Performance Testing Workload Modeling: Ramp-Up Duration and User Load Calculation (Technical Guide)

1. Overview of Workload Modeling in Performance Testing

Workload modeling is a crucial step in performance testing that defines how users interact with a system over time. The key components include:

- **User Load (Concurrency):** The number of virtual users (VUs) interacting with the system simultaneously.
- **Ramp-Up Strategy:** The rate at which users are introduced into the system.
- **Steady-State Duration:** The time for which the system is tested at peak load.
- **Ramp-Down Strategy:** The rate at which users exit the system.

These components ensure that the test accurately simulates real-world user behavior and helps in identifying system bottlenecks.

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2. Factors Influencing Ramp-Up Duration & User Load Calculation

A. Business and SLA Requirements

Workload modeling must align with business goals and Service Level Agreements (SLAs). Key business requirements include:

1. **Expected Peak Load:** How many concurrent users does the system need to handle?
2. **Transactions Per Second (TPS):** Business-defined throughput requirements.
3. **Response Time SLA:** Acceptable response time for critical transactions.

Example:

For an **e-commerce platform** expecting **10,000 concurrent users** on **Black Friday** with an SLA of **≤ 2s response time**, the performance test should simulate:

- Peak load of 10,000 users.
- Average **500-1000 transactions per second (TPS)**.
- A response time **≤ 2 seconds**.

B. Real-World Traffic Analysis

To simulate realistic user load, we analyze historical traffic data from:

1. **Monitoring Tools:**

- **Google Analytics, New Relic, Dynatrace, AppDynamics** provide insights into:
  - Peak traffic patterns.
  - Session durations.
  - User abandonment rates.

2. **Web Server & API Logs Analysis:**
   - Extract peak requests from web server logs:

```
grep "POST /checkout" access.log | wc -l
```

   - Use log analysis tools like **Splunk or ELK Stack** to visualize trends.
3. **User Distribution Patterns:**
   - Traffic varies across time zones and business hours:
     - **Enterprise applications:** 9 AM - 6 PM peak.
     - **E-commerce:** Traffic surges in the evening and weekends.
     - **Streaming services:** Peak usage at night.

C. System Capacity & Scaling Considerations

- **Fixed Infrastructure:** If no auto-scaling is enabled, a slow ramp-up prevents overloading.
- **Cloud Auto-Scaling (AWS ASG, Kubernetes HPA):**
  - The ramp-up should match the **auto-scaling threshold** (e.g., every 5 minutes).
  - Example: If AWS **Auto Scaling Group (ASG)** scales every **2 minutes**, the ramp-up should introduce **100 users every 2 minutes**.

Example: AWS ASG Scaling Thresholds

Metric	**Scaling Trigger**
CPU > 75%	Scale up by 2 instances
TPS > 1000	Scale up by 1 instance
Memory > 80%	Scale up by 3 instances

3. How to Calculate Ramp-Up Duration?

The ramp-up duration is determined based on:

- **Total Users (N):** Number of virtual users.

- **Ramp-Up Time (T):** Time to reach full load.
- **Ramp-Up Rate:** The speed at which users are added.

A. Linear Ramp-Up Formula

Ramp-Up Rate=Total Users / Ramp-Up Time (T)

Example:

- **5,000 users over 20 minutes**: 5000\20=250 users per minute
    - **JMeter Configuration:** Set **Thread Group Ramp-Up = 1200 seconds (20 min).**

B. Stepwise Ramp-Up (Batch Injection)

Rather than adding users continuously, they are injected in **batches** to prevent early failures.

Example: Stepwise Ramp-Up (Batch Injection)

- **1,000 users every 5 minutes** until full load is reached.

Time Interval	Users Added	Total Users
0 - 5 min	1,000	1,000
5 - 10 min	1,000	2,000
10 - 15 min	1,000	3,000
15 - 20 min	1,000	4,000
20 - 25 min	1,000	5,000

JMeter Configuration:

- Use **"Ultimate Thread Group"** to set **ramp-up batches**.

C. Arrival Rate-Based Ramp-Up (Little's Law)

If the system is **TPS-driven**, we calculate concurrency using:

Concurrent Users=TPS×Response Time

Example Calculation

- **Target TPS: 1,000 transactions per second**.
- **Average Response Time: 2 seconds**.
- **Required Concurrent Users:** 1000×2=2000 concurrent users
- **JMeter Configuration:**

    - Use **"Constant Throughput Timer"** to control the **TPS rate**.

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4. How to Determine Total User Load?

There are multiple approaches:

A. Production Traffic Analysis

- Extract peak **Concurrent Users** from **New Relic, Dynatrace, AppDynamics**.
- Web Server Logs:

```
cat access.log | grep "GET /home" | wc -l
```

B. Capacity Planning & SLA

- **Max Load Capacity**: If the database supports **2,000 TPS**, and avg response time is **3 sec**, then: 2000×3=6000 concurrent users
- **SLA-Based Load Testing**: Adjust user load to find the maximum sustainable number of users under the SLA constraints.

