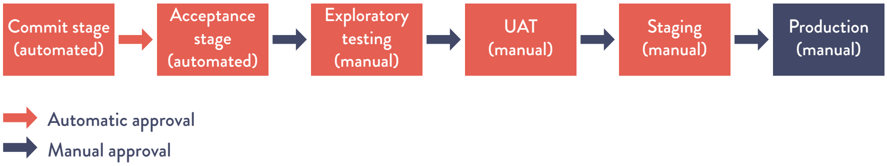


Figure 10.1: The Deployment Pipeline
Source: Humble and Farley, *Continuous Delivery*, 3.

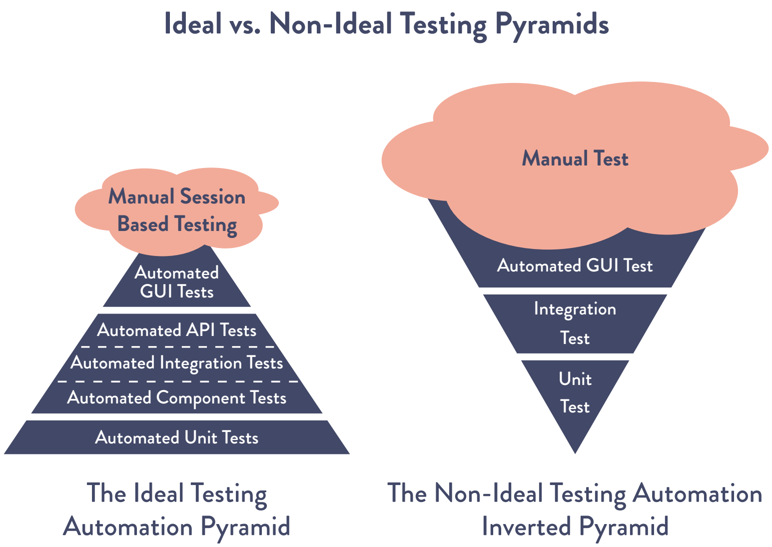


Figure 10.2: The Ideal and Non-Ideal Automated Testing Pyramids
Source: Martin Fowler, "TestPyramid," MartinFowler.com.

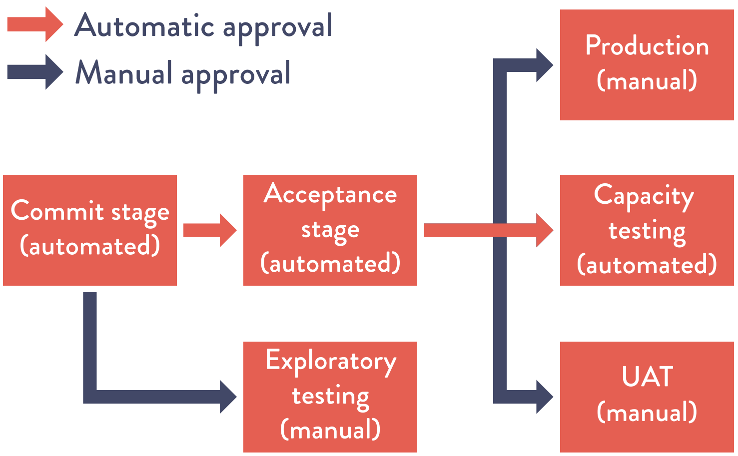


Figure 10.3: Running Automated and Manual Tests in Parallel

Source: Humble and Farley, *Continuous Delivery*, Kindle edition, location 3868.

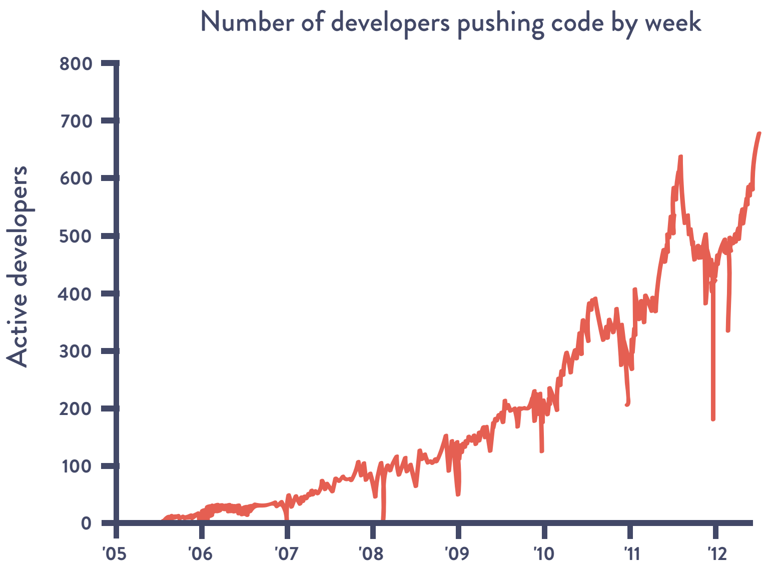


Figure 12.1: Number of Developers Deploying per Week at Facebook

Source: Chuck Rossi, "Ship early and ship twice as often."

Release Impact Improvements
Incidents by Release

Release	Incidents	Impact	Improvement
2013-Apr	201	455	0% (1x)
2014-Apr	67	153	66% (3x)
2015-May	41	97	79% (5x)
2015-Aug	18	45	90% (10x)

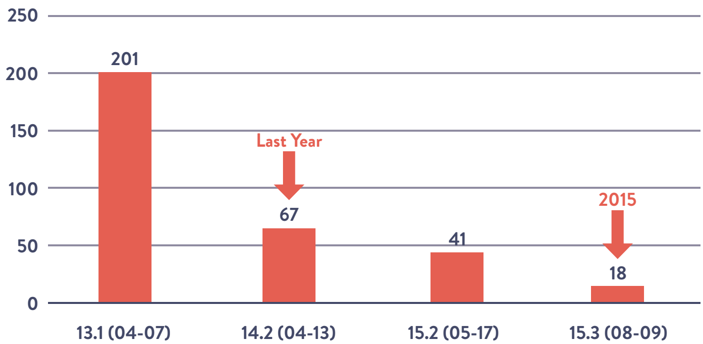


Figure 12.2: Daily Deployments at CSG International
Daily deployments and increasing release frequency resulted in a decrease in the number of production incidents and MTTR.

Source: "DOES15 - Scott Prugh & Erica Morrison—Conway & Taylor Meet the Strangler (v2.0)," YouTube video, 29:39, posted by DevOps Enterprise Summit, November 5, 2015, https://www.youtube.com/watch?v=tKdIHCL0DUg.

Deploy Frequency
1 = Fewer than once per six months
2 = Between once per month and once every six months
3 = Between once per week and once per month
4 = Between once per day and once per week
5 = Between once per hour and once per day
6 = On demand (multiple deploys per day)

Lead Time for Changes
1 = More than six months
2 = Between one month and six months
3 = Between one week and one month
4 = Between one day and one week
5 = Less than one day
6 = Less than one hour

Time to Restore Service
1 = More than six months
2 = Between one month and six months
3 = Between one week and one month
4 = Between one day and one week
5 = Less than one day
6 = Less than one hour

Change Fail Rate
1 = 76%–100%
2 = 61%–75%
3 = 46%–60%
4 = 31%–45%
5 = 16%–30%
6 = 0%–15%

Figure 12.3: Elite and High Performers Achieve Faster Deployment Lead Times and MTTR (2019)[1]
Source: Forsgren, et. al., *Accelerate: State of DevOps Report*, 2019.

1 We have replaced this figure with an updated metric for the second edition. This new figure more accurately portrays experiences over the last five years.

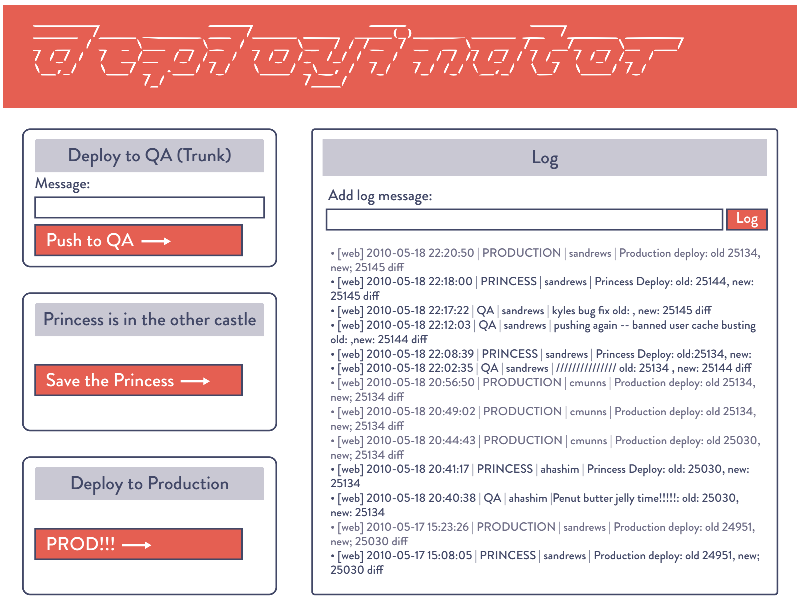


Figure 12.4: The Deployinator Console at Etsy

Source: Erik Kastner, "Quantum of Deployment," CodeasCraft.com, May 20, 2010, https://codeascraft.com/2010/05/20/quantum-of-deployment/.

