BI Governance Strategies: Guidelines and Best Practices

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Executive Summary

This review involves selecting relevant studies, news articles, and reports, and synthesizing their key themes and findings to provide an overview of best practices, opportunities, and considerations for the Business Intelligence (BI) governance.

Summary of Key Findings

Business Intelligence (BI) governance strategies among U.S. government agencies, including transportation agencies like state Departments of Transportation (DOTs), emphasize several best practices aimed at enhancing clarity, consistency, and usability. Agencies prioritize maintaining standardized visual designs for dashboards (e.g., simplicity, clear labeling, and consistent branding), complying with accessibility standards (Section 508 and WCAG), and ensuring open data transparency while safeguarding privacy and removing personally identifiable information (PII).

A critical component of BI governance is the use of authoritative data, central repositories, and structured data governance frameworks. Agencies typically establish dedicated governance bodies, clearly defined roles (e.g., data stewards, custodians), and strict data validation processes. Transportation agencies highlight the importance of leadership support, formal governance structures, and continuous stakeholder engagement. These agencies leverage BI tools to enhance operational efficiency, transparency, and informed decision-making.

Implementation Mechanisms

Successful BI governance implementation relies on some foundational mechanisms:

- **Governance Structures and Roles:** Establish clear roles such as Chief Data Officer, Data Governance Boards, and defined responsibilities for data stewardship and data review processes.
- **Standardized Design Guidelines:** Implement visual design standards to ensure simplicity, readability, and professional appearance across BI dashboards. Agencies can provide detailed guidelines and adhere to accessibility standards.
- **Centralized Data Management:** Deploy enterprise data warehouses or data lakes as authoritative repositories, ensuring BI tools access standardized and validated data.
- **Data Transparency and Accessibility:** Include open data practices, enabling public data downloads, ensuring accessibility compliance, and removing sensitive information before publishing dashboards publicly.
- **Continuous User Feedback:** Incorporate pilot testing and iterative feedback loops to refine dashboard usability and ensure clarity and relevance to the targeted audiences.
- **Security and Compliance:** Maintain stringent data security practices by using secure environments for BI development and deploying compliant cloud solutions.
- **Lifecycle Management:** Implement regular data refresh schedules, clear documentation, and defined accountability for dashboard maintenance and data retention.

Potential Challenges and Mitigation Strategies

- **Resistance to Change:** Staff and organizational resistance to adopting new BI practices could impede implementation. To mitigate this, Caltrans can engage stakeholders early, demonstrate clear benefits through pilot projects, and offer targeted change management training.
- **Resource Constraints:** Limited resources, including budget and skilled personnel, might impact the execution of BI governance initiatives. Prioritizing projects based on impact and feasibility, combined with phased rollouts, can alleviate resource pressures.
- **Technical Integration Complexity:** Integrating advanced analytics and ensuring interoperability between existing systems and new BI platforms could present significant technical challenges. Establishing dedicated cross-functional teams and investing in specialized training for technical staff would facilitate smoother integration.
- **Data Quality Issues:** Maintaining high-quality, authoritative data for accurate analytics is an ongoing challenge. Implementing rigorous data validation and establishing clear accountability for data quality can help sustain high standards.
- **Vendor Dependence and Lock-In:** Over-reliance on specific BI tool vendors could limit long-term flexibility. Developing clear guidelines for vendor selection and management, as well as adopting open standards where possible, can reduce this risk.

Next Steps for Caltrans

Caltrans can advance its BI governance strategy by addressing existing gaps and implementing targeted initiatives.

- **Scalable BI Framework:** Formulate strategic plans for sustainable, long-term BI governance expansion to accommodate growing analytical and data management needs.
- **BI Impact Metrics:** Establish clear, measurable indicators to evaluate the effectiveness of BI dashboards and their impact on decision-making and organizational efficiency.
- **Develop Interoperability Standards:** Adopt a unified interoperability framework across divisions, selecting common protocols and formats for seamless data exchange between the data warehouse and BI tools.
- **Implement a standardized Caltrans metadata model:** Standardize metadata with a single Caltrans-wide schema, supported by a clear, user-centered metadata strategy and staff training.
- **Deploy automated duplication controls and monitoring:** Minimize data duplication and regularly check the BI system for duplicate or unused data models and extracts.
- **Integration of Advanced Analytics:** Develop strategic frameworks and pilot projects for incorporating predictive and prescriptive analytics, as well as machine learning and artificial intelligence into existing BI processes.
- **Enhanced Workforce Development:** Invest in specialized BI training programs, certification opportunities, and continuous education tailored to developing advanced BI competencies.
- **Collaborative Knowledge Sharing:** Launch formal communities of practice or collaborative platforms to foster knowledge exchange and promote widespread adoption of best practices.
- **Vendor Management Strategy:** Establish explicit guidelines for vendor selection, management, and procurement practices to avoid vendor lock-in and ensure flexibility.

