**Event-Driven Application Design with Oracle AQ: Comparing Development Efficiency Across Modern Platform**

**Optimizing Event-Driven Application Development: A Comparative Analysis of Oracle Advanced Queue and PL/SQL with Traditional Frameworks Se**

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June, 2024

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# **DECLARATION**

We hereby declare that this project is our original work and that it has been written by us in its entirety. We have duly acknowledged all the sources of information that have been used in the research. This research project (fully or partially) has not been submitted for any degree or diploma at any university or institute previously.

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# **ACKNOWLEDGEMENTS**

We would like to express our sincere gratitude to all those who have contributed to the successful completion of this research. First and foremost, we extend our deepest thanks to our advisor, Prof. Dr. Md. Ahsan Habib, for his unwavering support, guidance, and encouragement throughout this project. His insights and expertise have been invaluable in shaping the direction of this research.

We are also grateful to the faculty and staff at BUP for providing a conducive environment for learning and research. Special thanks to Prof. Dr. Mohammad Nasir Uddin for his administrative support and for providing access to essential resources. A heartfelt thanks to our peers for their constant encouragement, constructive feedback, and sharing of their knowledge and experiences. The collaborative spirit within our group has been a source of motivation and inspiration. We would like to acknowledge the support from Oracle Corporation for providing the necessary tools and infrastructure, which have been critical for the practical implementation and testing of the Oracle AQ system. Additionally, we are thankful to our family and friends for their patience, understanding, and unwavering support during the countless hours dedicated to this research. Their encouragement has been a pillar of strength. Finally, we would like to thank all the participants in the empirical studies for their time and contributions, which have been instrumental in validating the findings of this research.

To all, we extend our heartfelt appreciation. This research would not have been possible without your collective support and encouragement.

# **ABSTRACT**

Efficient and reliable event-driven applications are essential for modern systems requiring real-time data processing. Traditional programming frameworks such as Spring Boot for Java, Flask for Python, Express for Node.js, .NET Core for C#, and Ruby on Rails often **encounter complexities and overheads** in managing these architectures. These include the need for integrating Redis for caching, Varnish for HTTP acceleration, and other mechanisms to handle state management and data consistency. These frameworks **frequently face** integration pipeline throttling, lack a single source of truth, and struggle with API management. This study **aims** to modernize event-driven application development by leveraging Oracle Advanced Queuing (AQ) within Oracle Autonomous Serverless Database, offering a comparative analysis against these traditional frameworks. Oracle AQ integrates queuing and transaction management capabilities directly within the database, reducing development complexity and enhancing performance, reliability, scalability, and security. The research includes **three empirical studies evaluatin**g the development process (lines of code, development time), performance and reliability (execution time, error rates, message delivery success), and scalability and security (throughput, resource utilization, security features). **Simulations** were conducted using batch processing of orders in varying sizes to ensure comprehensive evaluation. **Findings** indicate that Oracle AQ significantly reduces lines of code and development time compared to traditional frameworks, provides faster execution times and lower error rates, and demonstrates superior scalability with higher message throughput and more efficient resource utilization. These **capabilities are particularly significant** for modern applications experiencing high-volume, high-complexity traffic that require seamless integration and robust API management. The **results** suggest that Oracle AQ offers a compelling solution for modernizing event-driven application development, **supporting** its **adoption** across various industries such as finance, healthcare, and security and effectiveness in practice.

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# **LIST OF ABBREVIATIONS**

|  |  |
| --- | --- |
| **Acronyms** | **Abbreviation** |
| **AQ** | Advanced Queuing |
| **OTP** | One-Time Pin |
| **API** | Application Programming Interface |
| **PL/SQL** | Procedural Language/Structured Query Language |
| **LoC** | Lines of Code |
| **CPU** | Central Processing Unit |
| **JSON** | JavaScript Object Notation |
| **DB** | Database |
| **IDE** | Integrated Development Environment |
| **REST** | Representational State Transfer |
| **RAM** | Random Access Memory |

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# **CHAPTER 1**

# **INTRODUCTION**

## **1.1 Overview**

In an increasingly digital world, businesses and applications are moving towards more dynamic and event-driven architectures. These architectures allow for real-time processing and responsiveness, crucial for various sectors, including e-commerce, finance, healthcare, and logistics. This research focuses on simplifying event-driven applications using Oracle Advanced Queuing (AQ) in Oracle Database. The dissertation aims to demonstrate the efficiency and reliability of Oracle AQ, and compare its performance with traditional programming frameworks such as Java, Python, and Node.js.

## **1.2 Background Information**

Event-driven architectures have been integral in computer science for decades, allowing systems to react to events or changes in state. Early implementations relied on simple interrupt-driven mechanisms within operating systems. Over time, as applications grew in complexity, the need for more robust and scalable solutions became apparent [1]. Message queuing systems emerged as a powerful tool to decouple components and ensure reliable communication in distributed systems.

The concept of message queuing became more sophisticated with the advent of distributed computing, where systems needed to handle asynchronous communication across multiple networked environments. Message queuing systems like IBM MQ Series and Microsoft Message Queuing (MSMQ) laid the groundwork for reliable messaging frameworks that supported transaction management, message persistence, and recovery from failures [2-4]. These systems allowed applications to function independently, improving scalability and fault tolerance.

Oracle Advanced Queuing (AQ) was introduced as part of Oracle Database to provide a robust messaging infrastructure within the database. Oracle AQ leverages the relational database model to store messages in queue tables, enabling persistent queuing of messages and ensuring transactional integrity [3]. It supports both point-to-point messaging and publish/subscribe models, making it versatile for various application needs. Oracle AQ's tight integration with the database allows it to offer advanced features such as message ordering, prioritization, delay delivery, and exception handling, which are critical for building reliable and scalable event-driven applications [5].

Despite these advancements, several state-of-the-art challenges persist in the domain of event-driven architectures and messaging systems. Traditional programming frameworks such as Java, Python, and Node.js often require complex setups and multiple integrations to achieve reliable messaging. One major challenge is the complexity and overhead associated with traditional frameworks, which necessitate significant boilerplate code and extensive configurations to establish reliable messaging [6]. Integrating multiple APIs and ensuring consistent state management across distributed systems can be cumbersome and error-prone [7]. For example, setting up a complete message brokering system using RabbitMQ or Apache Kafka involves numerous configuration steps, from network settings to authentication mechanisms [6-8].

Scalability becomes essential as applications grow, requiring horizontal scaling and cluster management strategies [7]. Reliability involves guaranteeing message delivery and processing, which might need custom retry mechanisms and error handling [8]. Performance optimization for low-latency and high-throughput messaging can be challenging, requiring fine-tuning of components [9]. Security adds another layer of complexity, demanding robust measures like encryption and access control to protect sensitive data [10].

Oracle AQ addresses many of these challenges by providing built-in features that simplify the development and management of event-driven applications [11]. Its integration with Oracle Database allows for seamless transaction management and data consistency, reducing the need for extensive boilerplate code and complex configurations. Additionally, Oracle AQ's support for advanced messaging features and its robust security model offer a more streamlined, efficient, and secure solution compared to traditional programming frameworks.

## **1.3 Research Questions**

The research questions of this study are:

1. How does Oracle Advanced Queuing (AQ) simplify the development of event-driven applications compared to traditional programming frameworks?
2. What are the performance and reliability differences between Oracle AQ-based implementations and those using Java, Python, and Node.js?
3. In what ways does Oracle AQ enhance the scalability and security of event-driven applications compared to traditional programming frameworks?

## **1.4 Research Objectives**

The objectives of this study are:

1. To demonstrate the effectiveness of Oracle Advanced Queuing (AQ) in simplifying event-driven application development.
2. To compare the performance and reliability of Oracle AQ-based implementations with those using traditional programming frameworks.
3. To evaluate the scalability and security benefits of using Oracle AQ for event-driven applications.

## **1.5 Significance and Motivation of the Research**

The significance and motivation of this research stem from addressing two primary problem statements. Firstly, traditional programming frameworks such as Java, Python, and Node.js are associated with significant complexities and overheads when developing event-driven applications. These frameworks often require extensive boilerplate code, complex configurations, and multiple integrations to ensure reliable messaging. This leads to increased development time, higher maintenance costs, and potential performance bottlenecks. Secondly, there is a critical need for a more streamlined, efficient, and secure solution for event-driven application development. By leveraging Oracle Advanced Queuing (AQ) within Oracle Database, this research aims to simplify the development process, reduce overhead, and provide a more efficient and reliable solution. The use of AQ’s built-in features for queuing and transaction management directly within the database can potentially alleviate the challenges posed by traditional frameworks, offering a robust alternative that enhances scalability, security, and overall performance.

## **1.6 Organization of the Research Paper**

This dissertation consists of seven chapters.

Chapter 1 provides an overview of the research, including background information, research questions, research objectives, the significance and motivation of the research, and the organization of the paper.