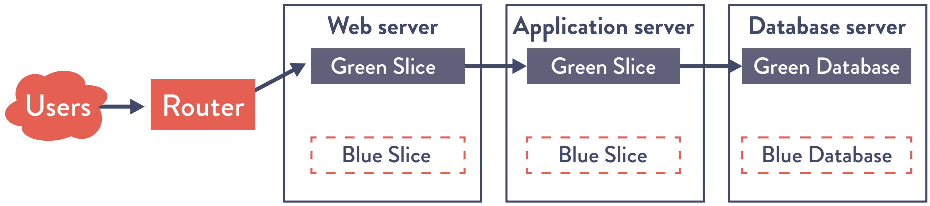


Figure 12.5: Blue-Green Deployment Patterns
Source: Humble and North, *Continuous Delivery*, 261.

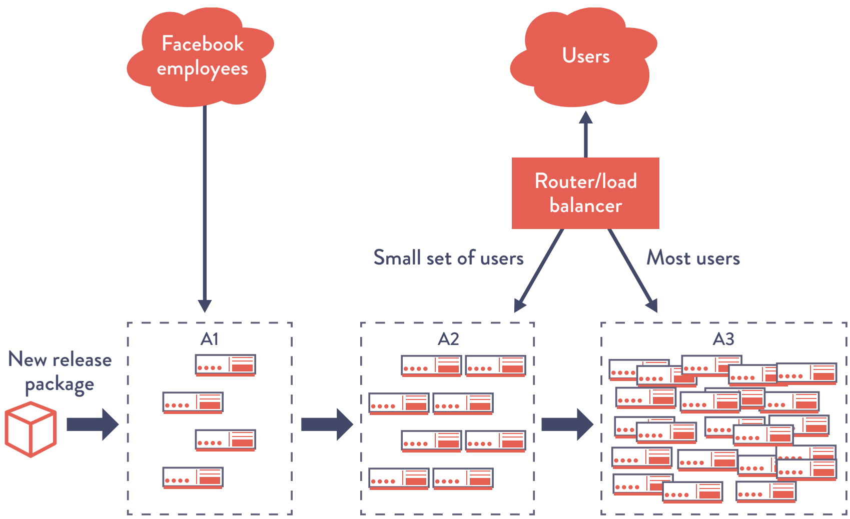


Figure 12.6: The Canary Release Pattern
Source: Humble and Farley, *Continuous Delivery*, 263.

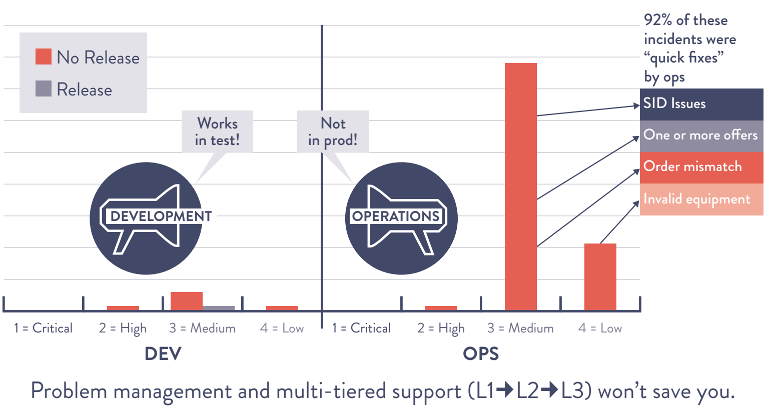


Figure 12.7: How Structure Influences Behavior and Quality
Image courtesy of Scott Prugh.

- encourage duct-tape engineering?

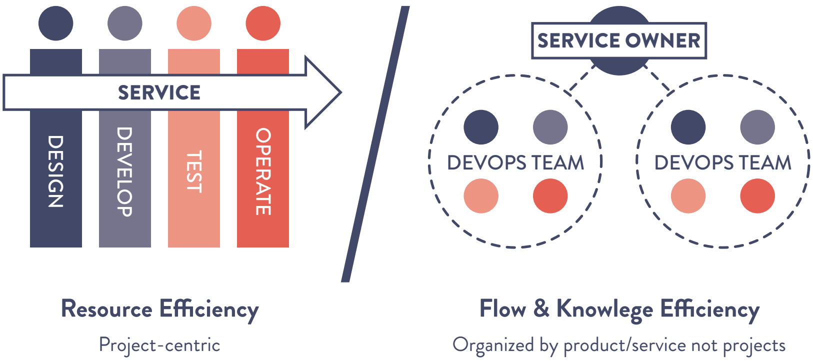


Figure 12.8: From Siloed Approach to Cross-Functional Teams
Image courtesy of Scott Prugh.

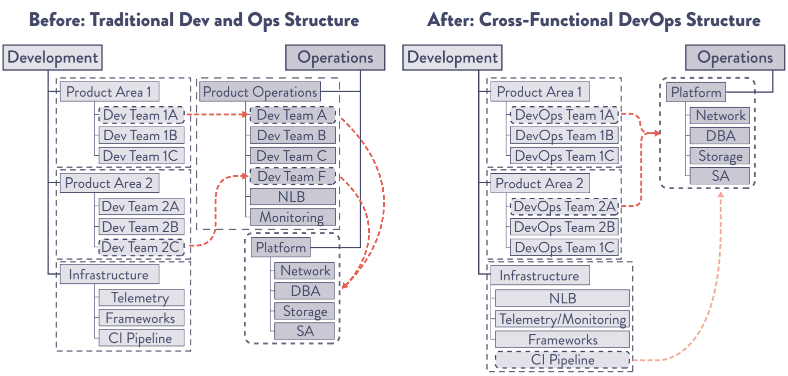


Figure 12.9: Conventional vs. Cross-Functional Structure
Image courtesy of Scott Prugh.

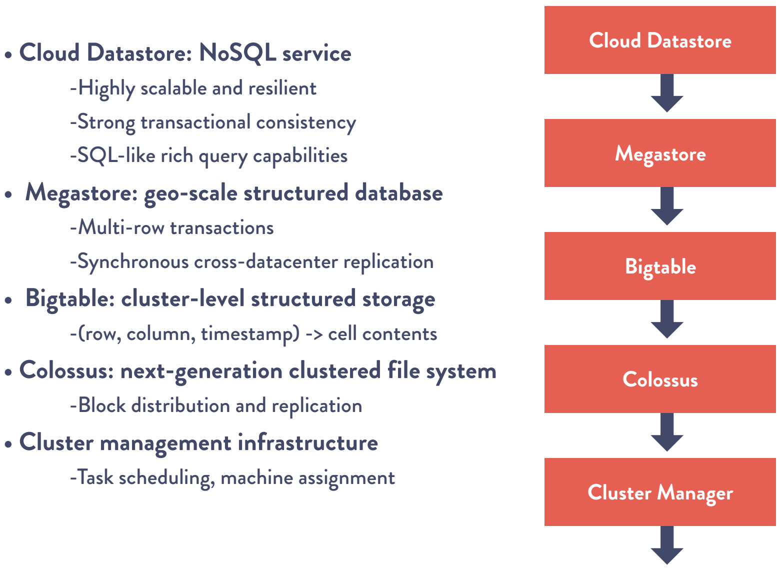


Figure 13.1: Google Cloud Datastore
Source: Shoup, "From the Monolith to Micro-services."

Table 13.1: Architectural Archetypes

	Pros	Cons
Monolithic v1 (all functionality in one application)	• Simple at first • Low interprocess latencies • Single code base; one deployment unit • Resource efficient at small scales	• Coordination overhead increases as team grows • Poor enforcement of modularity • Poor scaling • All-or-nothing deploy (downtime, failures) • Long build times
Monolithic v2 (sets of monolithic tiers: "front end presentation," "application server," "database layer")	• Simple at first • Join queries are easy • Single schema, deployment • Resource efficient at small scales	• Tendency for increased coupling over time • Poor scaling and redundancy (all-or-nothing, vertical only) • Difficult to tune properly • All-or-nothing schema management
Microservice (modular, independent, graph relationship vs. tiers, isolated persistence)	• Each unit is simple • Independent scaling and performance • Independent testing and deployment • Can optimally tune performance (caching, replication, etc.)	• Many cooperating units • Many small repos • Requires more sophisticated tooling and dependency management • Network latencies

Source: Shoup, "From the Monolith to Micro-services."