Detailed Findings

Government agencies across federal, state, and local levels have developed guidelines and best practices for using business intelligence (BI) tools like Tableau and Power BI. These guidelines cover the design and look and feel of visualizations, requirements for publishing dashboards publicly (including accessibility and open data considerations), and data governance practices (ensuring use of authoritative data and proper storage). Transportation agencies (e.g. state Departments of Transportation) have been actively creating BI strategies and governance plans aligned with these principles. Below is a review of key guidelines and examples.

Visual Design Standards and Look and Feel of Dashboards

Government data visualization standards emphasize clarity, simplicity, and consistency in design:

- **Keep it Simple and Remove Clutter:** Agencies stress that less is more in dashboard design[1]. Unnecessary elements (extra gridlines, ornate backgrounds, excessive pie slices[2], etc.) should be removed to avoid distracting the audience[3] [4]. The focus should be on the data story, not decorative extras.
- **Clear Titles and Labels:** Every visualization should have a clear, descriptive title that a layperson can understand. Subtitles or captions can be used to succinctly explain the key insight or takeaway of the chart. Direct labels help users quickly grasp information without confusion[3].
- **Visual Hierarchy:** Design guidelines encourage using visual hierarchy to make important information stand out. This means using larger or bolder elements for the most critical metrics and more subdued styling for details[1]. By guiding the eye to high-level indicators first (through size, color, or placement), and providing drill-down details second, dashboards become easier to scan and interpret.
- **Consistency in Style (Fonts, Colors, Branding):** Many agencies develop style guides for BI visuals. For example, the City of St. Louis's Tableau Style Guide advises using no more than two fonts and maintaining a clear title size hierarchy (e.g. bigger font for main title, smaller for subtitles)[4] . Color schemes should align with accessibility (colorblind-friendly palettes) and agency branding but avoid excessive variety. Consistent use of agency logos or headers depends on context (St. Louis noted that if a dashboard is embedded on the official website, separate logos/headers on the viz itself may be unnecessary). In short, dashboards should look professional and cohesive with other agency materials.
- **Test with Users:** A best practice is to pilot your visualization with someone less familiar with the data to ensure it is easily understood[5]. This helps verify that jargon has been minimized and that the dashboard's organization makes sense to an outsider.

Industry and academic sources echo these points. For instance, a federal case study on state DOT dashboards[6] report highlights that knowing your audience and designing as simply as possible are fundamental best practices. By focusing each dashboard on a well-defined purpose and audience, agencies avoid kitchen sink visuals and instead provide targeted and relevant information. The blog post from RIB

[1] https://www.gis.fhwa.dot.gov/case_studies/Data_Dashboards_at_State_DOTs.aspx
[2] https://www.perceptualedge.com/articles/visual_business_intelligence/save_the_pies_for_dessert.pdf
[3] https://portal.ct.gov/-/media/ct-data/data-visualization-guidelines.pdf
[4] https://www.stlouis-mo.gov/government/departments/information-technology/web-development/style/content/data-visualizations/tableau.cfm
[5] https://portal.ct.gov/-/media/ct-data/data-visualization-guidelines.pdf
[6] https://www.gis.fhwa.dot.gov/case_studies/Data_Dashboards_at_State_DOTs.aspx

Software titled Learn 25 Dashboard Design Principles & BI Best Practices[7] outlines key guidelines for designing effective and user-centric business intelligence (BI) dashboards. The key is to design dashboards that are goal-driven and tailored to the user's role (executives need high-level KPIs, while operational users may require more detail). A clear information hierarchy is essential: start with summary metrics and allow drill-down into specifics. Dashboards should follow the 5-second rule (users should grasp key insights almost instantly). Visual simplicity is emphasized: limit visuals, use consistent styling, and avoid clutter. Choose appropriate charts (e.g., bar for comparisons, line for trends) and format numbers clearly. Interactivity is also important (filters, drilldowns, and contextual information help users explore data meaningfully). The dashboards should load quickly, work across devices, and meet accessibility standards. Finally, the design process should include user feedback and follow consistent templates to ensure long-term usability and clarity.

