DATA WAREHOUSE DESIGN AND ETL OPTIMIZATION FOR ENTERPRISE BUSINESS INTELLIGENCE

Abstract

Modern enterprises operate in highly digitized environments, generating massive volumes of structured and semi-structured data from diverse operational systems such as sales, finance, human resources, supply chain, and customer management platforms. Although these systems are optimized for routine transaction processing, they are not designed to support complex analytical queries, historical analysis, or strategic decision-making. As a result, organizations often face challenges such as fragmented data, inconsistent reports, poor query performance, and limited visibility into business trends. To overcome these limitations, this project focuses on the design and implementation of a centralized enterprise data warehouse to enable efficient Business Intelligence (BI) and advanced analytics.

The proposed solution adopts a dimensional modeling methodology, employing star and snowflake schemas to structure data into fact and dimension tables that support efficient Online Analytical Processing (OLAP). A comprehensive Extract, Transform, and Load (ETL) pipeline is developed to integrate data from multiple heterogeneous source systems. The ETL process includes data extraction, cleansing, validation, transformation, and aggregation to ensure high data quality. Common data issues such as missing values, redundancy, inconsistency, and format mismatches are systematically resolved to provide a single, reliable version of enterprise data.

On top of the data warehouse, BI tools are utilized to design interactive dashboards and analytical reports that visualize key performance indicators (KPIs), trends, and patterns across business functions. The system is evaluated using metrics such as query response time, scalability, data accuracy, and reporting efficiency. Experimental results show significant improvements in analytical performance and data consistency compared to traditional operational databases. Overall, the proposed data warehouse framework provides a scalable, extensible, and reliable foundation for enterprise-level business intelligence, supporting data-driven decision-making and long-term strategic planning.

Step 1: Business Problem Identification

Goal: Define *why* the data warehouse is needed.

- Identify enterprise domains: Sales, HR, Finance, Inventory
- Define BI questions:
  - Monthly sales trend
  - Top-performing regions
  - Employee attrition rate
- Identify KPIs:
  - Revenue, profit, order count
  - Employee count, attrition %

Output:
✓ Problem statement
✓ List of KPIs and analytical queries

Step 2: Source System Analysis

Goal: Understand raw data characteristics.

- Data formats:
  - CSV files (sales, HR)
  - Relational tables (finance, inventory)
- Data issues:
  - Missing values
  - Duplicate records
  - Inconsistent formats
- OLTP nature: normalized, write-optimized

Output:
✓ Source data schema
✓ Data quality issues list

Step 3: Data Warehouse Design (Core Step)

3.1 Dimensional Modeling

Use **Kimball methodology**.

- **Fact Table**
  - fact_sales: sales_amount, quantity, profit
- **Dimension Tables**
  - dim_customer
  - dim_product
  - dim_time
  - dim_region

3.2 Schema Selection

- Star schema → fast query performance
- Snowflake schema → optional normalization

Output:
✓ Star schema diagram
✓ Fact–dimension relationships

Step 4: Staging Layer Implementation

Goal: Isolate raw data from analytics.

- Load raw data into staging tables
- Perform:
  - Schema validation
  - Duplicate removal
  - Data type correction
- No business logic here

Why this matters:
Prevents corrupt data from entering warehouse.

Output:
✓ Clean staging tables

Step 5: ETL Pipeline Development

5.1 Extract

- Incremental extraction using:
  - Timestamp
  - Primary key
- Avoid full reloads

5.2 Transform

- Data cleansing
- Surrogate key generation
- Slowly Changing Dimensions (SCD Type-1 / Type-2)
- Aggregations (daily / monthly totals)

5.3 Load

- Batch loading into fact & dimension tables
- Maintain referential integrity

Output:
✓ Working ETL scripts (Python + SQL)

Step 6: ETL Optimization (Your Differentiator)

Apply optimization techniques inspired by IEEE research:

- Incremental loading instead of full refresh
- Indexing foreign keys in fact tables
- Partition fact tables by date
- Pre-aggregation during ETL
- Remove redundant transformations

Measure:

- ETL execution time (before vs after)
- Query response time

Output:
✓ Optimized ETL pipeline
✓ Performance comparison results

Step 7: Data Warehouse Deployment

Goal: Make analytics efficient.

- Deploy warehouse in PostgreSQL/MySQL
- Apply:
    - Indexes
    - Constraints
    - Partitioning

Output:
✓ Production-ready data warehouse

Step 8: BI Dashboard Development

Goal: Convert data into insights.