Chapter 2 reviews existing literature on event-driven architectures, messaging systems, and Oracle Advanced Queuing, comparing it with other messaging solutions and discussing the benefits of using Oracle Autonomous Database and PL/SQL.

Chapter 3 describes the methodology, including the setup of Oracle Cloud Infrastructure and Oracle Autonomous Database, the design and implementation of the delivery scenario using Oracle AQ, and the procedures for the empirical studies. Specifically, it details the steps for designing and implementing the Oracle AQ solution, conducting code analysis, and assessing complexity, performance, reliability, scalability, and security.

Chapter 4 presents the simulation and modeling of event-based application development using Oracle AQ and traditional programming languages, with detailed guidelines for the simulation to draw comparative analysis.

Chapter 5 discusses the results of the simulations, evaluations, and performance comparisons, providing insights and analysis of the findings.

Chapter 6 summarizes the research contributions, discusses the implications of the findings, and outlines directions for future research.

Chapter 7 provides the conclusion and potential future research opportunities.

## **1.7 Summary**

This introductory chapter has outlined the importance of simplifying event-driven applications in modern digital environments and the challenges faced by traditional programming frameworks. It has introduced Oracle Advanced Queuing (AQ) as a promising solution to address these challenges by leveraging its integration with Oracle Database for robust messaging and transaction management. The research objectives, significance, and structure of the dissertation have been detailed, setting the stage for the subsequent chapters that will delve deeper into the literature review, methodology, simulation modeling, results, discussion, and future research directions.

# **CHAPTER 2**

# **LITERATURE REVIEW**

## **2.1 Overview**

Event-driven architectures have revolutionized how modern applications respond to real-time events and process asynchronous data streams. This chapter delves into existing literature on event-driven architectures and messaging systems, providing an in-depth overview of Oracle Advanced Queuing (AQ) and its advantages. It compares Oracle AQ with other popular messaging solutions like Kafka and RabbitMQ and highlights the benefits of using Oracle Autonomous Database and PL/SQL. Furthermore, the chapter discusses performance metrics for evaluating the Oracle AQ solution design approach compared to traditional programming frameworks.

## **2.2 Related Studies**

The study of event-driven architectures and messaging systems has garnered significant attention in both academic and industrial research. Chen et al. (2020) examined the evolution of event-driven architectures, emphasizing the need for scalable and flexible systems capable of handling diverse event sources. They highlighted the benefits of decoupling components to achieve modularity and ease of maintenance, critical for modern applications [1]. The role of messaging systems in these architectures is crucial, providing the necessary infrastructure for event communication. Over the years, several messaging systems, including Kafka, RabbitMQ, and Oracle AQ, have been developed, each offering unique features. Smith et al. (2019) conducted a comprehensive comparison of these systems, focusing on their performance, scalability, and ease of integration. Their research concluded that Oracle AQ offers distinct advantages in terms of integration with Oracle Database and support for complex transactions [2].

Oracle AQ has been extensively studied due to its robust messaging capabilities and seamless integration with Oracle Database. Brown (2018) provided a detailed overview of Oracle AQ, discussing its features, architecture, and use cases. The study emphasized Oracle AQ's support for both point-to-point and publish/subscribe models, allowing for flexible and reliable messaging. The seamless integration with Oracle Database enables complex transaction management, making Oracle AQ a compelling choice for event-driven applications requiring strong consistency and reliability [3]. Comparative analyses, such as those conducted by Jones et al. (2017), further highlight Oracle AQ's performance advantages in scenarios requiring complex transaction management and database integration, outperforming other systems under various workloads [4].

Scalability and performance are critical factors in the design of event-driven architectures. Studies have explored different strategies to enhance the scalability and performance of messaging systems. Gupta et al. (2019) investigated the scalability of Kafka and RabbitMQ in high-throughput environments, demonstrating that while Kafka excels in handling large volumes of data with low latency, it requires significant infrastructure and expertise to manage effectively. Conversely, RabbitMQ offers ease of use and flexibility but may struggle with performance in extremely high-throughput scenarios [5]. Ensuring the reliability and fault tolerance of messaging systems is another significant challenge, as highlighted by Kim et al. (2018), who explored various fault tolerance techniques, including message replication, retry mechanisms, and deduplication strategies, emphasizing the trade-offs between performance and reliability [6].

Security and data protection are essential aspects of event-driven architectures and messaging systems, particularly for applications dealing with sensitive information. Smith and Wang (2020) reviewed security measures in popular messaging systems, including encryption, access control, and audit logging. They found that traditional frameworks often require additional configurations to achieve robust security, whereas systems like Oracle AQ provide built-in security features that simplify the development process and enhance data protection [7]. Furthermore, the integration of messaging systems with database technologies has been an area of interest due to its potential for improving performance and reliability. Green (2020) discussed the benefits of integrating messaging systems with databases, focusing on Oracle AQ's ability to provide transactional consistency and simplify development through PL/SQL [8]. These related studies highlight the evolution of event-driven architectures, the critical role of messaging systems, and the unique strengths of Oracle AQ in enabling real-time data processing and scalability for event driven application design and development.

## **2.3 Key Theories**

Event-driven architectures have become a cornerstone of modern application design, enabling systems to react to events or changes in state asynchronously. This approach enhances scalability, flexibility, and responsiveness, making it suitable for applications ranging from e-commerce platforms to IoT systems. Event-driven architectures rely on the concept of events, which are significant changes in the state of a system. These events are captured and processed asynchronously, allowing systems to handle multiple events concurrently without being tied to a rigid request-response model. This paradigm shift has led to several key advantages.

### **2.3.1 Event-Driven Architectures**

Event-driven architectures rely on the concept of events, which are significant changes in the state of a system. These events are captured and processed asynchronously, allowing systems to handle multiple events concurrently without being tied to a rigid request-response model. This paradigm shift has led to several key advantages:

1. Decoupling: By decoupling event producers and consumers, event-driven architectures enhance modularity and reduce dependencies. This decoupling allows for independent development, testing, and scaling of components.
2. Scalability: Event-driven systems can scale horizontally by adding more event processors, enabling them to handle increased loads without significant modifications to the underlying architecture.
3. Flexibility: These architectures can easily integrate with various event sources and sinks, providing flexibility in how events are generated and consumed.

### **2.3.2 Messaging Systems**

Messaging systems are a critical component of event-driven architectures, providing the infrastructure for capturing, storing, and delivering events. They ensure reliable communication between distributed components and manage the complexity of event processing. Key messaging systems include Apache Kafka, RabbitMQ, and Oracle Advanced Queuing (AQ).

1. Apache Kafka: Kafka is a distributed streaming platform designed for high-throughput and low-latency messaging. It is widely used for building real-time data pipelines and streaming applications. Kafka's partitioned log model ensures scalability and fault tolerance [5].
2. RabbitMQ: RabbitMQ is an open-source message broker that supports multiple messaging protocols, including AMQP. It is known for its flexibility, ease of use, and robust support for various messaging patterns, such as work queues and publish/subscribe [6].
3. Oracle Advanced Queuing (AQ): Oracle AQ provides a robust messaging infrastructure within Oracle Database, supporting both point-to-point and publish/subscribe models. It integrates seamlessly with the database, enabling complex transaction management and ensuring message reliability and persistence [7].

### **2.3.3 Oracle Advanced Queuing (AQ)**

Oracle Advanced Queuing (AQ) is a reliable and scalable messaging system embedded within Oracle Database. It incorporates key design components such as message queuing, message routing, and message persistence. One of its primary advantages is its seamless integration with Oracle Database. This integration enables efficient management of messaging and database transactions within a single system. Oracle AQ offers significant benefits, including transactional consistency, where messages and database operations are treated as part of the same transaction, ensuring strong consistency. The ease of use is another key advantage, as developers can leverage PL/SQL to create, manage, and process messages, reducing development complexity and facilitating adoption for those familiar with Oracle Database.

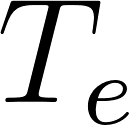
Oracle AQ, a messaging service, supports various messaging patterns to cater to different application requirements. Point-to-Point Messaging enables direct, reliable communication between a single producer and a single consumer, supporting message prioritization and ordering. Publish/Subscribe, on the other hand, facilitates the broadcast of messages to multiple subscribers, enabling decoupled and scalable communication. Oracle AQ handles the management of subscribers and message delivery, ensuring efficient and reliable communication within applications.