Publishing Public Dashboards: Accessibility and Open Data Requirements

When government agencies publish Tableau or Power BI visualizations for the public, there are stringent requirements to ensure accessibility, transparency, and data privacy:

- **Section 508[8] / WCAG Compliance:** Public-facing BI content must be accessible to people with disabilities. The Oregon Health Authority's Accessible Data Visualizations Quick Guide[9] provides examples to ensure charts, graphs, and dashboards are accessible to all users, including those with disabilities. It emphasizes readable typography, sufficient color contrast, and avoiding reliance on color alone to convey meaning. The guide also highlights the use of provided theme files for tools like Tableau and Power BI to simplify compliance with the standards. Additional recommendations include providing alternative formats (like data tables and CSVs), ensuring keyboard navigation, and including plain-language titles and summaries. Including a text summary of key insights alongside the visualization not only benefits screen reader users but also aids general comprehension[10]. The summary can describe patterns or trends shown in the chart in a few sentences.
- **Standard Look and Feel for Public Dashboards:** Some agencies have specific templates or style requirements for any dashboard that goes on a public site. For example, Minnesota's Tableau Design Guide for Accessibility[11] (and similar city/state guidelines) outline how to structure charts for readability and compliance with the related standards. Common advice includes using readable fonts and font sizes and using plain language.
- **Open Data and Transparency:** Governments encourage publishing the *underlying data* or providing download access for transparency. Connecticut's Open Data visualization guidelines[10] explicitly suggest that agencies should publish the data used in the visualization as open data, so that the public can download it or use APIs for their own analysis. In practice, many public dashboards (whether built in Tableau, Power BI, or other tools) include a download data button. The St. Louis Tableau guide[12] similarly directs developers to enable the ability for users to download the dashboard's data. This approach builds public trust and allows power users to validate or explore the data further.

[7] https://www.rib-software.com/en/blogs/bi-dashboard-design-principles-best-practices
[8] https://www.section508.gov/
[9] https://www.oregon.gov/oha/digital-accessibility/pages/accessible-data-visualizations-quick-guide.aspx
[10] https://portal.ct.gov/-/media/ct-data/data-visualization-guidelines.pdf
[11] https://mn.gov/mnit/assets/Tableau%20Design%20Guide%20for%20Accessibility_tcm38-545008.pdf
[12] https://www.stlouis-mo.gov/government/departments/information-technology/web-development/style/content/data-visualizations/tableau.cfm

- **Privacy and Sensitive Data Removal:** Before any public release, authoritative review of data is required to strip out Personally Identifiable Information (PII) or any sensitive fields. Agencies often have checklists or data review teams to vet dashboards. For example, the State of Indiana's Data Visualization Standards[13] (2025) mandate that if a visualization is publicly available, any PII or confidential data must be removed. In practice, this might mean aggregating or anonymizing data before visualization. A real-world case: the Arkansas DOT's crash analytics dashboard (built in Tableau) pulls data from State Police, but they only upload the data after removing any personal identifiers[14]. This ensures compliance with privacy laws while still sharing useful information.
- **Approval and Publication Process:** The Indiana statewide policy provides a good example of governance around publishing. It requires each published visualization (internal or public) to have an identified owner responsible for its maintenance and quality[15]. It also strongly recommends agencies form a Data Review Team that checks each visualization against standards and legal requirements before publication[15] [16]. Only cleansed and reviewed data should be used in production dashboards, and no dashboard should go live with known data quality issues or defective (incomplete or inaccurate) data[15] .
- **Retention and Archiving:** Another often overlooked requirement is data retention. Indiana's guidance notes that if a public dashboard is published, the agency is responsible for archiving the data behind it in compliance with record retention laws[15] [17]. This means agencies must treat the data powering a public-facing BI report as an official record – it should be preserved (or at least the version of the dataset displayed should be retrievable) for the required period.