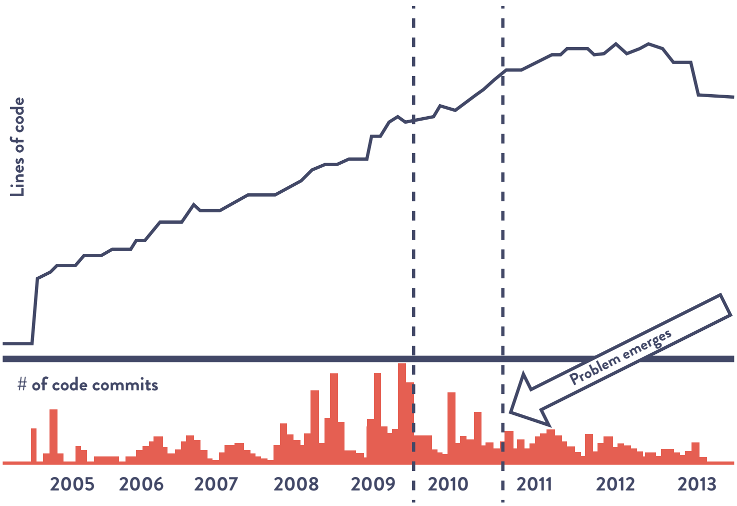
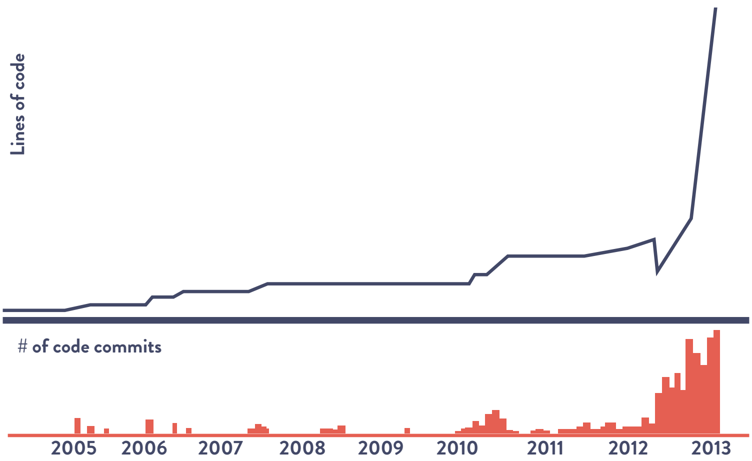


Figure 13.2: Blackboard Learn Code Repository: Before Building Blocks

Source: “DOES14—David Ashman—Blackboard Learn—Keep Your Head in the Clouds,” YouTube video, 30:43, posted by DevOps Enterprise Summit 2014, October 28, 2014, https://www.youtube.com/watch?v=SSmixnMpsI4.



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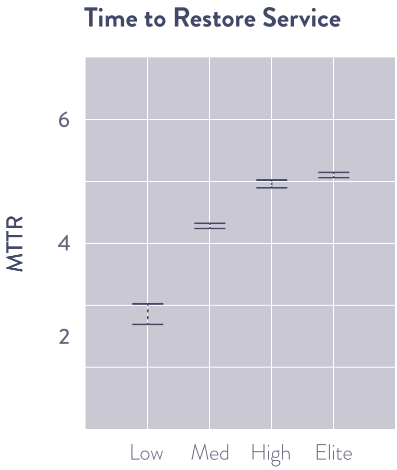

Figure 14.1: Incident Resolution Time for Elite, High, Medium, and Low Performers (2019)
Source: Forsgren et al., *Accelerate: State of DevOps* (2019).

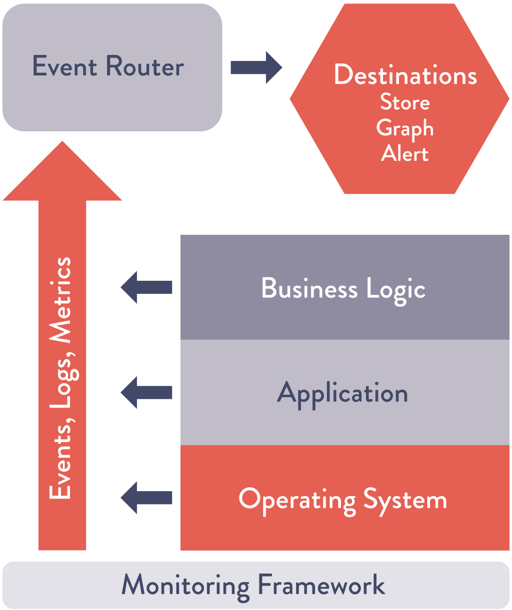

Figure 14.2: Monitoring Framework
Source: Turnbull, *The Art of Monitoring*, Kindle edition, chap. 2.

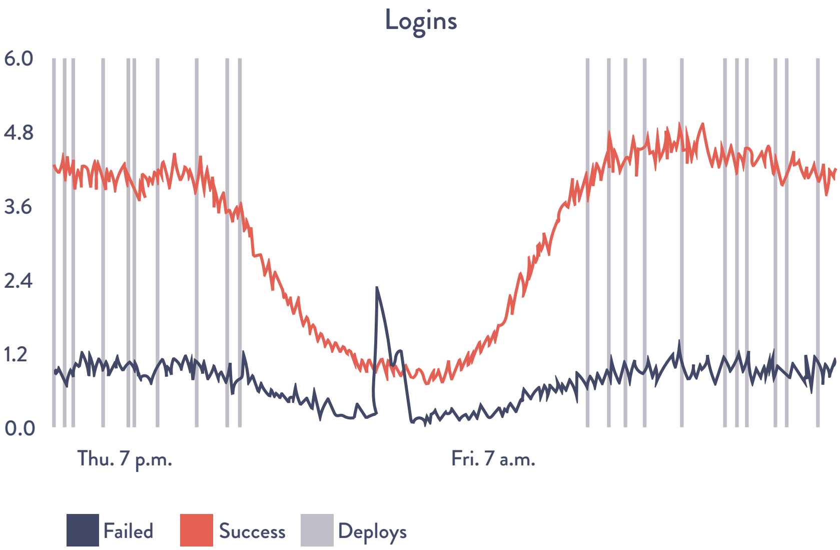

Figure 14.3: One Line of Code to Generate Telemetry using StatsD and Graphite at Etsy
Source: Ian Malpass, "Measure Anything, Measure Everything."

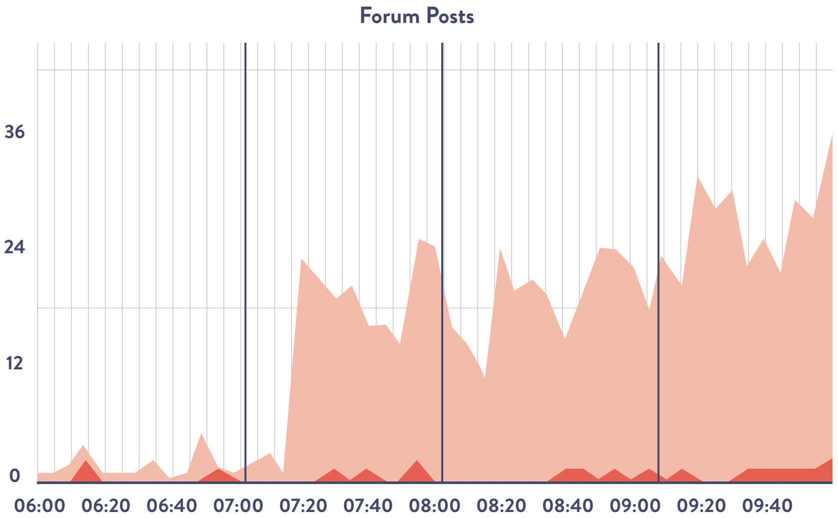

Figure 14.4: User Excitement of New Features in User Forum Posts after Deployments
Source: Mike Brittain, "Tracking Every Release," CodeasCraft.com, December 8, 2010, https://codeascraft.com/2010/12/08/track-every-release/.

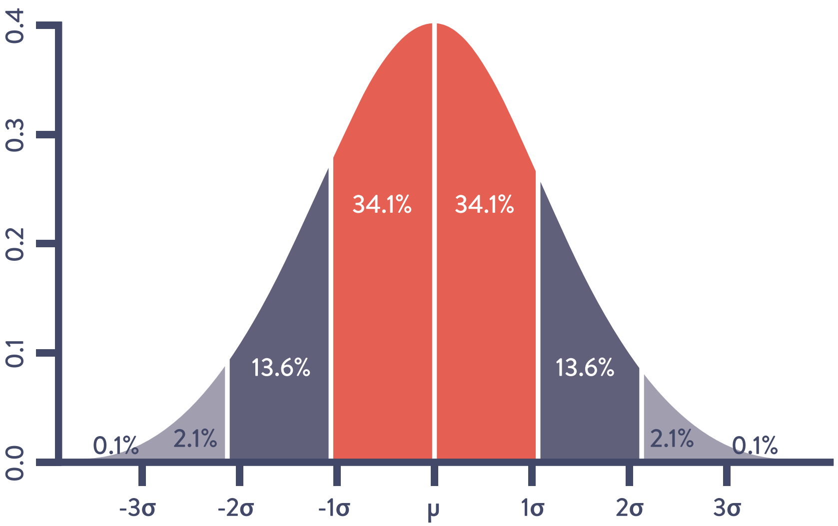

Figure 15.1: Standard Deviations (σ) & Mean (μ) with Gaussian Distribution

Source: *Wikipedia,* "Normal Distribution," https://en.wikipedia.org/wiki/Normal_distribution.

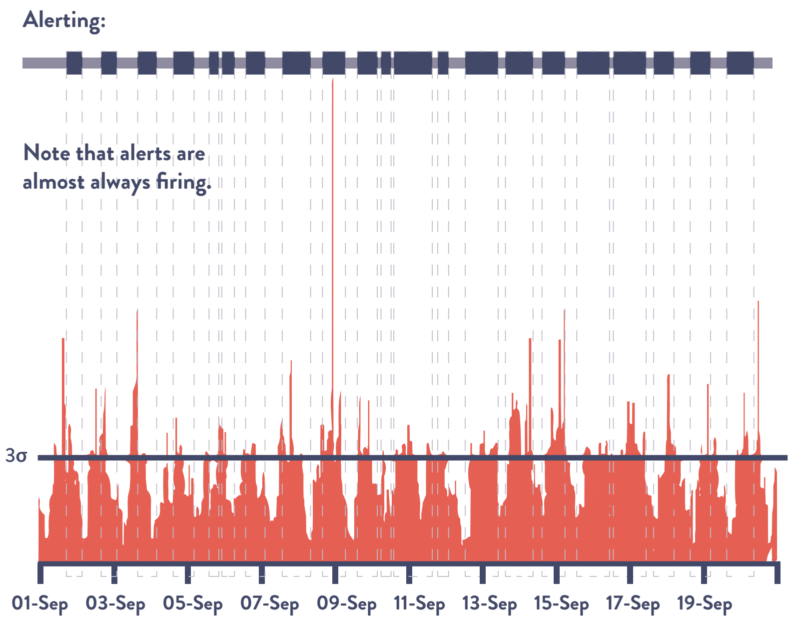

Figure 15.2: Downloads per Minute: Over-Alerting when Using "Three Standard Deviations" Rule

Source: Dr. Toufic Boubez, "Simple math for anomaly detection."