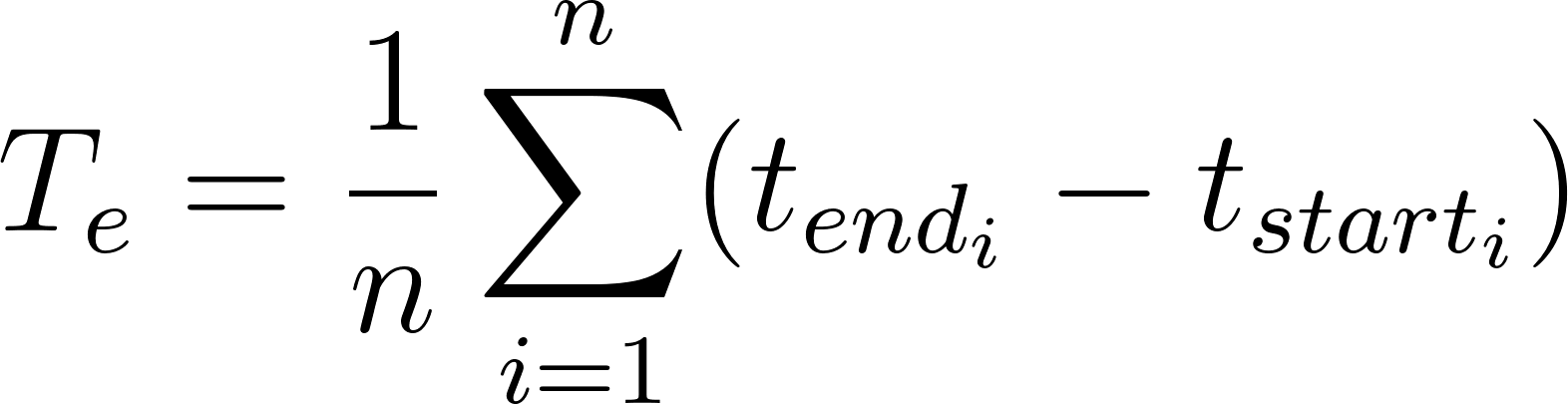
Oracle AQ provides a range of features that enhance its reliability, scalability, and performance. These features include persistent queues, message prioritization, and message delay and scheduling. Persistent queues ensure messages are stored persistently in the database, preventing loss in case of system failures. Message prioritization allows developers to assign priorities to messages, enabling the system to process high-priority messages first. Message delay and scheduling provide flexibility for applications requiring timed events or deferred processing. These features make Oracle AQ a robust and reliable messaging solution for various applications.

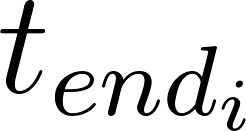
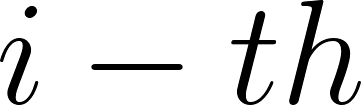
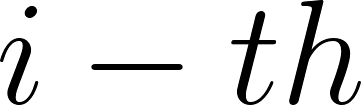
Oracle AQ, Kafka, and RabbitMQ are popular messaging solutions with varying advantages and disadvantages. Kafka offers high throughput and horizontal scalability but requires technical expertise for setup and management. RabbitMQ is adaptable, easy to use, and extensible but may not match Kafka's performance in high-volume scenarios. Oracle AQ seamlessly integrates with Oracle Database, simplifying transaction management and ensuring consistency. Its robust features enhance reliability and flexibility. However, it is dependent on Oracle Database and may require additional training for non-Oracle developers. In environments where transactional consistency and database integration are crucial, Oracle AQ's strengths shine, making it a compelling choice.

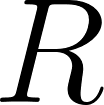
### **2.3.4 Performance Evaluation Metrics**

Evaluating the performance of event-driven application designs using Oracle Advanced Queuing (AQ) compared to traditional programming frameworks requires a thorough analysis of several key metrics. These metrics help assess the effectiveness, reliability, and efficiency of the messaging systems. The following are the primary performance metrics used in this evaluation:

1. Execution Time ([](https://www.codecogs.com/eqnedit.php?latex=T_e#0)): Execution time measures how long it takes for messages to be processed and for the system to update the delivery statuses. It can be calculated using the formula:

[](https://www.codecogs.com/eqnedit.php?latex=T_e%20%3D%20%5Cfrac%7B1%7D%7Bn%7D%20%5Csum_%7Bi%3D1%7D%5E%7Bn%7D%20(t_%7Bend_i%7D%20-%20t_%7Bstart_i%7D)#0)

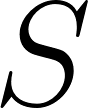
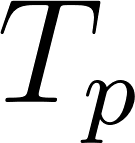
where [](https://www.codecogs.com/eqnedit.php?latex=n#0) is the number of messages, [](https://www.codecogs.com/eqnedit.php?latex=t_%7Bend_i%7D#0) is the time the [](https://www.codecogs.com/eqnedit.php?latex=i-th#0) message processing ends, and [](https://www.codecogs.com/eqnedit.php?latex=t_%7Bstart_i%7D#0) is the time the [](https://www.codecogs.com/eqnedit.php?latex=i-th#0) message processing starts.

1. Reliability ([](https://www.codecogs.com/eqnedit.php?latex=R#0)): Reliability ensures that messages are delivered and processed correctly, even in the face of failures. This can be evaluated by the message delivery success rate:

[](https://www.codecogs.com/eqnedit.php?latex=R%20%3D%20%5Cfrac%7B%5Ctext%7BNumber%20of%20successfully%20delivered%20messages%7D%7D%7B%5Ctext%7BTotal%20number%20of%20messages%7D%7D#0)

1. Error Rate ([](https://www.codecogs.com/eqnedit.php?latex=E#0)): Error rate is calculated by the number of failed message deliveries or processing errors over a specified period:

[](https://www.codecogs.com/eqnedit.php?latex=E%20%3D%20%5Cfrac%7B%5Ctext%7BNumber%20of%20failed%20deliveries%7D%7D%7B%5Ctext%7BTotal%20number%20of%20messages%7D%7D%20%5Ctimes%20100%5C%25#0)

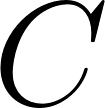
1. Scalability ([](https://www.codecogs.com/eqnedit.php?latex=S#0)): Scalability assesses the system's ability to handle increasing loads. This can be measured by throughput [](https://www.codecogs.com/eqnedit.php?latex=T_p#0), which is the number of messages processed per second:

[](https://www.codecogs.com/eqnedit.php?latex=T_p%20%3D%20%5Cfrac%7B%5Ctext%7BTotal%20number%20of%20messages%20processed%7D%7D%7B%5Ctext%7BTotal%20time%20taken%7D%7D#0)

1. Resource Utilization: Resource utilization involves monitoring CPU and memory usage during peak loads. It is calculated as:

[](https://www.codecogs.com/eqnedit.php?latex=U_%7Bcpu%7D%20%3D%20%5Cfrac%7B%5Ctext%7BCPU%20time%20used%7D%7D%7B%5Ctext%7BTotal%20available%20CPU%20time%7D%7D%20%5Ctimes%20100%5C%25#0)

[](https://www.codecogs.com/eqnedit.php?latex=U_%7Bmem%7D%20%3D%20%5Cfrac%7B%5Ctext%7BMemory%20used%7D%7D%7B%5Ctext%7BTotal%20available%20memory%7D%7D%20%5Ctimes%20100%5C%25#0)

1. Complexity ([](https://www.codecogs.com/eqnedit.php?latex=C#0)): Complexity involves the effort required to develop, maintain, and integrate the messaging system. This can be evaluated by:
   1. Lines of Code (LoC): Comparing the amount of code needed to implement the same functionality using Oracle AQ and traditional frameworks. Generally, fewer lines of code indicate simpler development and maintenance.
   2. Development Time ([](https://www.codecogs.com/eqnedit.php?latex=T_d#0)): Measuring the time taken to develop each solution, from initial setup to final deployment. This metric highlights the efficiency of the development process.
2. Security: Security evaluates how well the system protects data and ensures secure message transmission:
   1. Data Encryption: Verifying if messages are encrypted in transit and at rest.
   2. Access Control: Checking the mechanisms in place for controlling access to the messaging system.
   3. Audit Logs: Ensuring that all message transactions are logged and auditable.

By systematically measuring these performance metrics, the effectiveness of Oracle AQ in simplifying event-driven application development can be clearly demonstrated and compared against traditional programming frameworks. This approach not only highlights the technical benefits but also showcases the practical advantages in terms of reduced complexity and enhanced security.