By adhering to these practices, government agencies aim to make public dashboards both useful and trustworthy – the public can understand them (clear design, context provided), access the data (downloads/open data), and be confident that personal or sensitive information is not inadvertently exposed.

Data Governance and Authoritative Data Usage in BI

A crucial aspect of BI best practices in government is ensuring the data itself is well-governed. Authoritative data refers to using official, trusted data sources for analytics, and managing data properly throughout its lifecycle. Key principles and practices include:

- **Use Approved Data:** Rather than each analyst bringing their own spreadsheet, agencies encourage use of central data repositories or certified datasets for Tableau/ Power BI dashboards. Only data that has passed quality checks and been approved for the intended business use should feed into published visualizations. Indiana's standards[13] explicitly state that all data in a production dashboard must be vetted and appropriate for the stated purpose. This ensures that metrics on the dashboard align with official figures and definitions used by the agency.
- **Enterprise Data Warehouses and Authoritative Repositories:** Many agencies have invested in enterprise data hubs to serve BI tools. For example, the Centers for Medicare and Medicaid Services (CMS) built an Integrated Data Repository (IDR) Cloud which acts as the primary authoritative enterprise data asset for the agency[18] [19]. Power BI, Tableau, and other BI tools at

[13] https://www.in.gov/mph/cdo/files/State-of-Indiana-OCDO-Guidance-Data-Visualization-Standards.pdf
[14] https://www.gis.fhwa.dot.gov/case_studies/Data_Dashboards_at_State_DOTs.aspx
[15] https://www.stlouis-mo.gov/government/departments/information-technology/web-development/style/content/data-visualizations/tableau.cfm
[16] https://www.in.gov/mph/cdo/files/20230420-FINAL-OCDO-Procedure-MPH-Data-Review-Team-and-OCDO-Privacy-Board.pdf
[17] https://www.in.gov/iara/divisions/records-management/state-records-management/
[18] https://www.cms.gov/tra/Data_Management/DM_0220_Business_Intelligence_Environment.htm
[19] https://www.cms.gov/tra/Data_Management/DM_0080_IDRC_Cloud.htm

CMS are connected to this centralized, consolidated data environment, rather than to individual siloed databases. By consolidating data into an authoritative warehouse, CMS improved data consistency and made sure all users are drawing from the same source of truth. Similarly, many state governments have data hubs or lakes that house authoritative data (often managed by a Chief Data Officer or a data governance board)[20].

- **Data Governance Policies and Roles:** Successful BI governance goes hand-in-hand with data governance frameworks. Under the federal Evidence-Based Policymaking[21] Act, agencies must have data governance bodies chaired by a Chief Data Officer[22]. These bodies set policies on data quality, access, and use. In practice, this often means defining roles and having processes for data cataloging, metadata documentation, and data quality validation before data is used in analytics. For example, Maryland DOT (MDOT) created a Data Governance and Data Hub Action Plan[23] that lays out roles and procedures for managing data across the department. Their plan emphasizes establishing clear data guidelines and standardized documentation for how data is managed and integrated across different units. They also stress maintaining up-to-date metadata (data dictionaries, owner contacts, etc.) so that anyone building a report knows the context and limitations of each dataset[23].
- **Security and Appropriate Access:** BI guidelines in government also mandate securing data properly, especially when using cloud services or self-service BI. Microsoft Power BI, for instance, offers government community cloud versions (e.g. GCC High) that comply with federal security standards[24]. Agencies will often require that any data with sensitivity be kept within approved IT environments. Indiana's rules, for example, say any development work on dashboards containing confidential data must occur in a protected environment (not on a local laptop or an unapproved cloud workspace)[25]. Data with PII should never be extracted to personal devices; instead, analysts should work in secure sandboxes or virtual desktop infrastructure (VDI) environments. Furthermore, production dashboards should not rely on personal user accounts to access data (which could break when that person leaves); instead, a service account or system identity tied to the agency should be used[22]. These controls help maintain security and continuity.
- **Refresh Schedules and Maintenance:** Once a dashboard is live, governance includes keeping data up to date. Agencies recommend defining a clear refresh schedule for public-facing dashboards (e.g. updated weekly, monthly) and communicating it to users. If a dataset is no longer updated, that should be indicated, or the visualization should be retired to avoid showing stale data. Additionally, having an assigned dashboard owner means someone is accountable for periodically reviewing the visualization for accuracy and updating it as needed when data definitions or sources change[26].