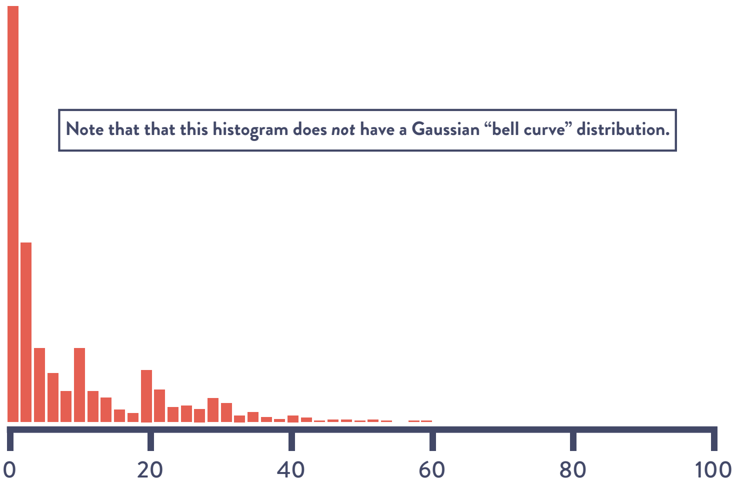

Figure 15.3: Downloads per Minute: Histogram of Data Showing Non-Gaussian Distribution

Source: Dr. Toufic Boubez, "Simple math for anomaly detection."

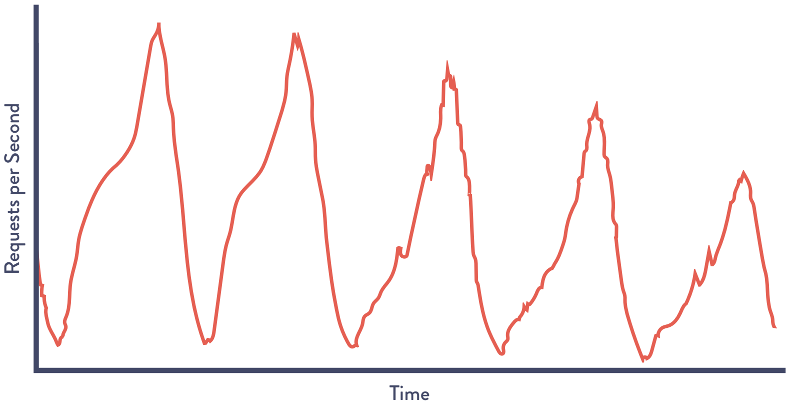

Figure 15.4: Netflix Customer Viewing Demand for Five Days

Source: Jacobson, Yuan, and Joshi, “Scryer: Netflix’s Predictive Auto Scaling Engine,” The Netflix Tech Blog, November 5, 2013, http://techblog.netflix.com/2013/11/scryer-netflixs-predictive-auto-scaling.html.

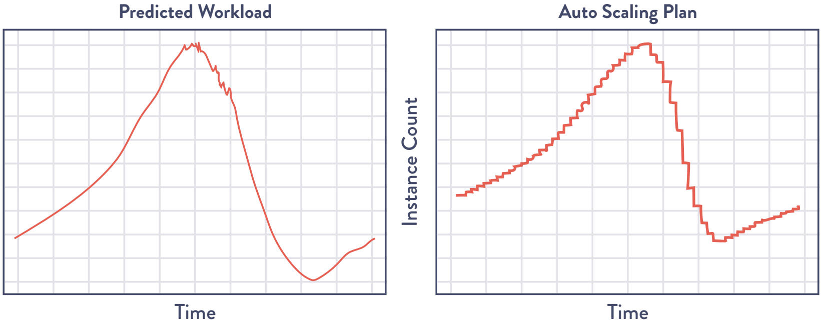

Figure 15.5: Netflix Scryer Forecasting Customer Traffic and the Resulting AWS Schedule of Compute Resources

(Source: Jacobson, Yuan, Joshi, "Scryer: Netflix's Predictive Auto Scaling Engine.")

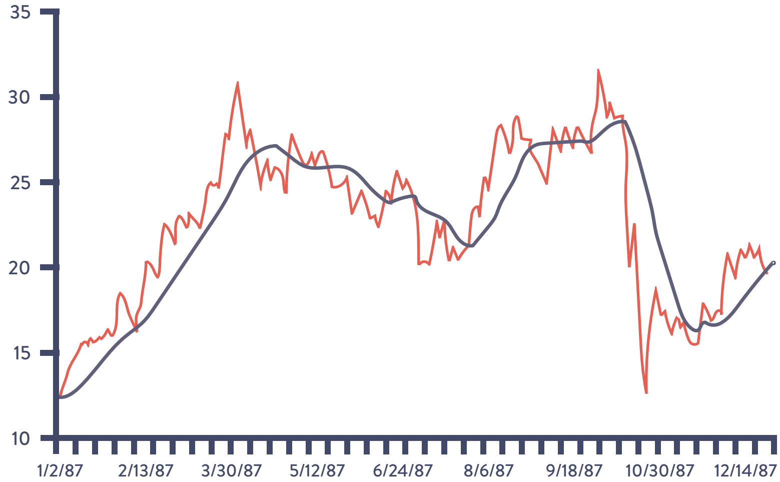

Figure 15.6: Autodesk Share Price and Thirty-Day Moving Average Filter
Source: Jacobson, Yuan, Joshi, "Scryer: Netflix's Predictive Auto Scaling Engine."

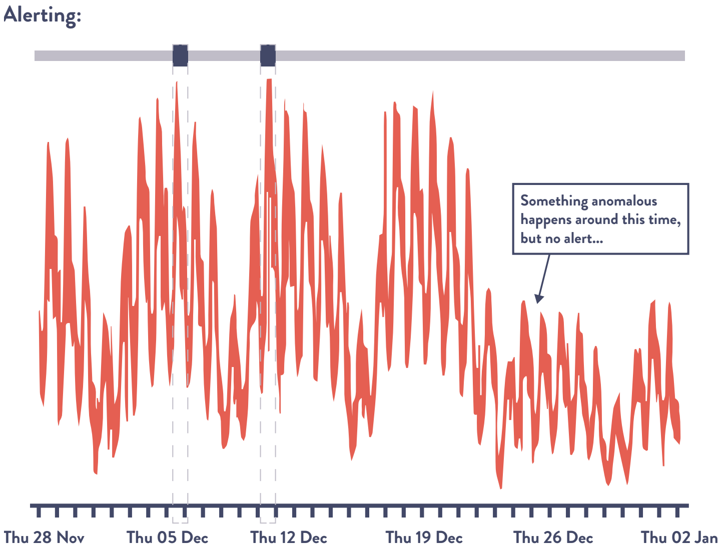

Figure 15.7: Transaction Volume: Under-Alerting Using "Three Standard Deviations" Rule
(Source: Dr. Toufic Boubez, "Simple math for anomaly detection.")

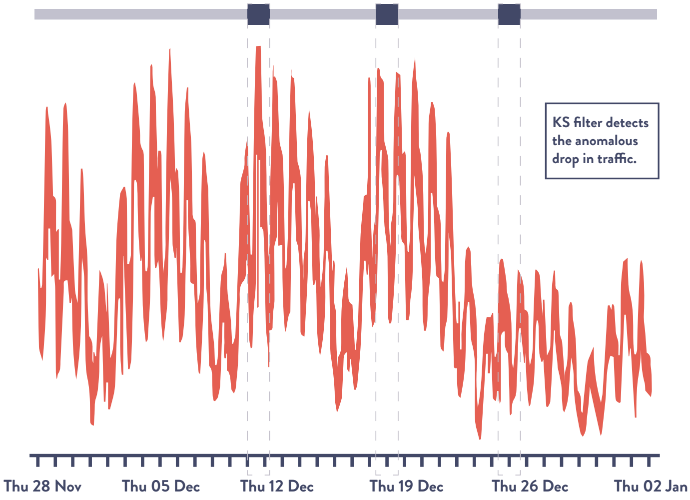

Figure 15.8: Transaction Volume: Using Kolmogorov-Smirnov Test to Alert on Anomalies
Source: Dr. Toufic Boubez, "Simple math for anomaly detection."