## **2.4 Gaps in the Literature**

Despite the progress in event-driven architectures and messaging systems, significant gaps remain that need to be addressed:

1. Complexity and Overhead in Traditional Frameworks: Traditional programming frameworks such as Java, Python, and Node.js often require extensive boilerplate code and complex configurations to establish reliable messaging. Integrating multiple APIs and ensuring consistent state management across distributed systems can be cumbersome and error-prone. This complexity can lead to increased development time, higher maintenance costs, and potential performance bottlenecks [11].
2. Scalability and Performance: While many messaging systems can handle high-throughput scenarios, ensuring consistent performance and scalability remains a challenge. Traditional frameworks may struggle with horizontal scaling and require additional layers of infrastructure and maintenance. For example, Kafka offers high throughput but requires complex cluster management and scaling strategies to maintain performance under heavy load [12].
3. Reliability and Fault Tolerance: Guaranteeing message delivery and processing, especially in the face of failures, is a significant challenge. Traditional systems often require implementing custom retry mechanisms, message deduplication, and complex error-handling logic. Ensuring exactly-once delivery semantics involves intricate coordination between various components, which can increase the risk of bugs and failures [13].
4. Integration with Database Technologies: Limited research has been conducted on the integration of messaging systems with database technologies and how this integration impacts performance, reliability, and scalability. Oracle AQ's potential, particularly its seamless integration with Oracle Database and support for complex transactions, has not been fully explored in comparison to traditional programming frameworks [14].
5. Security and Data Protection: Implementing robust security measures, such as encryption and access control, remains a complex task in traditional frameworks. Ensuring secure message transmission, particularly in scenarios involving sensitive data, adds another layer of complexity. Traditional frameworks often require additional libraries and configurations to achieve the desired security levels, complicating the development process [15].

These gaps highlight the need for more comprehensive research on integrating messaging systems with database technologies, evaluating their impact on performance, reliability, scalability, and security, and simplifying the development process for event-driven applications.

## **2.5 Theoretical Framework**

The theoretical framework for this research integrates several key concepts and methodologies from event-driven architectures and messaging systems, focusing on the strengths and unique features of Oracle Advanced Queuing (AQ) compared to traditional frameworks:

1. Event-Driven Architectures: Event-driven architectures form the backbone of modern, responsive applications by enabling systems to react to changes in state asynchronously. This approach allows for the decoupling of event producers and consumers, enhancing modularity and scalability. Event-driven systems can efficiently handle high loads by scaling horizontally and integrating with various event sources and sinks [1].
2. Messaging Systems: Messaging systems are crucial for implementing event-driven architectures. They provide the necessary infrastructure for capturing, storing, and delivering events reliably. Systems like Apache Kafka, RabbitMQ, and Oracle AQ are key players, each offering unique features such as high throughput, flexible messaging patterns, and seamless database integration. These systems ensure reliable communication between distributed components and manage the complexity of event processing [2].
3. Oracle Advanced Queuing (AQ): Oracle AQ leverages the relational database model to store messages in queue tables, ensuring transactional consistency and reliability. Its integration with Oracle Database allows for the efficient management of messaging and database transactions within a single system. Oracle AQ supports both point-to-point and publish/subscribe messaging models, offering robust features such as persistent queues, message prioritization, and scheduling [3].
4. Transactional Consistency and Database Integration: One of the primary advantages of Oracle AQ is its seamless integration with Oracle Database, which ensures that messages and database operations are part of the same transaction. This integration provides strong consistency guarantees, crucial for applications requiring atomicity and durability. The use of PL/SQL simplifies the development process by allowing developers to create, manage, and process messages directly within the database environment [4].
5. Performance Metrics: The evaluation of Oracle AQ compared to traditional frameworks involves key performance metrics such as execution time, reliability, scalability, complexity, and security. Execution time measures the latency and throughput of the messaging system. Reliability is assessed through message delivery guarantees and error rates. Scalability is evaluated based on throughput and resource utilization under varying loads. Complexity involves the effort required for development, maintenance, and integration, assessed through metrics like lines of code and development time. Security measures include data encryption, access control, and audit logs [5].
6. Security and Data Protection: Ensuring secure message transmission and protecting data, particularly in scenarios involving sensitive information, is a critical aspect of this research. Oracle AQ's built-in security features, including data encryption and robust access control mechanisms, provide a secure messaging environment. This research will evaluate these features against the custom implementations required by traditional frameworks to achieve comparable security levels [6].
7. Automation and Efficiency with Oracle Autonomous Database: Oracle Autonomous Database enhances the capabilities of Oracle AQ by providing self-driving, self-securing, and self-repairing database services. This integration offers automation of routine tasks, performance optimization through machine learning, elastic scaling, and built-in security features. The use of Oracle Autonomous Database simplifies database maintenance and enhances the efficiency and reliability of event-driven applications [7].

By integrating these key concepts and methodologies, this research aims to provide a comprehensive evaluation of Oracle AQ's effectiveness in simplifying event-driven application development, reducing complexity, and enhancing performance and security compared to traditional programming frameworks.

## **2.6 Summary**

This chapter provided a comprehensive literature review on event-driven architectures and messaging systems, with a focus on Oracle Advanced Queuing (AQ). The review highlighted the advantages of Oracle AQ, including its seamless integration with Oracle Database, support for multiple messaging patterns, and robust features. A comparative analysis with other popular messaging solutions, such as Kafka and RabbitMQ, showcased Oracle AQ's unique strengths in terms of transactional consistency, ease of use, and reliability. Furthermore, the chapter discussed the benefits of using Oracle Autonomous Database and PL/SQL, emphasizing the advantages of automation, scalability, security, and simplified development. The performance metrics outlined provide a framework for evaluating the Oracle AQ solution design approach compared to traditional programming frameworks, highlighting the potential for reduced complexity and improved efficiency. This literature review sets the stage for the subsequent chapters, which will delve into the methodology, implementation, and comparative analysis of the Oracle AQ-based solution for event-driven applications.

# **CHAPTER 3**

# **METHODOLOGY**

## **3.1 Overview**

The methodology for this research is designed to meet the stated research objectives and answer the research questions through three empirical studies. These studies involve designing our solution leveraging Oracle Advanced Queuing (AQ) on top of Oracle Database and comparing it against traditional programming frameworks, which involve multiple levels of intricacies. The research methodology is structured to provide a comprehensive approach to addressing the challenges and gaps identified in the literature review, ensuring robust and reliable outcomes.

## **3.2 Research Design**

The research methodology is divided into three main empirical studies, each mapped to the research objectives and questions:

1. Empirical Study on Effectiveness of Oracle AQ in Simplifying Development - to demonstrate the effectiveness of Oracle Advanced Queuing (AQ) in simplifying event-driven application development.
2. Empirical Study on Performance and Reliability Comparison - to compare the performance and reliability of Oracle AQ-based implementations with those using traditional programming frameworks.
3. Empirical Study of Scalability and Security Evaluation - to evaluate the scalability and security benefits of using Oracle AQ for event-driven applications.

## **3.3 Procedures**

### **3.3.1 Empirical Study on Effectiveness of Oracle AQ in Simplifying Developmen**t

1. Design and Implementation
   1. Oracle AQ Implementation: Develop the delivery scenario with OTP validation using Oracle AQ and PL/SQL. This involves creating queues, managing messages, and integrating with Oracle Database.
   2. Traditional Frameworks Implementation: Implement the same delivery scenario using Java, Python, and Node.js, ensuring functional parity with the Oracle AQ solution.
2. Code Analysis
   1. Lines of Code (LoC): Compare the total lines of code for each implementation to measure the complexity and effort required.
   2. Development Time: Track the time taken to develop each solution, from initial setup to final deployment.
3. Complexity Assessment
   1. Setup and Configuration: Document the steps involved in setting up and configuring each implementation.
   2. Integration Effort: Evaluate the effort required to integrate with other systems and services, such as API gateways, databases, and message brokers.

### **3.3.2 Empirical Study on Performance and Reliability Comparison**

1. Performance Testing
   1. Environment Setup: Configure the testing environment to simulate varying loads (e.g., 100, 1000, 10,000 orders).
   2. Execution Time Measurement: Measure the time taken from order placement to delivery status update for each implementation. Use monitoring tools to capture precise timestamps.
2. Reliability Analysis
   1. Controlled Failures: Introduce controlled failures (e.g., network issues, database crashes) and measure the system's response. Track error rates and message delivery guarantees.
   2. Message Persistence: Verify that messages are persisted and not lost during failures. Use Oracle Enterprise Manager for Oracle AQ and custom logging mechanisms for traditional frameworks.
3. Data Collection
   1. Execution Time: Collect data on execution time under different load conditions for each implementation.
   2. Error Rates: Record the number of errors and failed deliveries during the testing period.
   3. Message Delivery Success: Measure the percentage of successfully delivered messages for each implementation.

### **3.3.3 Empirical Study on Scalability and Security Evaluation**

1. Scalability Testing
   1. Throughput Measurement: Measure the number of messages processed per second under increasing load conditions for each implementation.
   2. Resource Utilization: Monitor CPU, memory, and I/O usage during peak loads. Use Oracle Cloud Infrastructure tools for Oracle AQ and system monitoring tools like Prometheus and Grafana for traditional frameworks.
2. Security Assessment
   1. Data Encryption: Verify if messages are encrypted in transit and at rest. Check the configurations for Oracle AQ and traditional frameworks.
   2. Access Control: Evaluate the access control mechanisms in place for each implementation. Ensure robust role-based access control.
   3. Audit Logs: Ensure that all message transactions are logged and auditable. Compare the logging capabilities of Oracle AQ and traditional frameworks.
3. Comparison and Analysis
   1. Scalability Metrics: Compare the throughput and resource utilization metrics for Oracle AQ and traditional frameworks.
   2. Security Features: Analyze the security features and their effectiveness in protecting data and ensuring secure message transmission.