Collectively, these governance measures ensure that Tableau, Power BI, or other tools are used in a responsible, sustainable way. Data integrity and security are maintained even as analytics are democratized. This balance is crucial in government, where errors or inconsistencies can have public consequences.

[20] https://2022state.results4america.org/criteria/data-leadership-governance/
[21] https://www.congress.gov/115/plaws/publ435/PLAW-115publ435.pdf
[22] https://coe.gsa.gov/coe/ai-guide-for-government/data-governance-management/
[23] https://transops.s3.amazonaws.com/uploaded_files/MDOT%20Data%20Governance%20Action%20Plan_FINAL%20May%2020%202019_0.pdf
[24] https://learn.microsoft.com/en-us/fabric/enterprise/powerbi/service-government-us-overview
[25] https://www.in.gov/mph/cdo/files/State-of-Indiana-OCDO-Guidance-Data-Visualization-Standards.pdf
[26] https://www.in.gov/mph/cdo/files/State-of-Indiana-OCDO-Guidance-Data-Visualization-Standards.pdf

The CMS Business Intelligence (BI) Architecture[27] outlines a structured approach for transforming raw data into actionable insights. It includes a Business View that guides data transformation from raw data to actionable insights for various user roles, and a Technical View that outlines the supporting IT infrastructure, including data integration, analytics tools, metadata management, and layered security. Core components include operational data sources, extract, transform, load (ETL) processes, data warehouses/marts, role-based access via BI portals, and compliance with CMS privacy and security policies.

The report Data Dashboards at State DOTs[28] also presents case studies from five transportation agencies (Arkansas, Michigan, Montana, Oklahoma, and Puerto Rico) highlighting how GIS-enabled dashboards are used to improve decision-making, transparency, and operational efficiency. Common best practices across agencies include identifying the target audience and their needs, designing with simplicity and visual clarity, involving stakeholders from the beginning, and using prototyping to refine features. Lessons learned across agencies include the importance of early and continuous stakeholder engagement, managing expectations about development timelines, and the value of iterative design with prototypes. Technical challenges were often outweighed by the benefits, such as saving staff time, reducing data requests, and improving organizational transparency. Overall, the report underscores that while dashboards are still a relatively new tool for State DOTs, they are increasingly recognized as valuable for promoting data-driven management and fostering interagency and public communication.

General Best Practices to Minimize Data Duplication in BI

All modern BI platforms support strategies to reduce redundant data copies. Key best practices include:

- **Connect to Central Data Repositories:** Wherever possible, connect BI reports directly to the enterprise data warehouse or data lakehouse. For example, DirectQuery is one of three dataset modes in Power BI (alongside Import and Composite). Unlike Import mode, DirectQuery does not import data into Power BI; instead, it queries data directly from the source every time a report is viewed. However, it can lead to slower performance since every interaction sends a query to the data source, and it has limitations with some Power BI features[29]. In Tableau, the choice between a live connection and an extract depends on your data needs. A live connection links directly to the data source, providing real-time updates and eliminating the need for data duplication, but it relies on the source's performance and constant connectivity. An extract, on the other hand, is a stored snapshot of the data that offers faster performance, offline access, and flexibility for data transformations, though it can become outdated and requires local storage[30].
- **Use a Single Source of Truth Data Model:** Establish a single, certified data model or semantic layer that multiple reports can leverage. A shared dataset in Power BI is a data model that can be used in many reports, so you don't have to rebuild the same things over and over. It lets teams work better together (one person can build the data model, and others can create reports from it). These reports, called thin reports, stay connected to the shared dataset and get updates when the dataset changes. Power BI also lets you mark trusted datasets as "Promoted" or "Certified," so others know which ones are safe to use[31]. Managing data source changes in Tableau is hard because data often gets duplicated, logic is repeated, and updates require a lot of manual work, causing confusion and

[27] https://www.cms.gov/tra/Data_Management/DM_0230_Business_Intelligence_Architecture.htm
[28] https://www.gis.fhwa.dot.gov/case_studies/Data_Dashboards_at_State_DOTs.aspx
[29] https://www.onlc.com/blog/what-is-directquery-mode-in-power-bi/
[30] https://www.h2kinfosys.com/blog/extract-vs-live-in-tableau/
[31] https://radacad.com/power-bi-shared-datasets-what-is-it-how-does-it-work-and-why-should-you-care/

errors. The dbt Semantic Layer helps by centralizing all the business logic and metrics in one place upstream, so when data changes happen, you only update it once in dbt. This integration with Tableau keeps data consistent, reduces duplicate work, and makes sure everyone is using the same trusted data without extra hassle[32].