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5. Performance Test Workload Models

Model	Description	Use Case
Peak Load	Simulates the highest expected user load.	SLA validation
Step Load	Gradually increases load in steps to find breaking points.	Capacity planning
Spike Load	Sudden large user injection.	Flash sales, DDoS testing
Soak Test	Sustains load for long periods.	Memory leaks, stability testing

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6. Example Workload Scenario

E-Commerce Black Friday Load Test

- **Expected Peak Users: 50,000**
- **TPS Estimate: 4,000 TPS**
- **Avg Response Time: 3 sec**
- **Concurrent Users Calculation:** 4,000×3=12,000

Ramp-Up Strategy:

- **First 10% (5,000 users) in 5 min**
- **Next 30% (15,000 users) in 15 min**
- **Final 60% (30,000 users) in 30 min**

Steady State: 1 hour Ramp-Down: Gradual drop over **15 minutes**.

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7. Conclusion

- **Linear and stepwise ramp-up** are most commonly used.
- **Arrival rate-based ramp-up** aligns with real-world TPS expectations.
- **JMeter can implement these strategies using Thread Groups & Timers**.

There are **multiple models** for calculating **ramp-up duration** in performance testing. While **linear, stepwise, and arrival rate-based ramp-ups** are common, **several other methods exist** based on real-world usage patterns, system architecture, and scalability constraints.

Below are **other 3 ramp-up models**, each with detailed calculations and examples.

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4. Spike Ramp-Up (Sudden Traffic Burst)

- **All users are injected within a short time** (e.g., 1-2 minutes).
- Used for **stress testing, DDoS simulation, and flash sales scenarios**.

Example Calculation:

- **5000 users injected in 2 minutes**: 5000\2=2500 users per minute

Time Interval	Users Added	Total Users
0 - 1 min	2500	2500
1 - 2 min	2500	5000

JMeter Configuration:

- Use **Stepping Thread Group** to inject all users quickly.

Use Case:

- **Ticket booking, Black Friday sales, breaking news websites**.

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5. Wave-Based Ramp-Up (Oscillating Load)

- Load fluctuates **up and down in waves** to simulate **real-world traffic fluctuations**.
- Useful for **handling scaling challenges in cloud environments**.

Example Calculation (Waves Every 5 Minutes)

Time Interval	Users Added	Total Users
0 - 5 min	+1000	1000
5 - 10 min	-500	500
10 - 15 min	+1500	2000
15 - 20 min	-1000	1000
20 - 25 min	+2500	3500

JMeter Configuration:

- Use **Custom Thread Groups** to define wave-like traffic.
- Ideal for **IoT applications, streaming platforms, and mobile apps**.

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6. Ramp-Up with Auto-Scaling Considerations

- Designed for **AWS Auto Scaling, Kubernetes Horizontal Pod Autoscaler (HPA), Azure VM Scale Sets**.
- Users are added in **sync with scaling triggers**.

Example Calculation (Scaling Every 5 Minutes)

Time Interval	Users Added	Total Users	Scaling Action
0 - 5 min	1000	1000	1 instance added
5 - 10 min	1500	2500	2 instances added
10 - 15 min	2500	5000	4 instances added
15 - 20 min	5000	10,000	8 instances added

JMeter Configuration:

- Set **gradual ramp-up matching cloud scaling intervals**.

Use Case:

- **Cloud-native microservices that rely on Kubernetes auto-scaling**.

Comparison of Ramp-Up Models

Model	Best For	Ramp-Up Strategy
Linear Ramp-Up	General applications	Fixed rate increase
Stepwise Ramp-Up	Legacy systems	Users injected in batches
Arrival Rate-Based Ramp-Up	APIs, backend services	TPS-driven load
Spike Ramp-Up	Flash sales, stress testing	Sudden load increase
Wave-Based Ramp-Up	Streaming, IoT systems	Oscillating traffic patterns
Auto-Scaling Aware Ramp-Up	Cloud-based microservices	Matches scaling policies

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Example Workload Scenario: E-Commerce Black Friday Sale

A **retail website** expecting **50,000 concurrent users** during **Black Friday** should use a **hybrid ramp-up strategy**:

1. **Stepwise Ramp-Up** for first **10,000 users** (to warm up caches, CDNs).
2. **Spike Load** (20,000 users in 5 min) simulating a flash sale.
3. **Wave-Based Load** (±5,000 users every 10 min) to mimic real-world purchase behavior.

Test Configuration

Phase	Users	Ramp-Up Time	Load Model
Warm-Up	10,000	10 min	Stepwise

Flash Sale	20,000	5 min	Spike Load
Steady-State	50,000	1 hour	Linear
Load Drop	-20,000	15 min	Wave-Based

Conclusion

1. **Not all performance tests use simple linear ramp-up.**
2. **Stepwise and wave-based ramp-up models** better replicate **real-world traffic.**
3. **Cloud-based tests** should align with **auto-scaling policies.**
4. **Arrival rate-based models (TPS-driven) are best for APIs.**
5. **Spike ramp-up is essential for stress testing and event-driven traffic surges.**