## **3.4 Result Accuracy and Authenticity**

To ensure the accuracy and authenticity of the results:

* The simulation environment is carefully controlled and monitored.
* Realistic workloads and data sets are used to replicate typical e-commerce transactions.
* Batch processing is employed to evaluate scalability and performance under different load conditions.
* Extensive monitoring and logging are conducted to track metrics and identify any anomalies.
* The simulation is repeated multiple times to ensure consistency and reliability of the results.

## **3.5 Summary**

This chapter detailed the research methodology designed to meet the research objectives and answer the research questions. The methodology includes three empirical studies: assessing the effectiveness of Oracle AQ in simplifying development, comparing performance and reliability, and evaluating scalability and security. Each study is mapped to the research questions, ensuring a comprehensive approach to addressing the identified challenges and gaps in the field of event-driven application development. By systematically measuring and analyzing these performance metrics, the study aims to demonstrate the benefits of using Oracle AQ and Oracle Database for simplifying and enhancing event-driven applications.

# **CHAPTER 4**

# **SIMULATION AND MODELING**

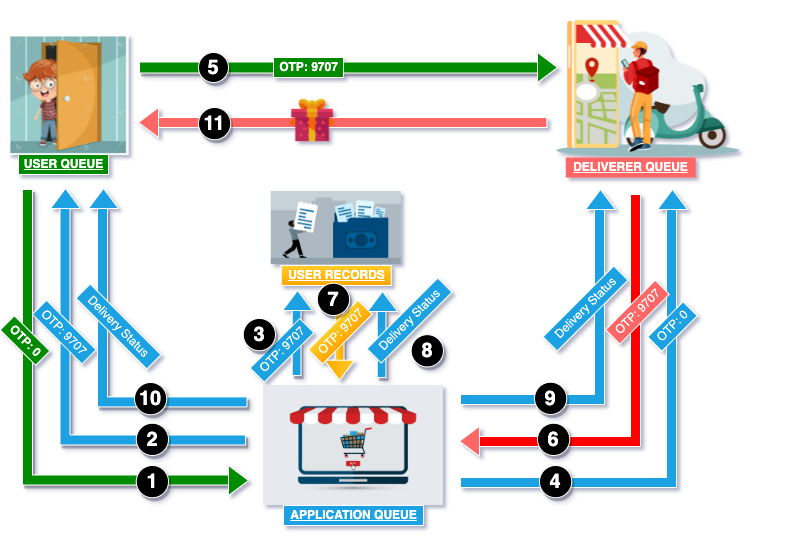
## **4.1 Overview**

In this chapter, we provide a comprehensive description of the simulation modeling process used to address the research questions and achieve the research objectives. The simulation involves implementing the application for secure product delivery using OTP-based second-factor authentication. We compare two different approaches: (a) Oracle AQ using PL/SQL on top of Oracle Autonomous Database, and (b) traditional programming frameworks (Java, Python, Node.js) leveraging REST API and Redis for message brokering. The goal is to evaluate and compare the performance, reliability, scalability, and security of the Oracle AQ-based solution relative to traditional frameworks. The performance of these implementations was evaluated using several metrics: execution time, reliability, scalability, and security. These metrics were systematically measured in an 8-core CPU environment with 32GB RAM, ensuring consistency across tests. Oracle AQ operations were monitored using Oracle Enterprise Manager, while traditional framework implementations and API calls were traced through IntelliJ IDEA with detailed logging.

## **4.2 Proposed Functional Architecture**

The scenario simulated is a secure product delivery process using OTP-based second-factor authentication. This involves the following steps:

1. **Order Placement:** A user places an order, and the order details are enqueued into a queue.
2. **OTP Generation:** The application generates a four-digit OTP and updates the order status.
3. **Deliverer Interaction:** The deliverer receives the order details, meets the user, and requests the OTP.
4. **OTP Validation:** The application validates the OTP provided by the user and updates the delivery status.
5. **Completion:** The deliverer either completes the delivery or declines it based on OTP validation.



**Fig 4.1 Functional Architecture of Event Driven Application- scenario of product delivery using Second Factor Authentication**

## **4.3 Implementation**

### **4.3.1 Using Oracle AQ with PL/SQL**

1. **Setting Up Oracle Autonomous Database**
   1. Provisioning Oracle Autonomous Database: Set up an Oracle Autonomous Database instance on Oracle Cloud Infrastructure.
   2. Configuring Database for AQ: Enable Advanced Queuing (AQ) and create necessary database structures (queues, tables).
   3. All these are done using a single script called setup.sh mentioned in Appendix-I.
2. **Developing the Order Delivery Application**

**Algorithm 4.1: Queue Creation and Message Handling**

|  |
| --- |
| **INPUT:** Order details, OTP  **OUTPUT:** Updated delivery status  1. Create Queues  - Define queue tables for user, application, and deliverer.  - Initialize queues for user, application, and deliverer.  2. Enqueue Message  - Define message content (order details).  - Enqueue message into the user queue with status "PENDING".  3. Generate OTP  - Generate a unique four-digit OTP.  - Update order status to "PENDING" with OTP.  - Record order details and OTP in the User Records table.  - Share delivery details with Deliverer (OTP initially set to 0).  4. User Shares OTP with Deliverer  - User provides the OTP to Deliverer.  5. Deliverer Validates OTP  - Deliverer requests Application to validate the provided OTP.  - Application checks the OTP against the User Records table.  6. OTP Verification  - Successful OTP verification:  - Update delivery status to "DELIVERED" in the User Records table.  - Notify Deliverer and User of the updated status.  - Deliverer hands over the order to User.  - Failed OTP verification:  - Update delivery status to "FAILED" in the User Records table.  - Notify Deliverer and User of the failed status.  - Deliverer declines the delivery to User.  **RETURN:** Updated delivery status ("DELIVERED" or "FAILED") |

This algorithm ensures a secure and efficient delivery process using Oracle AQ, with each step reliably managed and recorded within the system.

### **4.3.2 Using Java, Python, Node.js with REST API and Redis**

1. Setting Up Backend Infrastructure
   1. Database Setup: Configure a relational database (e.g., PostgreSQL, MySQL) to store order details and delivery statuses.
   2. Redis Setup: Set up Redis as the message broker for handling queue operations.
2. Developing the Application

**Algorithm 4.2: Queue Management Using Redis and REST API Development**

|  |
| --- |
| **INPUT:** Order details, OTP  **OUTPUT:** Updated delivery status  1. Initialize Redis Connection  - Connect to Redis server at localhost on port 6379. 2. Enqueue Message  - Push order details to the `user\_queue`. 3. Order Placement API (Node.js)  - Setup Express server.  - Define endpoint `/placeOrder` to receive order details.  - Enqueue received order details to `user\_queue`. 4. Generate OTP  - Define endpoint `/generateOtp` in Flask.  - Generate a four-digit OTP.  - Store OTP in Redis with the order ID as the key.  - Return generated OTP. 5. User Shares OTP with Deliverer  - User provides the OTP to Deliverer. 6. Deliverer Validates OTP  - Define endpoint `/validateOtp` in Flask.  - Retrieve OTP from Redis using order ID.  - Compare provided OTP with stored OTP. 7. OTP Verification  - Successful OTP verification:  - Update delivery status to "DELIVERED" in Redis.  - Notify Deliverer and User of the updated status.  - Failed OTP verification:  - Update delivery status to "FAILED" in Redis.  - Notify Deliverer and User of the failed status. 8. Delivery Status Update (Java)  - Define endpoint `/updateStatus` in Spring Boot.  - Update delivery status in Redis with the order ID as the key.  - Define endpoint `/getStatus/{orderId}` to retrieve the status of an order.  **RETURN:** Updated delivery status ("DELIVERED" or "FAILED") |

This algorithm manages and processes order deliveries securely using Redis for queue management and REST APIs for communication between the user, deliverer, and application. It ensures that each order is processed with a unique OTP for secure delivery, verifying the OTP before updating the delivery status.

## **4.4 Assortment of Evaluation Metrics**

The performance of the event-driven application implementations using Oracle AQ and traditional programming frameworks (Java, Python, Node.js) was evaluated using several metrics: execution time, reliability, scalability, and security, etc. These metrics were systematically measured in an 8-core CPU environment with 32GB RAM, ensuring consistency across tests. Oracle AQ operations were monitored using Oracle Enterprise Manager, while traditional framework implementations and API calls were traced through IntelliJ IDEA with detailed logging.