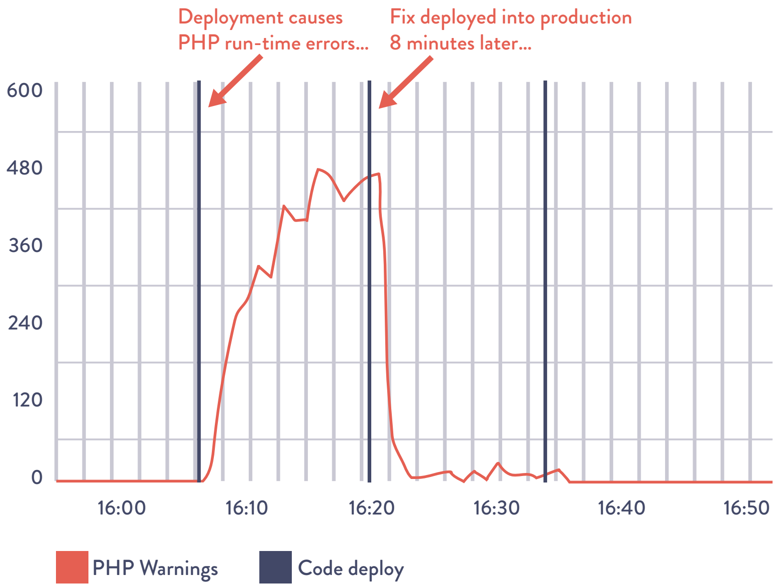

Figure 16.1: Deployment to Etsy.com Causes PHP Run-Time Warnings and Is Quickly Fixed
Source: Mike Brittain, "Tracking Every Release."

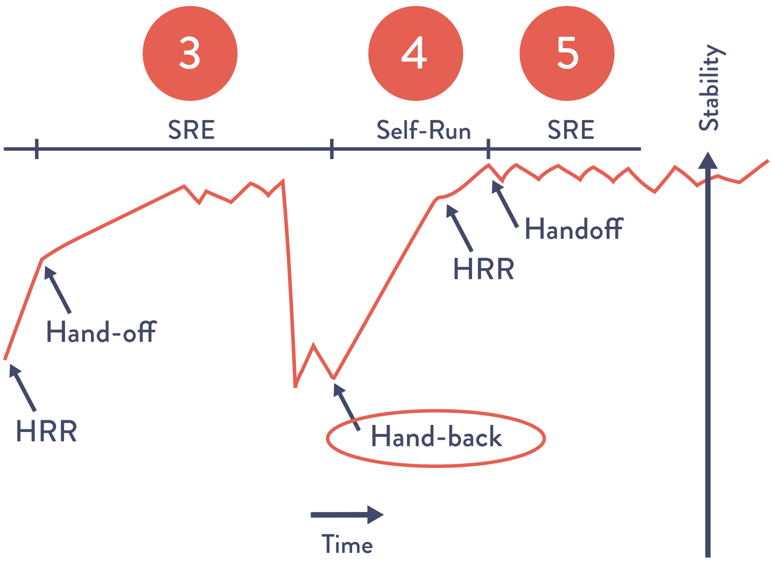

Figure 16.2: The "Service Handback" at Google

Source: "SRE@Google: Thousands of DevOps Since 2004," YouTube video, 45:57, posted by USENIX, January 12, 2012, https://www.youtube.com/watch?v=iIuTnhdTzK0.

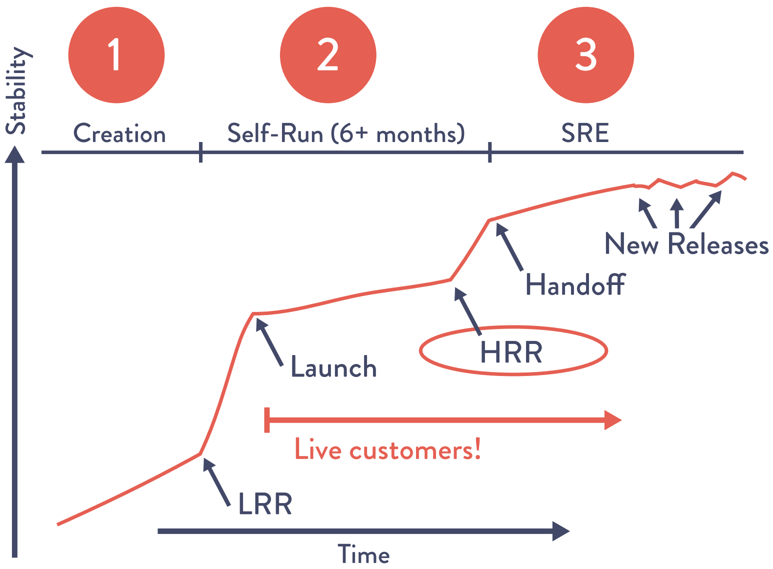

Figure 16.3: The LRR and HRR at Google

Source: "SRE@Google: Thousands of DevOps Since 2004," YouTube video, 45:57, posted by USENIX, January 12, 2012, https://www.youtube.com/watch?v=iIuTnhdTzK0.

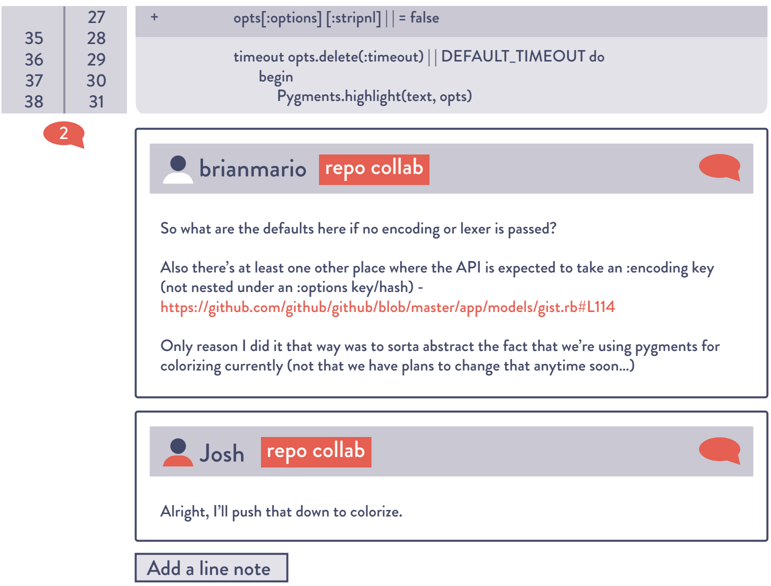

Figure 18.1: Comments and Suggestions on a GitHub Pull Request

Source: Scott Chacon, "GitHub Flow," ScottChacon.com, August 31, 2011, http://scottchacon.com/2011/08/31/github-flow.html.

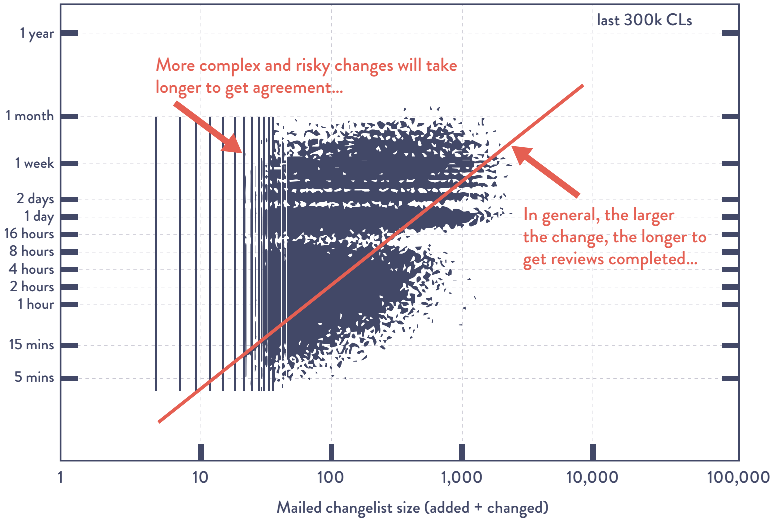

Figure 18.2: Size of Change vs. Lead Time for Reviews at Google
Source: Ashish Kumar, "Development at the Speed and Scale of Google," presentation at QCon, San Francisco, CA, 2010, qconsf.com/sf2010/dl/qcon-sanfran-2010/slides/AshishKumar_DevelopingProductsattheSpeedandScaleofGoogle.pdf.

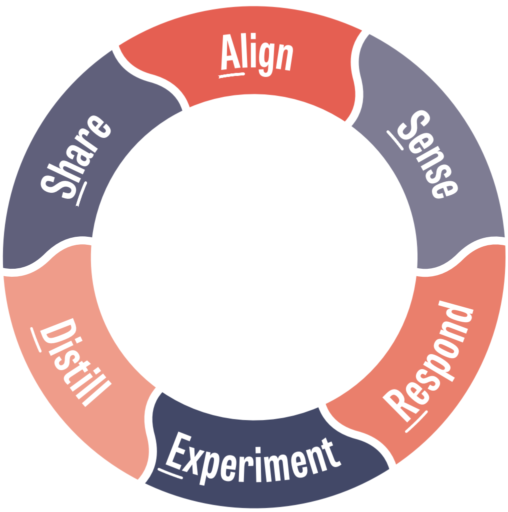

Figure 21.1: The ASREDS Learning Loop
Source: Smart et al., *Sooner Safer Happier: Antipatterns and Patterns for Business Agility* (Portland, OR: IT Revolution, 2020).

Jenkins

S	W	Name	Last Success	Last Failure	Last Duration
		Static analysis scan	7 days 1 hr - #2	N/A	6.3 sec
		Check known vulnerabilities in dependencies	N/A	7 days 1 hr - #2	1.6 sec
		Download and unit test	7 days 1 hr - #2	N/A	32 sec
		Scan with OWASP ZAP	7 days 1 hr - #2	N/A	4 min 43 sec
		Start	7 days 1 hr - #2	N/A	5 min 46 sec
		Virus scanning	7 days 1 hr - #2	N/A	4.7 sec

Figure 22.1: Jenkins Running Automated Security Testing
Source: James Wicket and Gareth Rushgrove, "Battle-tested code without the battle," Velocity 2014 conference presentation, posted to Speakerdeck.com, June 24, 2014, https://speakerdeck.com/garethr/battle-tested-code-without-the-battle.