Using Power BI / Tableau:

- KPI dashboards
- Trend analysis
- Drill-down reports

Examples:

- Sales by region
- Monthly revenue growth
- Product performance

Output:
✓ Interactive BI dashboards

Step 9: Evaluation & Performance Analysis

Metrics:

- Query response time
- ETL execution time
- Data accuracy
- Reporting efficiency

Comparison:

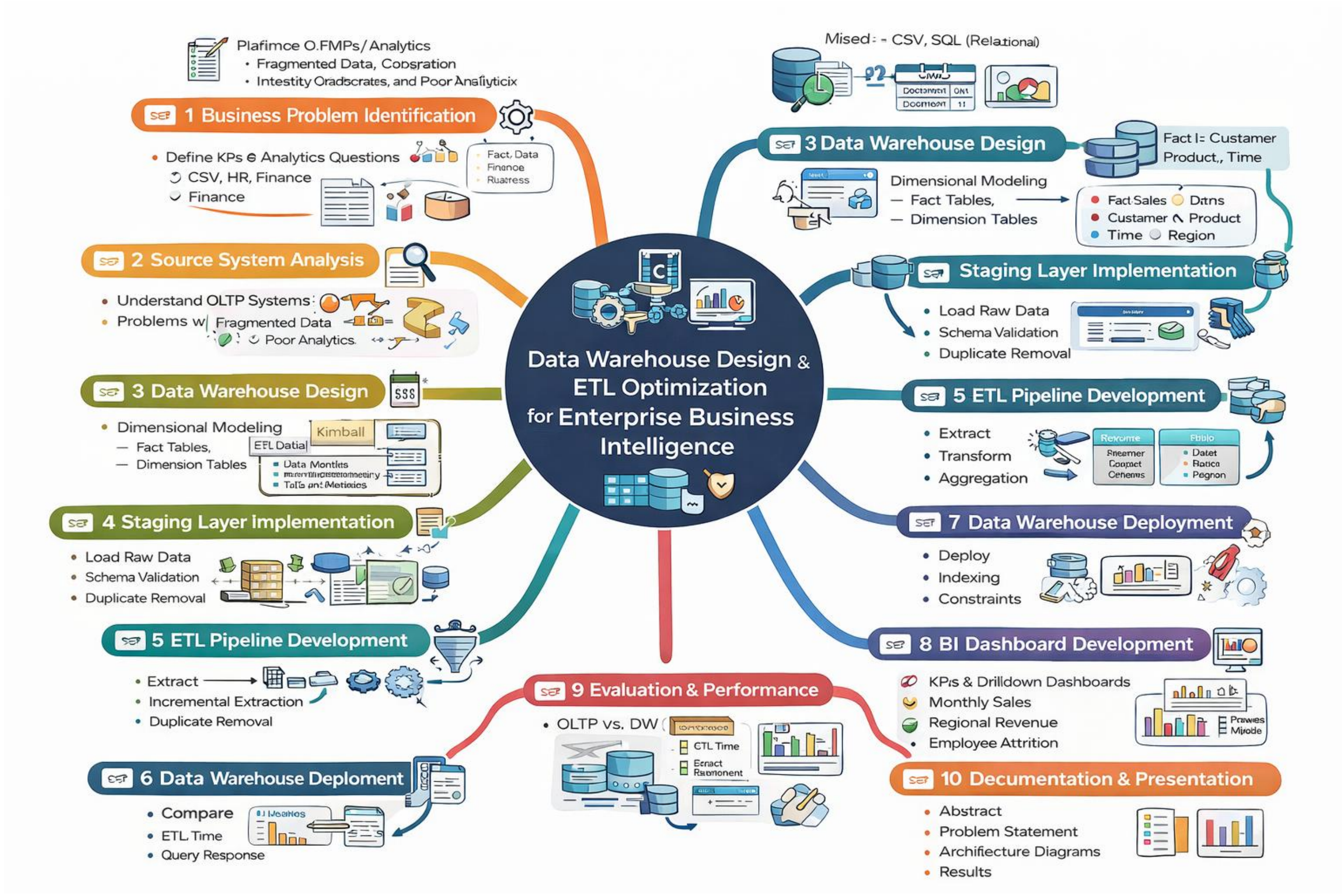
- OLTP vs Data Warehouse

Output:
✓ Evaluation tables and charts

Step 10: Documentation & IEEE Alignment

Deliverables:

- Abstract
- Problem statement
- Architecture diagram
- Schema design
- ETL workflow
- Results & discussion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2 Source System Analysis
• Understand OLTP Systems
• Problems w
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3 Data Warehouse Design
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• Dimensional Modeling
— Fact Tables,
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• Incremental Extraction
• Duplicate Removal
6 Data Warehouse Deploment
• Compare
• ETL Time
• Query Response
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5 ETL Pipeline Development
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• Transform
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8 BI Dashboard Development
KPis & Drilldown Dashboards
Monthly Sales
Regional Revenue
• Employee Attrition
Prawes
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9 Evaluation & Performance
• OLTP vs. DW (
CTL Time
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10 Decumentation & Presentation
• Abstract
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• Results