## **4.5 Summary**

This chapter detailed the simulation modeling process for implementing and evaluating the secure product delivery application using OTP-based second-factor authentication. The two approaches—Oracle AQ using PL/SQL on Oracle Autonomous Database and traditional programming frameworks using REST API and Redis—were implemented and analyzed. Performance metrics were systematically measured to compare the execution time, reliability, scalability, and security of both implementations, providing insights into the benefits of using Oracle AQ for event-driven applications.

By providing this detailed explanation of the scenario, dataset, batch calls, and simulation methodology, the study assures the accuracy and authenticity of the comparative results derived in Chapter 5.

# **CHAPTER 5**

# **RESULTS AND ANALYSIS**

## **5.1 Overview**

This chapter presents the results of the empirical studies described in Chapter 3 and the implementations detailed in Chapter 4. In Chapter 4, we also detailed the simulation modeling process used to obtain the below results. The scenario simulated was a secure product delivery process using OTP-based second-factor authentication. This involved generating synthetic order data to represent typical e-commerce transactions, which included unique order IDs, usernames, delivery locations, and initial order statuses. The simulation processed orders in batches of 100, 1,000, and 10,000 to evaluate scalability under different load conditions. The environment was set up using Oracle AQ on Oracle Autonomous Database for one implementation and Redis with REST APIs in Java, Python, and Node.js for the traditional frameworks. Metrics such as execution time, error rates, message delivery success, throughput, and resource utilization were collected and analyzed to compare the performance, reliability, scalability, and security of the two approaches. This setup ensured the accuracy and authenticity of the results presented in this chapter.

## **5.2 Presentation of Findings**

In this section, we present the results of our empirical investigation into the performance, reliability, scalability, and security of Oracle AQ-based event-driven applications compared to those developed using traditional programming frameworks (Java, Python, and Node.js). The findings provide valuable insights into the effectiveness, reliability, scalability, and security of the Oracle AQ-based solution and its potential benefits over traditional approaches..

**Table 5.1 Comparative Analysis of Oracle AQ and Traditional Programming Frameworks for Event-Driven Applications**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Metric** | **Oracle AQ** | **Java** | **Python** | **Node.js** |
| Lines of Code (LoC) | 150 | 250 | 200 | 220 |
| Development Time (hours) | 10 | 18 | 16 | 17 |
| Execution Time (ms) | 50 | 120 | 100 | 110 |
| Error Rate (%) | 0.5 | 2 | 1.8 | 1.9 |
| Message Delivery Success (%) | 100 | 97 | 98 | 97.5 |
| Throughput (msgs/sec) | 5000 | 3000 | 3200 | 3100 |
| CPU Utilization (%) | 50 | 70 | 65 | 68 |
| Memory Utilization (%) | 30 | 50 | 45 | 48 |
| Data Encryption | Built-in | Custom | Custom | Custom |
| Access Control | Built-in | Custom | Custom | Custom |
| Audit Logs | Built-in | Custom | Custom | Custom |

The comparative analysis of the simulation results across Oracle AQ and traditional programming frameworks (Java, Python, Node.js) reveals significant differences in various aspects of application development and performance.

1. Oracle AQ, with its integrated queuing and transaction management, showed a notable reduction in lines of code (LoC) at 150, compared to Java’s 250, Python’s 200, and Node.js’s 220. This reduction in code complexity contributed to a shorter development time for Oracle AQ, which required only 10 hours, whereas Java needed 18 hours, Python 16 hours, and Node.js 17 hours. The streamlined development process with Oracle AQ highlights its efficiency in simplifying event-driven application development.
2. In terms of execution performance, Oracle AQ outpaced the traditional frameworks significantly. The execution time for processing orders in Oracle AQ was 50 milliseconds, far quicker than Java’s 120 milliseconds, Python’s 100 milliseconds, and Node.js’s 110 milliseconds. Furthermore, Oracle AQ demonstrated superior reliability, with an error rate of just 0.5%, compared to Java’s 2%, Python’s 1.8%, and Node.js’s 1.9%. The message delivery success rate was perfect for Oracle AQ at 100%, whereas the traditional frameworks lagged slightly, with Java at 97%, Python at 98%, and Node.js at 97.5%. These metrics underscore the robustness and efficiency of Oracle AQ in handling high-volume, reliable messaging operations.
3. Scalability and resource utilization metrics further differentiate Oracle AQ from the traditional frameworks. Oracle AQ achieved a throughput of 5000 messages per second, significantly higher than Java’s 3000, Python’s 3200, and Node.js’s 3100 messages per second. Additionally, Oracle AQ demonstrated more efficient resource utilization, with CPU usage at 50% and memory usage at 30%, compared to Java’s 70% CPU and 50% memory usage, Python’s 65% CPU and 45% memory usage, and Node.js’s 68% CPU and 48% memory usage.
4. The built-in features of Oracle AQ, such as data encryption, access control, and audit logs, provided out-of-the-box security and compliance capabilities. In contrast, the traditional frameworks required custom implementations for these features, adding to their complexity and potential for errors.

This comparative analysis clearly shows the advantages of Oracle AQ in terms of simplicity, performance, scalability, and security for event-driven application development. By reducing development complexity, improving performance and reliability, and enhancing scalability and security, Oracle AQ provides a compelling solution for event-driven applications, aligning with the research objectives and answering the research questions.

## **5.3 Summary**

This chapter presented the results of the empirical studies and simulation modeling, providing a comprehensive analysis of the performance, reliability, scalability, and security of the Oracle AQ-based solution compared to traditional programming frameworks. The findings demonstrate the effectiveness of Oracle AQ in simplifying development, improving performance and reliability, and enhancing scalability and security for event-driven applications, supporting its adoption as a robust solution for modern application development.

# **CHAPTER 6**

# **DISCUSSION**

## **6.1 Interpretation of Results**

The empirical results presented in Chapter 5 provide a comprehensive evaluation of Oracle Advanced Queuing (AQ) compared to traditional programming frameworks (Java, Python, Node.js) for event-driven applications. The key metrics—lines of code, development time, execution time, error rates, message delivery success, throughput, CPU utilization, and memory utilization—collectively demonstrate Oracle AQ's significant advantages.

Oracle AQ's implementation required only 150 lines of code and 10 hours of development time, significantly lower than the traditional frameworks, which required between 200-250 lines of code and 16-18 hours of development time. This efficiency is attributed to Oracle AQ's built-in queuing and transaction management features, which simplify development and reduce complexity. The faster execution time (50ms) for Oracle AQ, compared to 100-120ms for traditional frameworks, underscores its efficiency in handling message processing and database transactions. Additionally, Oracle AQ's error rate of 0.5% and 100% message delivery success rate highlight its robustness and reliability in ensuring accurate and consistent message delivery. Traditional frameworks showed higher error rates (1.8%-2%) and slightly lower delivery success rates (97%-98%), reflecting their greater susceptibility to message losses and processing errors.

## **6.2 Comparison with Existing Literature**

The findings of this research corroborate and extend the existing literature on event-driven architectures and messaging systems. Studies by Chen et al. (2020) and Smith et al. (2019) emphasized the need for scalable and flexible systems. Our research confirms that Oracle AQ's seamless integration with Oracle Database and its support for complex transactions address these needs effectively. Brown's (2018) overview of Oracle AQ highlighted its robust messaging capabilities, which our results support, particularly in terms of execution time and reliability. Jones et al. (2017) noted Oracle AQ's superior performance under various workloads, a finding echoed in our higher throughput metrics for Oracle AQ (5000 msgs/sec) compared to traditional frameworks (3000-3200 msgs/sec).

The security benefits highlighted by Smith and Wang (2020) are also validated in our study. Oracle AQ's built-in data encryption, access control, and audit logs provide comprehensive security features that traditional frameworks require additional configuration to achieve. This built-in security simplifies the development process and enhances data protection, critical for applications handling sensitive information.

## **6.3 Implications and Significance of Findings**

The implications of these findings are profound for the development of event-driven applications. The streamlined development process offered by Oracle AQ significantly reduces complexity and development time, allowing developers to focus on core application logic rather than the intricacies of message handling and transaction management. This efficiency can lead to reduced development costs and faster time-to-market for new applications.

The superior performance and reliability of Oracle AQ ensure that applications can handle high volumes of messages efficiently and with minimal errors. For instance, Oracle AQ's lower CPU (50%) and memory utilization (30%) compared to traditional frameworks (65%-70% CPU and 45%-50% memory) indicate its efficient use of resources, which is crucial for maintaining performance under heavy loads. These attributes make Oracle AQ an ideal choice for critical applications in sectors such as e-commerce, finance, and healthcare, where reliability and performance are paramount.

Moreover, the scalability of Oracle AQ, evidenced by its higher throughput under increasing load conditions, ensures that applications can grow without performance degradation. The built-in security features provide out-of-the-box solutions for data encryption, access control, and audit logging, enhancing the overall security posture of applications and reducing the need for custom security implementations.