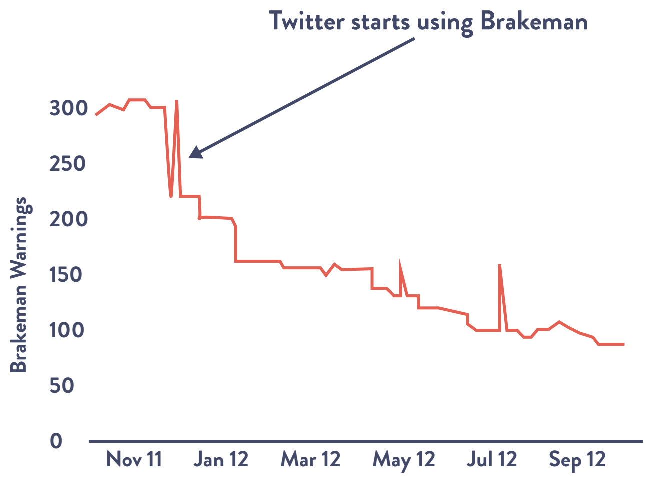

Figure 22.2: Number of Brakeman Security Vulnerabilities Detected

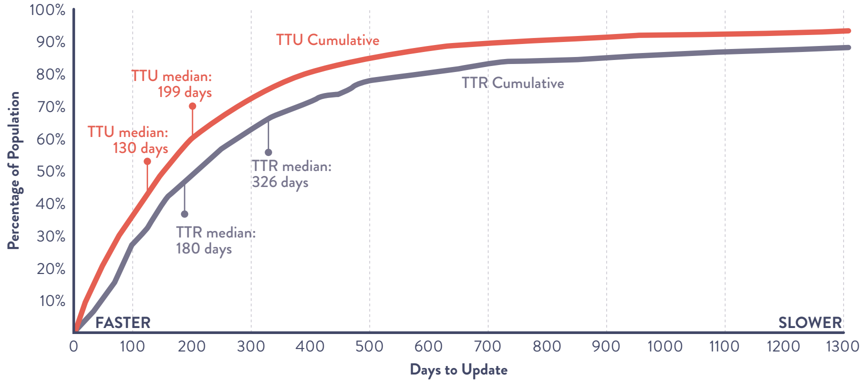

Figure 22.3: Time to Remediate vs. Time to Update Dependencies (TTU)

Source: Sonatype, 2019 *Software Supply Chain Report*.

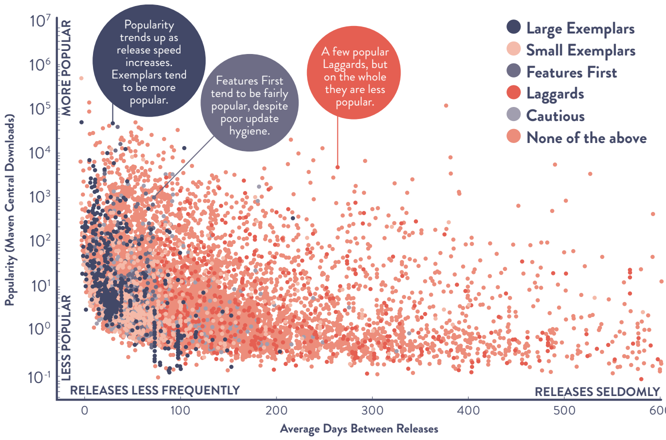

Figure 22.4: Five Behavioral Clusters for Open-Source Projects
Source: Sonatype, 2019 *Software Supply Chain Report*.

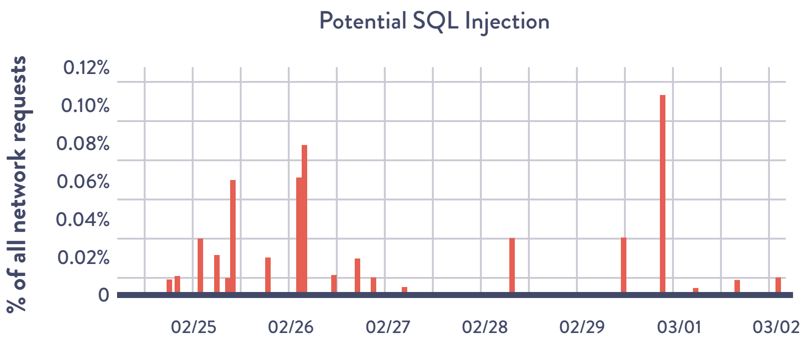

Figure 22.5: Developers See SQL Injection Attempts in Graphite at Etsy

Source: "DevOpsSec: Applying DevOps Principles to Security, DevOpsDays Austin 2012," SlideShare.net, posted by Nick Galbreath, April 12, 2012, http://www.slideshare.net/nickgsuperstar/devopssec-apply-devops-principles-to-security.

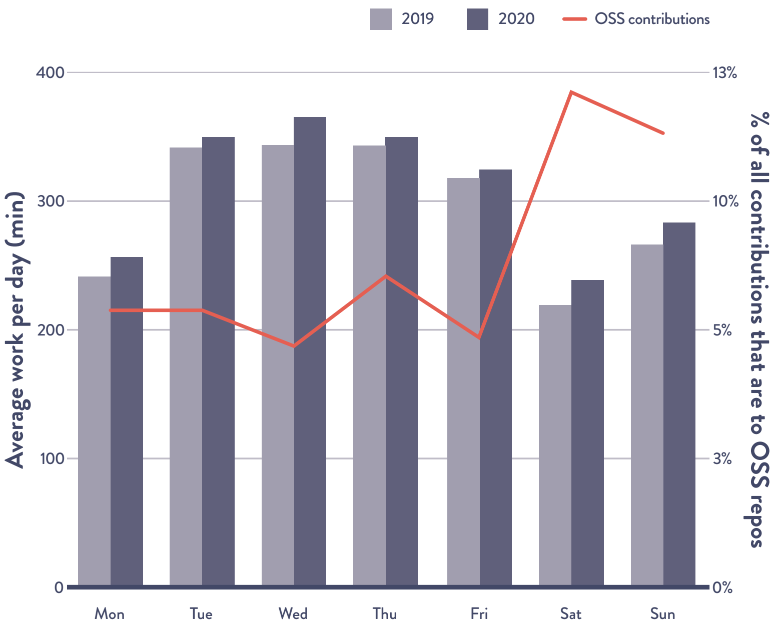

Figure AF.1: Average Development Window by Day of Week per User
Source: Forsgren et. al., *2020 State of the Octoverse*.

APPENDICES

Appendix 1: The Convergence of DevOps

We believe that DevOps is benefiting from an incredible convergence of management movements, which are all mutually reinforcing and can help create a powerful coalition to transform how organizations develop and deliver IT products and services.

John Willis named this "the convergence of DevOps." The various elements of this convergence are described below in approximate chronological order. (Note that these descriptions are not intended to be exhaustive, but merely enough to show the progression of thinking and the rather improbable connections that led to DevOps.)

The Lean Movement

The Lean Movement started in the 1980s as an attempt to codify the Toyota Production System with the popularization of techniques such as value stream mapping, kanban boards, and total productive maintenance.[1]

Two major tenets of Lean were the deeply held belief that lead time (i.e., the time required to convert raw materials into finished goods) was the best predictor of quality, customer satisfaction, and employee happiness; and that one of the best predictors of short lead times was small batch sizes, with the theoretical ideal being "single piece flow" (i.e., "1x1" flow: inventory of 1, batch size of 1).

Lean principles focus on creating value for the customer—thinking systematically, creating constancy of purpose, embracing scientific thinking, creating flow and pull (versus push), assuring quality at the source, leading with humility, and respecting every individual.

The Agile Movement

Started in 2001, the Agile Manifesto was created by seventeen of the leading thinkers in software development, with the goal of turning lightweight methods such as DP and DSDM into a wider movement that could take on heavyweight software development processes such as waterfall development and methodologies such as the rational unified process.

A key principle was to "deliver working software frequently, from a couple of weeks to a couple of months, with a preference to the shorter timescale."[2] Two other principles focus on the need for small, self-motivated teams, working in a high-trust management model and an emphasis on small batch sizes. Agile is also associated with a set of tools and practices such as Scrum, Standups, and so on.

The Velocity Conference Movement

Started in 2007, the Velocity Conference was created by Steve Souders, John Allspaw, and Jesse Robbins to provide a home for the IT Operations and Web Performance tribe. At the Velocity 2009 conference, John Allspaw and Paul Hammond gave the seminal "10 Deploys per Day: Dev and Ops Cooperation at Flickr," presentation.

The Agile Infrastructure Movement

At the 2008 Agile Toronto conference, Patrick Debois and Andrew Shafer held a "birds of a feather" session on applying Agile principles to infrastructure as opposed to application code. They rapidly gained a following of like-minded thinkers, including John Willis. Later, Debois was so excited by Allspaw and Hammond's "10 Deploys per Day: Dev and Ops Cooperation at Flickr" presentation that he created the first DevOpsDays in Ghent, Belgium, in 2009, coining the word "DevOps."