- **Avoid Full Data Imports When Unnecessary:** By default, some tools encourage importing data into their own in-memory engine (e.g. Power BI's import mode). While importing can improve performance for complex calculations, it essentially creates a snapshot of the data. Runs live queries directly on the data source, giving up-to-date data without storing it, but it can be slower and limits some transformations. Choosing runs live queries depends on your need for real-time data, report speed, data size, and costs[33]. There are scenarios where copying data into the BI tool is justified. In those cases, follow best practices to mitigate downsides:
    - **Refresh Frequently or Incrementally:** If you must import data, schedule automated refreshes so the dataset stays in sync with the warehouse. Use incremental refresh[34] [35] or partial extract refresh[36] [37] to update only changed data. This reduces load and egress costs while keeping data fresh.
    - **Centralize the Extracts:** Instead of every user creating their own extract, create a single shared extract/data source that is refreshed on a schedule and used by all relevant analyses. For example, A Published Data Source is a centralized, shared data connection that lives on Tableau Server or Tableau Cloud. Instead of each user creating their own copy of the data extract or connection, the published data source acts as a single, verified source that multiple users and workbooks can connect to[38]. Power BI similarly allows deploying one imported dataset to the service and reusing it in multiple reports[39].
    - **Scope Extracts to Necessary Data Only:** If the full data set is huge, consider extracting a subset (e.g. aggregate tables or recent data) to improve report speed. This way you aren't duplicating all data, only the portion needed for analysis, which minimizes redundancy while solving performance needs[40].
- **Audit and Reduce Redundant Datasets:** It's wise to periodically audit your BI environment for duplicate data models or extracts[41]. It identifies duplicate or unused datasets through usage logs and data lineage, enabling organizations to consolidate and clean up unnecessary copies. By encouraging reuse of trusted sources and extracts, auditing reduces costs and streamlines BI performance.

Interoperability Between Data Warehouses and BI Tools

Modern business intelligence (BI) workflows depend on seamless integration between cloud data warehouses and BI tools. Interoperability (the ability for systems to connect, exchange data, and share definitions) is critical for enabling data exploration without friction. This section examines how major cloud data warehouses support interoperability with BI platforms.

[32] https://www.getdbt.com/blog/managing-data-source-changes-in-tableau
[33] https://www.phdata.io/blog/import-vs-direct-query-power-bi/
[34] https://learn.microsoft.com/en-us/power-bi/connect-data/incremental-refresh-overview
[35] https://help.tableau.com/current/prep/en-us/prep_incremental_refresh.htm
[36] https://help.tableau.com/current/pro/desktop/en-us/extracting_refresh.htm
[37] https://learn.microsoft.com/en-us/power-bi/connect-data/refresh-data
[38] https://help.tableau.com/current/pro/desktop/en-us/publish_datasources_about.htm
[39] https://radacad.com/power-bi-shared-datasets-what-is-it-how-does-it-work-and-why-should-you-care/
[40] https://b-eye.com/blog/optimize-power-bi-data-models-large-datasets/
[41] https://datalere.com/articles/power-bi-best-practices-from-the-field-lessons-from-enterprise-deployments

Data Connectivity Protocols

Effective BI integration starts with robust data connectivity. Most warehouses support SQL-based interfaces that BI tools can use to query data in place. The dominant standards are ODBC (Open Database Connectivity) and JDBC (Java Database Connectivity). JDBC and ODBC are both APIs used to connect applications to databases, but they serve different purposes. JDBC is Java-specific and ideal for Java-based applications, offering high performance and seamless integration in Java environments. ODBC, on the other hand, is language-independent and suited for connecting various applications across platforms, especially useful in legacy systems and multi-database setups[42]. All major cloud warehouses provide certified ODBC and JDBC drivers for this purpose. For example, BigQuery partners with Simba to offer dedicated ODBC/JDBC drivers, allowing third-party tools to run SQL against BigQuery's engine[43]. Beyond ODBC/JDBC, warehouses expose RESTful APIs[44] for programmatic access. For instance, developers can use client libraries as well as BigQuery's REST API and RPC API to transform and manage data[45]. Snowflake provides a SQL API (a REST endpoint) to execute SQL statements and retrieve results[46].