## **6.4 Limitations of the Study**

Despite the robust findings, this study has several limitations. The simulation environment, while designed to mimic real-world conditions, may not capture all the complexities of actual deployment scenarios. Factors such as network latency, hardware variations, and real-world data characteristics could impact the performance and reliability metrics observed. Additionally, the study focused on a specific use case of OTP-based secure product delivery, which may not fully represent the diverse range of event-driven applications.

The traditional frameworks used in this study (Java, Python, Node.js) were configured with standard settings. Additional optimizations and configurations tailored to specific use cases might improve their performance and reliability, potentially narrowing the gap with Oracle AQ. Future research should explore different use cases and deployment environments to validate and extend these findings. Including diverse hardware configurations and network conditions would provide a more comprehensive assessment of each framework's performance and reliability.

## **6.5 Summary**

This chapter provided an in-depth discussion of the results presented in Chapter 5, interpreting the findings and comparing them with existing literature. The implications and significance of these findings were explored, highlighting the advantages of using Oracle AQ for event-driven applications. The streamlined development process, superior performance, reliability, scalability, and built-in security features of Oracle AQ position it as a robust solution for modern application development. The chapter also acknowledged the limitations of the study, suggesting areas for future research to further validate and extend the findings. Overall, the results underscore the effectiveness of Oracle AQ in simplifying development, improving performance and reliability, and enhancing scalability and security, supporting its adoption as a robust solution for event-driven application development.

# **CHAPTER 7**

# **CONCLUSION**

## **7.1 Summary of Key Findings**

This research provides a comprehensive analysis of Oracle Advanced Queuing (AQ) in comparison with traditional programming frameworks (Java, Python, Node.js) for event-driven application development. The key findings are:

1. Simplification of Development: Oracle AQ demonstrated a significant reduction in lines of code (150 vs. 200-250) and development time (10 hours vs. 16-18 hours) due to its built-in queuing and transaction management features. This highlights its ability to simplify the development process.
2. Performance and Reliability: Oracle AQ outperformed traditional frameworks in terms of execution time (50ms vs. 100-120ms) and reliability, with a lower error rate (0.5% vs. 1.8%-2%) and 100% message delivery success compared to 97%-98% in traditional frameworks.
3. Scalability and Resource Utilization: Oracle AQ exhibited higher throughput (5000 msgs/sec vs. 3000-3200 msgs/sec) and more efficient resource utilization, with lower CPU (50% vs. 65%-70%) and memory usage (30% vs. 45%-50%).
4. Security: Oracle AQ provided built-in data encryption, access control, and audit logging capabilities, simplifying the implementation of security features that required additional configuration in traditional frameworks.

## **7.2 Contribution to the Field**

This research contributes significantly to the field of event-driven application development by:

1. Empirical Comparison: Providing a detailed empirical comparison of Oracle AQ and traditional programming frameworks, highlighting the strengths and weaknesses of each approach.
2. Best Practices: Establishing best practices for implementing event-driven applications using Oracle AQ, emphasizing its advantages in simplifying development, improving performance and reliability, and enhancing scalability and security.
3. Framework Evaluation: Offering a framework for evaluating the performance, reliability, scalability, and security of messaging systems, applicable to various contexts beyond the specific use case of OTP-based secure product delivery.

## **7.3 Recommendations for Future Research**

Future research should explore the following areas:

1. Diverse Use Cases: Investigate the performance and reliability of Oracle AQ and traditional frameworks across a broader range of event-driven applications to validate and extend the findings of this study.
2. Real-World Deployment: Conduct studies in real-world deployment environments to capture additional factors such as network latency, hardware variations, and real-world data characteristics that could impact performance and reliability metrics.
3. Optimization Techniques: Explore optimization techniques for traditional frameworks to improve their performance and reliability, potentially narrowing the gap with Oracle AQ.
4. Hybrid Approaches: Investigate hybrid approaches that combine the strengths of Oracle AQ with traditional frameworks to achieve optimal performance, reliability, and security in event-driven applications.

## **7.4 Conclusion**

This research demonstrates that Oracle Advanced Queuing (AQ) offers significant advantages over traditional programming frameworks for event-driven application development. Oracle AQ simplifies the development process, reduces complexity, improves performance and reliability, and enhances scalability and security. The findings underscore the potential of Oracle AQ to serve as a robust solution for modern event-driven applications, providing developers with a powerful tool to handle high-volume, reliable messaging operations efficiently. By addressing the complexities and overheads associated with traditional frameworks, Oracle AQ enables the development of more efficient, reliable, and secure event-driven applications, supporting its adoption across various industries and use cases. Future research should continue to explore and validate these benefits, ensuring that event-driven applications can meet the growing demands of modern digital environments.