The Continuous Delivery Movement

Building upon the Development discipline of continuous build, test, and integration, Jez Humble and David Farley extended the concept of continuous delivery, which included a "deployment pipeline" to ensure that code and infrastructure are always in a deployable state and that all code checked into truck is deployed into production.[3] This idea was first presented at Agile 2006 and was also independently developed by Tim Fitz in a blog post titled "Continuous Deployment."[4]

The Toyota Kata Movement

In 2009, Mike Rother wrote *Toyota Kata: Managing People for Improvement, Adaptiveness and Superior Results*, which described learnings over his twenty-year journey to understand and codify the causal mechanisms of the Toyota Production System. *Toyota Kata* describes the "unseen managerial routines and thinking that lie behind Toyota's success with continuous improvement and adaptation . . . and how other companies develop similar routines and thinking in their organizations."[5]

His conclusion was that the Lean community missed the most important practice of all, which he described as the Improvement Kata. He explains that every organization has work routines, and the critical factor in Toyota was making improvement work habitual and building it into the daily work of everyone in the organization. The Toyota Kata institutes an iterative, incremental, scientific approach to problem-solving in the pursuit of a shared organizational true north.[6]

The Lean Startup Movement

In 2011, Eric Ries wrote *The Lean Startup: How Today's Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses*, codifying the lessons he learned at IMVU, a Silicon Valley startup, which built upon the work of Steve Blank in *The Four Steps to the Epiphan*y as well as continuous deployment techniques. Eric Ries also codified related practices and terms including minimum viable product, the build-measure-learn cycle, and many continuous deployment technical patterns.[7]

The Lean UX Movement

In 2013, Jeff Gothelf wrote *Lean UX: Applying Lean Principles to Improve User Experience*, which codified how to improve the "fuzzy front end" and explained how product owners can frame business hypotheses, experiment, and gain confidence in those business hypotheses before investing time and resources in the resulting features. By adding Lean UX, we now have the tools to fully optimize the flow between business hypotheses, feature development, testing, deployment, and service delivery to the customer.

The Rugged Computing Movement

In 2011, Joshua Corman, David Rice, and Jeff Williams examined the apparent futility of securing applications and environments late in the life cycle. In response, they created a philosophy called "Rugged Computing," which attempts to frame the non-functional requirements of stability, scalability, availability, survivability, sustainability, security, supportability, manageability, and defensibility.

Because of the potential for high release rates, DevOps can put incredible pressure on QA and Infosec, because when deploy rates go from monthly or quarterly to hundreds or thousands daily, no longer are two-week turnaround times from Infosec or QA tenable. The Rugged Computing movement posited that the current approach to fighting the vulnerable industrial complex being employed by most information security programs is hopeless.

Appendix 2: Theory of Constraints and Core, Chronic Conflicts

The Theory of Constraints body of knowledge extensively discusses the use of creating core conflict clouds (often referred to as "C3"). Figure A.1 shows the conflict cloud for IT:

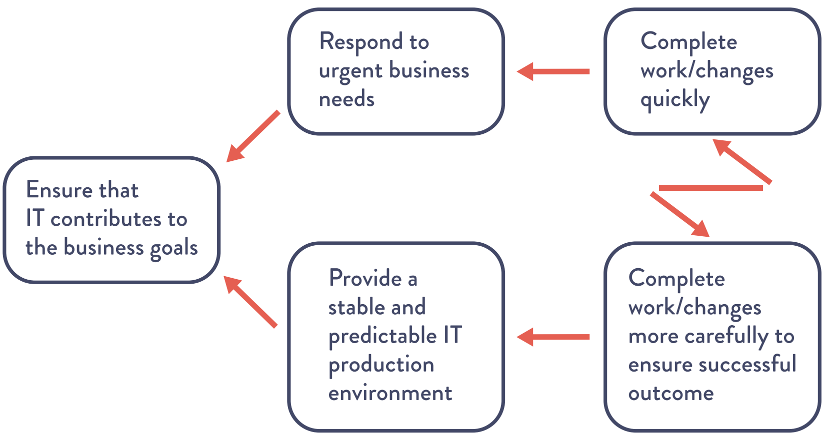

Figure A.1: The Core, Chronic Conflict Facing Every IT Organization

During the 1980s, there was a very well-known core, chronic conflict in manufacturing. Every plant manager had two valid business goals: protect sales and reduce costs. The problem was that in order to protect sales, sales management was incentivized to increase inventory to ensure that it was always possible to fulfill customer demand.

On the other hand, in order to reduce cost, production management was incentivized to decrease inventory to ensure that money was not tied up in work-in-progress that wasn't immediately shippable to the customer in the form of fulfilled sales.

They were able to break the conflict by adopting Lean principles, such as reducing batch sizes, reducing work in process, and shortening and amplifying feedback loops. This resulted in dramatic increases in plant productivity, product quality, and customer satisfaction.

The principles behind DevOps work patterns are the same as those that transformed manufacturing, allowing us to optimize the IT value stream, converting business needs into capabilities and services that provide value for our customers.

Appendix 3: Tabular Form of Downward Spiral

The tabular form of the downward spiral depicted in *The Phoenix Project* is shown in Table A.1.

Table A.1: The Downward Spiral

IT Operations sees…	Development sees…
Fragile applications are prone to failure	Fragile applications are prone to failure
Long time required to figure out which bit got flipped	More urgent, date-driven projects put into the queue
Detective control is a salesperson	Even more fragile code (less secure) put into production
Too much time required to restore service	More releases have increasingly turbulent installs
Too much firefighting and unplanned work	Release cycles lengthen to amortize cost of deployments
Urgent security rework and remediation	Failing bigger deployments more difficult to diagnose
Planned project work cannot be completed	Most senior and constrained IT ops resources have less time to fix underlying process problems

Frustrated customers leave	Ever increasing backlog of work that could help the business win
Market share goes down	Ever increasing amount of tension between IT Ops, Development, Design
Business misses Wall Street commitments	—
Business makes even larger promises to Wall Street	—

Appendix 4: The Dangers of Handoffs and Queues

The problem with high amounts of queue time is exacerbated when there are many handoffs, because that is where queues are created. Figure A.2 shows wait time as a function of how busy a resource at a work center is. The asymptotic curve shows why a "simple thirty-minute change" often takes weeks to complete—specific engineers and work centers often become problematic bottlenecks when they operate at high utilization. As a work center approaches 100% utilization, any work required from it will languish in queues and won't be worked on without someone expediting/escalating.

In Figure A.2, the x-axis is the percent busy for a given resource at a work center and the y-axis is the approximate wait time (or, more precisely stated, the queue length). What the shape of the line shows is that as resource utilization goes past 80%, wait time goes through the roof.

In *The Phoenix Project*, Bill and his team realized the devastating consequences of this property on lead times for the commitments they were making to the project management office:[8]

> I tell them about what Erik told me at MRP-8, about how wait times depend upon resource utilization. "The wait time is the 'percentage of time busy' divided by the 'percentage of time idle.' In other words, if a resource is fifty percent busy, then it's fifty percent idle. The wait time is fifty percent divided by fifty percent, so one unit of time. Let's call it one hour.
>
> So, on average, our task would wait in the queue for one hour before it gets worked.
>
> "On the other hand, if a resource is ninety percent busy, the wait time is 'ninety percent divided by ten percent or nine hours'. In other words,

our task would wait in queue nine times longer than if the resource were fifty percent idle."

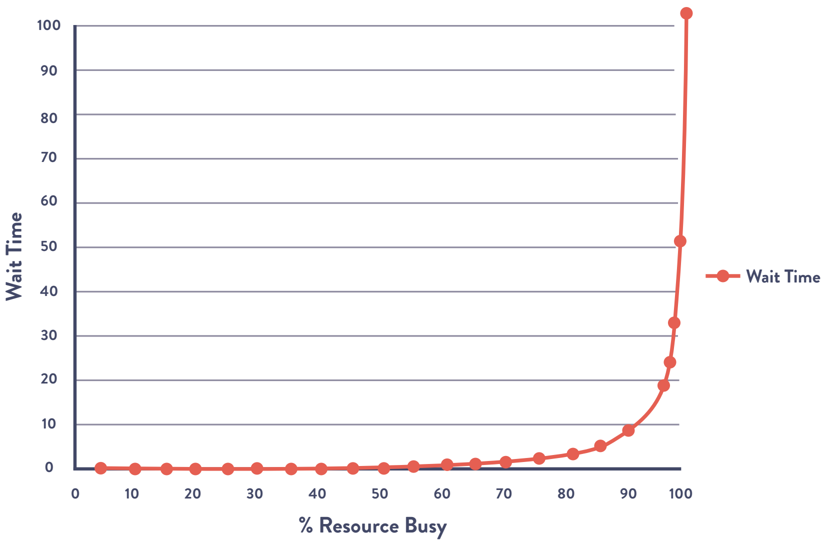

Figure A.2: Queue Size and Wait Times as a Function of Percent Utilization

Source: Kim, Behr, and Spafford, *The Phoenix Project*, ePub edition, 557.

I conclude, "So . . . For the Phoenix task, assuming we have seven handoffs, and that each of those resources is busy ninety percent of the time, the tasks would spend in queue a total of nine hours times the seven steps . . ."

"What? Sixty-three hours, just in queue time?" Wes says, incredulously. "That's impossible!"

Patty says with a smirk, "Oh, of course. Because it's only thirty seconds of typing, right?"

Bill and team realize that their "simple thirty-minute task" actually requires seven handoffs (e.g., server team, networking team, database team, virtualization team, and, of course, Brent, the "rockstar" engineer).

Assuming that all work centers were 90% busy, Figure A.2 shows us that the average wait time at each work center is nine hours—and because the work had to go through seven work centers, the total wait time is seven times that: sixty-three hours.