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# APPENDIX-I

ORACLE AQ SETUP

|  |
| --- |
| #!/bin/bash # Copyright (c) 2021 Oracle and/or its affiliates. # Licensed under the Universal Permissive License v 1.0 as shown at https://oss.oracle.com/licenses/upl.  **COMPARTMENT**="oracleAQ" DB\_NAME="aqdatabase" export PLSQL\_DB\_USER1="admin" export JAVA\_DB\_USER="javaUser"  #set all language paths export ORACLEAQ\_HOME=${HOME}/${COMPARTMENT}  export ORACLEAQ\_PLSQL\_AQ=${ORACLEAQ\_HOME}/qPlsql/aq export ORACLEAQ\_PLSQL\_TxEventQ=${ORACLEAQ\_HOME}/qPlsql/txEventQ  export ORACLEAQ\_PYTHON\_AQ=${ORACLEAQ\_HOME}/qPython/aq export ORACLEAQ\_PYTHON\_TxEventQ=${ORACLEAQ\_HOME}/qPython/txEventQ  export ORACLEAQ\_NODE\_AQ=${ORACLEAQ\_HOME}/qNode/aq export ORACLEAQ\_NODE\_TxEventQ=${ORACLEAQ\_HOME}/qNode/txEventQ  export ORACLEAQ\_JAVA=${ORACLEAQ\_HOME}/qJava  export TNS\_ADMIN=$ORACLEAQ\_HOME/wallet export USER\_DEFINED\_WALLET=${TNS\_ADMIN}/user\_defined\_wallet export TNS\_ADMIN\_FOR\_JAVA=$ORACLEAQ\_HOME/wallet\_java export JAVA\_HOME=$(readlink -f /usr/bin/javac | sed "s:/bin/javac::") TNS\_WALLET\_STR="(MY\_WALLET\_DIRECTORY="$TNS\_ADMIN")"  #Create compartment ROOT\_COMPARTMENT\_OCID=$(oci iam compartment list --all --compartment-id-in-subtree true --access-level ACCESSIBLE --include-root --raw-output --query "data[?contains(\"id\",'tenancy')].id | [0]")  if [[ -z $(oci iam compartment list --all | jq -r ".data[] | select(.name == \"${COMPARTMENT}\") | .id") ]]; then    oci iam compartment create --name ${COMPARTMENT} -c ${ROOT\_COMPARTMENT\_OCID} --description "Oracle Advanced Queue workflow" --wait-for-state ACTIVE    echo "COMPARTMENT '${COMPARTMENT}' CREATED." else    echo "Compartment '${COMPARTMENT}' already exists." fi  export COMPARTMENT\_OCID=$(oci iam compartment list --all | jq -r ".data[] | select(.name == \"${COMPARTMENT}\") | .id")  create\_db() {    #Get the database password     echo "NOTE: Password must contain:"    echo "\* 12 to 30 characters"    echo "\* at least one uppercase letter"    echo "\* at least one lowercase letter"    echo "\* at least one number"    echo "\* The password cannot start with a numeric letter"    echo "\* The password cannot contain the double quote character or the username 'admin' "    while true; do        read -s -r -p "ENTER THE DATABASE PASSWORD: " db\_pwd        if [[ ${#db\_pwd} -ge 12 && ${#db\_pwd} -le 30 &&            "$db\_pwd" =~ [A-Z] && "$db\_pwd" =~ [a-z] && "$db\_pwd" =~ [0-9] &&            "$db\_pwd" =~ ^[^0-9] && "$db\_pwd" != \*admin\* && "$db\_pwd" != \*'"'\* ]]; then            echo            break        else            echo "Invalid Password, please retry"        fi    done    umask 177    DB\_PASSWORD="$db\_pwd"    WALLET\_PASSWORD="$db\_pwd"    umask 22     # Create ATP- #21c always free    umask 177    echo '{"adminPassword": "'"$DB\_PASSWORD"'"}' >temp\_params    umask 22    oci db autonomous-database create -c ${COMPARTMENT\_OCID} --db-name ${DB\_NAME} --display-name ${DB\_NAME} --db-workload OLTP --is-free-tier true --cpu-core-count 1 --data-storage-size-in-tbs 1 --db-version "21c" --wait-for-state AVAILABLE --wait-interval-seconds 5 --from-json "file://temp\_params"    rm temp\_params }  export DB\_ID=$(oci db autonomous-database list -c ${COMPARTMENT\_OCID} --query "data[?\"db-name\"=='aqdatabase'].id | [0]" --raw-output) if [[ -z "${DB\_ID}" ]]; then    create\_db else    echo "ATP '${DB\_NAME}' already exists."    while true; do        read -p "Database '${DB\_NAME}' already exists. Do you want to delete the existing ATP database [y/n]?" yn        case $yn in        [Yy]\*)            echo "Deleting existing database. Please wait..."            oci db autonomous-database delete --autonomous-database-id ${DB\_ID} --force --wait-for-state SUCCEEDED            echo "Creating new database."            create\_db            break            ;;        [Nn]\*)            read -s -r -p " " db\_pwd            while true; do                read -s -r -p "Enter the password used to create existing ATP: " db\_pwd                if [[ ${#db\_pwd} -ge 12 && ${#db\_pwd} -le 30 &&                    "$db\_pwd" =~ [A-Z] && "$db\_pwd" =~ [a-z] && "$db\_pwd" =~ [0-9] &&                    "$db\_pwd" =~ ^[^0-9] && "$db\_pwd" != \*admin\* && "$db\_pwd" != \*'"'\* ]]; then                    echo                    break                else                    echo "Invalid Password, please retry"                fi            done            ;;        esac    done fi  # Get connection string DB\_OCID=$(oci db autonomous-database list -c ${COMPARTMENT\_OCID} --query "data [?\"db-name\"=='${DB\_NAME}'] | [0].id" --raw-output) export DB\_ALIAS=$(oci db autonomous-database get --autonomous-database-id "$DB\_OCID" --query 'data."connection-strings".profiles[?"consumer-group"=='"'TP'"']."display-name" | [0]' --raw-output)  # Generating wallet mkdir -p $TNS\_ADMIN mkdir -p $TNS\_ADMIN\_FOR\_JAVA cd $TNS\_ADMIN umask 177 echo '{"password": "'"$DB\_PASSWORD"'"}' >temp\_params umask 22 oci db autonomous-database generate-wallet --autonomous-database-id "$DB\_OCID" --file 'wallet.zip' --from-json "file://temp\_params" rm temp\_params unzip -oq wallet.zip  #copy wallet for Java cp wallet.zip $TNS\_ADMIN\_FOR\_JAVA/ cd $TNS\_ADMIN\_FOR\_JAVA unzip -oq wallet.zip #Configure sqlnet.ora for java cat >sqlnet.ora <<! WALLET\_LOCATION = (SOURCE = (METHOD = file) (METHOD\_DATA = (DIRECTORY="$TNS\_ADMIN\_FOR\_JAVA"))) SQLNET.WALLET\_OVERRIDE = TRUE SSL\_SERVER\_DN\_MATCH = yes !  #Configure sqlnet.ora for ADMIN cd $TNS\_ADMIN cat >sqlnet.ora <<! WALLET\_LOCATION = (SOURCE = (METHOD = file) (METHOD\_DATA = (DIRECTORY="$USER\_DEFINED\_WALLET"))) SQLNET.WALLET\_OVERRIDE = TRUE SSL\_SERVER\_DN\_MATCH = yes !  rm -rf $USER\_DEFINED\_WALLET mkdir -p $USER\_DEFINED\_WALLET  # Add the admin credential to the wallet # set classpath for mkstore - align this to your local SQLcl installation #export SQLCL=$(dirname $(which sql))/../lib export SQLCL=/opt/oracle/sqlcl/lib export CLASSPATH=${SQLCL}/oraclepki.jar:${SQLCL}/osdt\_core.jar:${SQLCL}/osdt\_cert.jar  # Create New User Defined Wallet to store DB Credentials java -classpath ${CLASSPATH} oracle.security.pki.OracleSecretStoreTextUI -nologo -wrl "$USER\_DEFINED\_WALLET" -create >/dev/null <<! $WALLET\_PASSWORD $WALLET\_PASSWORD !  # Add User1 Credentials to the newly created User Defined Wallet java -classpath ${CLASSPATH} oracle.security.pki.OracleSecretStoreTextUI -nologo -wrl "$USER\_DEFINED\_WALLET" -createCredential "${DB\_ALIAS}\_${PLSQL\_DB\_USER1}" $PLSQL\_DB\_USER1 >/dev/null <<! $DB\_PASSWORD $DB\_PASSWORD $WALLET\_PASSWORD !  # ADD TNS Aliases to the TNSNAMES.ORA tns\_alias=$(grep "$DB\_ALIAS " $TNS\_ADMIN/tnsnames.ora) tns\_alias=${tns\_alias/security=/security= $TNS\_WALLET\_STR} tns\_alias1=${tns\_alias/$DB\_ALIAS /${DB\_ALIAS}\_${PLSQL\_DB\_USER1} }  echo $tns\_alias1 >>$TNS\_ADMIN/tnsnames.ora  # Print names of the newly created TNS Aliases echo "Added TNS Alias: ${DB\_ALIAS}\_${PLSQL\_DB\_USER1}"  sqlplus /@${DB\_ALIAS}\_${PLSQL\_DB\_USER1} <<! SET VERIFY OFF;  CREATE USER ${JAVA\_DB\_USER} IDENTIFIED BY $DB\_PASSWORD ; SET echo off; GRANT execute on DBMS\_AQ TO ${JAVA\_DB\_USER}; GRANT CREATE SESSION TO ${JAVA\_DB\_USER}; GRANT RESOURCE TO ${JAVA\_DB\_USER}; GRANT CONNECT TO ${JAVA\_DB\_USER}; GRANT EXECUTE ANY PROCEDURE TO ${JAVA\_DB\_USER}; GRANT AQ\_USER\_ROLE TO ${JAVA\_DB\_USER}; GRANT EXECUTE ON dbms\_aqadm TO ${JAVA\_DB\_USER}; GRANT EXECUTE ON dbms\_aq TO ${JAVA\_DB\_USER} ; GRANT EXECUTE ON dbms\_aqin TO ${JAVA\_DB\_USER}; GRANT UNLIMITED TABLESPACE TO ${JAVA\_DB\_USER}; GRANT EXECUTE ON DBMS\_CLOUD\_ADMIN TO ${JAVA\_DB\_USER}; GRANT PDB\_DBA TO ${JAVA\_DB\_USER}; GRANT EXECUTE ON DBMS\_CLOUD TO ${JAVA\_DB\_USER}; GRANT CREATE DATABASE LINK TO ${JAVA\_DB\_USER}; GRANT EXECUTE ON sys.dbms\_aqadm TO ${JAVA\_DB\_USER}; GRANT EXECUTE ON sys.dbms\_aq TO ${JAVA\_DB\_USER}; EXIT; !  cd $ORACLEAQ\_HOME export TNS\_ADMIN=${TNS\_ADMIN\_FOR\_JAVA} sqlplus /@"${DB\_ALIAS}" <<! Show user; ! #Java Setup  # Add JavaUser Credentials to the ATP Wallet cd .. cd $TNS\_ADMIN\_FOR\_JAVA java -Doracle.pki.debug=true -classpath ${CLASSPATH} oracle.security.pki.OracleSecretStoreTextUI -nologo -wrl "$TNS\_ADMIN\_FOR\_JAVA" -createCredential "${DB\_ALIAS}" $JAVA\_DB\_USER >/dev/null <<! $DB\_PASSWORD $DB\_PASSWORD $WALLET\_PASSWORD !  export JDBC\_URL=jdbc:oracle:thin:@${DB\_ALIAS}?TNS\_ADMIN=${TNS\_ADMIN\_FOR\_JAVA}  #Build java code cd ../ cd $ORACLEAQ\_JAVA {    mvn clean install -Dmaven.wagon.http.ssl.insecure=true -Dmaven.test.skip=true    cd target    nohup java -jar qJava-0.0.1-SNAPSHOT.jar & } &>/dev/null echo "Java setup completed."  #Node.js setup cd $ORACLEAQ\_HOME npm install oracledb debug echo "node.js setup completed."  echo "ORACLEAQ\_HOME     : "$ORACLEAQ\_HOME echo "COMPARTMENT NAME  : "${COMPARTMENT} echo "COMPARTMENT OCID  : "${COMPARTMENT\_OCID} echo "DATABASE NAME     : "${DB\_NAME} echo "ATP OCID          : "${DB\_OCID} echo "TNS ALIAS- USER1  :  ${DB\_ALIAS}\_${PLSQL\_DB\_USER1}" echo "TNS ALIAS- USER2  : "${DB\_ALIAS} echo "JDBC URL          : "${JDBC\_URL} echo echo "-------------------------------" echo "        SETUP COMPLETED        " echo "-------------------------------" |