In other words, the total % of *value added time* (sometimes known as process time) was only 0.16% of the total lead time (thirty minutes divided by sixty-three hours). That means that for 99.8% of our total lead time, the work was simply sitting in queue, waiting to be worked on.

Appendix 5: Myths of Industrial Safety

Decades of research into complex systems shows that countermeasures are based on several myths. In "Some Myths about Industrial Safety," by Denis Besnard and Erik Hollnagel, they are summarized as such:

Myth 1: "Human error is the largest single cause of accidents and incidents."[9]
Myth 2: "Systems will be safe if people comply with the procedures they have been given."[10]
Myth 3: "Safety can be improved by barriers and protection; more layers of protection results in higher safety."[11]
Myth 4: "Accident analysis can identify the root cause (the 'truth') of why the accident happened."[12]
Myth 5: "Accident investigation is the logical and rational identification of causes based on facts."[13]
Myth 6: "Safety always has the highest priority and will never be compromised."[14]

The differences between what is myth and what is true are shown in Table A.2.

Table A.2: Two Stories

Myth	Reality
Human error is seen as the cause of failure.	Human error is seen as the effect of systemic vulnerabilities deeper inside the organization.
Saying what people should have done is a satisfying way to describe failure.	Saying what people should have done doesn't explain why it made sense for them to do what they did.

Telling people to be more careful will make the problem go away.	Only by constantly seeking out their vulnerabilities can organizations enhance safety.

Appendix 6: The Toyota Andon Cord

Many ask, how can any work be completed if the Andon cord is being pulled over five thousand times per day? To be precise, not every Andon cord pull results in stopping the entire assembly line. Rather, when the Andon cord is pulled, the team leader overseeing the specified work center has fifty seconds to resolve the problem. If the problem has not been resolved by the time the fifty seconds is up, the partially assembled vehicle will cross a physically drawn line on the floor, and the assembly line will be stopped.[15]

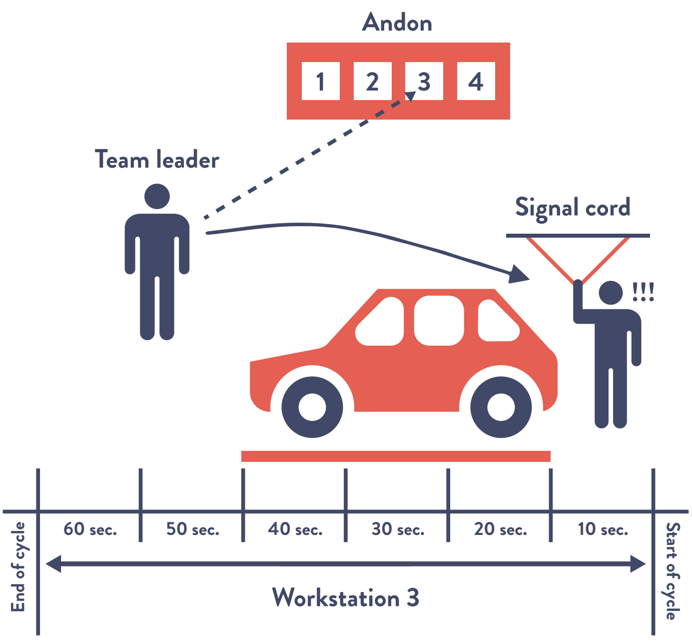

Figure A.3: The Toyota Andon Cord

Appendix 7: COTS Software

Currently, in order to get complex COTS (commercial off-the-shelf) software (e.g., SAP, IBM WebSphere, Oracle WebLogic) into version control, we may have to eliminate the use of graphical point-and-click vendor installer tools. To do that, we need to discover what the vendor installer is doing, and we may need to do an install on a clean server image, diff the file system, and put those added files into version control. Files that don't vary by environment are put into one place ("base install"), while environment-specific files are put into their own directory ("test" or "production"). By doing this, software install operations become merely a version control operation, enabling better visibility, repeatability, and speed.

We may also have to transform any application configuration settings so that they are in version control. For instance, we may transform application configurations that are stored in a database into XML files and vice versa.

Appendix 8: Post-Mortem Meetings (Retrospective)

A sample agenda of the post-mortem meeting is shown below:[16]

- An initial statement will be made by the meeting leader or facilitator to reinforce that this meeting is a blameless post-mortem and that we will not focus on past events or speculate on "would haves" or "could haves." Facilitators might read the "Retrospective Prime Directive" from the website Retrospective.com.
- Furthermore, the facilitator will remind everyone that any countermeasures must be assigned to someone, and if the corrective action does not warrant being a top priority when the meeting is over, then it is not a corrective action. (This is to prevent the meeting from generating a list of good ideas that are never implemented.)
- Those at the meeting will reach an agreement on the complete timeline of the incident, including when and who detected the issue, how it was discovered (e.g., automated monitoring, manual detection, customer notified us), when service was satisfactorily restored, and so forth. We will also integrate into the timeline all external communications during the incident.
- When we use the word "timeline," it may evoke the image of a linear set of steps of how we gained an understanding of the problem and eventually

fixed it. In reality, especially in complex systems, there will likely be many events that contributed to the accident, and many troubleshooting paths and actions will have been taken in an effort to fix it. In this activity, we seek to chronicle all of these events and the perspectives of the actors and establish hypotheses concerning cause and effect where possible.

- The team will create a list of all the factors that contributed to the incident, both human and technical. They may then sort them into categories, such as "design decision," "remediation," "discovering there was a problem," and so forth. The team will use techniques such as brainstorming and the "infinite hows" to drill down on contributing factors they deem particularly important to discover deeper levels of contributing factors. All perspectives should be included and respected—nobody should be permitted to argue with or deny the reality of a contributing factor somebody else has identified. It's important for the post-mortem facilitator to ensure that sufficient time is spent on this activity and that the team doesn't try and engage in convergent behavior such as trying to identify one or more "root causes."
- Those at the meeting will reach an agreement on the list of corrective actions that will be made top priorities after the meeting. Assembling this list will require brainstorming and choosing the best potential actions to either prevent the issue from occurring or enable faster detection or recovery. Other ways to improve the systems may also be included.
- Our goal is to identify the smallest number of incremental steps to achieve the desired outcomes, as opposed to "Big Bang" changes, which not only take longer to implement, but delay the improvements we need.
- We will also generate a separate list of lower-priority ideas and assign an owner. If similar problems occur in the future, these ideas may serve as the foundation for crafting future countermeasures.
- Those at the meeting will reach an agreement on the incident metrics and their organizational impact. For example, we may choose to measure our incidents by the following metrics:
    - Event severity: How severe was this issue? This directly relates to the impact on the service and our customers.
    - Total downtime: How long were customers unable to use the service to any degree?

- Time to detect: How long did it take for us or our systems to know there was a problem?
- Time to resolve: How long after we knew there was a problem did it take for us to restore service?

Bethany Macri from Etsy observed, "Blamelessness in a post-mortem does not mean that no one takes responsibility. It means that we want to find out what the circumstances were that allowed the person making the change or who introduced the problem to do this. What was the larger environment? . . . The idea is that by removing blame, you remove fear, and by removing fear, you get honesty."[17]

Appendix 9: The Simian Army

After the 2011 AWS US-East outage, Netflix had numerous discussions about engineering their systems to automatically deal with failure. These discussions have evolved into a service called "Chaos Monkey."[18]

Since then, Chaos Monkey has evolved into a whole family of tools, known internally as the "Netflix Simian Army," to simulate increasingly catastrophic levels of failures:[19]

- **Chaos Gorilla:** simulates the failure of an entire AWS availability zone.
- **Chaos Kong:** simulates failure of entire AWS regions, such as North America or Europe.

Other member of the Simian Army now include:

- **Latency Monkey:** induces artificial delays or downtime in their RESTful client-server communication layer to simulate service degradation and ensure that dependent services respond appropriately.
- **Conformity Monkey:** finds and shuts down AWS instances that don't adhere to best-practices (e.g., when instances don't belong to an auto-scaling group or when there is no escalation engineer email address listed in the service catalog).
- **Doctor Monkey:** taps into health checks that run on each instance and finds unhealthy instances and proactively shuts them down if owners don't fix the root cause in time.

- **Janitor Monkey:** ensures that their cloud environment is running free of clutter and waste; searches for unused resources and disposes of them.
- **Security Monkey:** an extension of Conformity Monkey; finds and terminates instances with security violations or vulnerabilities, such as improperly configured AWS security groups.

Appendix 10: Transparent Uptime

Lenny Rachitsky wrote about the benefits of what he called "transparent uptime:"[20]

> Your support costs go down as your users are able to self-identify system wide problems without calling or emailing your support department. Users will no longer have to guess whether their issues are local or global and can more quickly get to the root of the problem before complaining to you.
>
> You are better able to communicate with your users during downtime events, taking advantage of the broadcast nature of the internet versus the one-to-one nature of email and the phone. You spend less time communicating the same thing over and over and more time resolving the issue.
>
> You create a single and obvious place for your users to come to when they are experiencing downtime. You save your users' time currently spent searching forums, Twitter, or your blog.
>
> Trust is the cornerstone of any successful SaaS adoption. Your customers are betting their business and their livelihoods on your service or platform. Both current and prospective customers require confidence in your service. Both need to know they won't be left in the dark, alone and uninformed, when you run into trouble. Real time insight into unexpected events is the best way to build this trust. Keeping them in the dark and alone is no longer an option.
>
> It's only a matter of time before every serious SaaS provider will be offering a public health dashboard. Your users will demand it.

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