Another approach uses native connectors provided by BI vendors, which internally rely on ODBC/JDBC or APIs but simplify configuration. For instance, Tableau and Power BI include built-in connectors for Snowflake, BigQuery, etc., so users can select the data source by name. Under the hood, these connectors use the appropriate protocol[47] [48]. High-performance data transfer is another emerging theme. Protocols like Apache Arrow Flight are designed for rapidly moving large analytic datasets which can accelerate BI queries[49]. All these connectivity options allow BI platforms to either query data in-place (live connection) or import data for in-memory analysis. For example, Power BI supports Import, DirectQuery, Live Connection, and Composite Models. Import is fastest and most flexible but has size limits. DirectQuery handles large data in real time but is slower and limited. Live Connection is ideal for SSAS models with no data import. Composite Models mix Import and DirectQuery for balanced performance and scale. Choosing the right method depends on data size, source type, flexibility, and performance needs[50].

Semantic Layer Compatibility

A semantic layer provides a business-friendly abstraction over raw data – defining metrics, dimensions, and relationships in a consistent way. It lets different BI tools interpret data with the same shared business logic and terminology[51]. Traditionally, BI tools implement their own semantic models[52] [53]. Power BI semantic models in Microsoft Fabric provide a business-friendly way to analyze data. Starting August 25, 2025, they must be created manually, as defaults are no longer auto-generated. The recommended Direct Lake mode enables fast, real-time analysis by reading data directly from the lake. Models can also use Import or DirectQuery modes and are managed via Fabric or Power BI Desktop[54]. Organizations typically adopt one of three architectures: a metadata-first logical layer for scalable, enterprise-wide integration; built-for-purpose models that give autonomy to individual business units; or centralized semantic layers within data warehouses/lakes for consistent analytics[55]. Snowflake has taken a notable step in this direction with Semantic Views. The semantic view stores business concepts (logical tables representing entities, their

[42] https://www.cdata.com/blog/jdbc-vs-odbc
[43] https://cloud.google.com/bigquery/docs/reference/odbc-jdbc-drivers
[44] https://aws.amazon.com/what-is/restful-api/
[45] https://cloud.google.com/bigquery/docs/introduction
[46] https://docs.snowflake.com/en/developer-guide/sql-api/index
[47] https://help.tableau.com/current/pro/desktop/en-us//exampleconnections_overview.htm
[48] https://www.biconnector.com/blog/what-are-microsoft-power-bi-connectors/
[49] https://www.dremio.com/blog/a-data-analysts-guide-to-jdbc-odbc-rest-and-arrow-flight/
[50] https://radacad.com/directquery-live-connection-or-import-data-tough-decision/
[51] https://www.ibm.com/think/topics/semantic-layer
[52] https://learn.microsoft.com/en-us/power-bi/connect-data/service-datasets-understand
[53] https://help.tableau.com/current/pro/desktop/en-us/examples_tableau_semantics.htm
[54] https://learn.microsoft.com/en-us/fabric/data-warehouse/semantic-models
[55] https://enterprise-knowledge.com/the-top-3-ways-to-implement-a-semantic-layer/

relationships, and metrics definitions) directly in Snowflake database. This ensures consistent definitions and correct aggregations for key metrics, reducing errors and duplication across reports and tools. This benefits AI applications by improving SQL generation accuracy, supports BI users with reliable, reusable metrics, and helps technical analysts simplify data models and maintain centralized business logic[56]. Databricks is also introducing Unity Catalog Metric Views. In public preview, metric views let you define core measures and dimensions in YAML and register them in the catalog[57].

Data Governance and Security

Interoperability is not just about connectivity and semantics, but also about consistent governance across the warehouse-BI boundary. Data warehouses enforce security and governance policies (like who can see what data), and BI tools need to integrate with these controls. For example, Amazon Redshift's Role-based access control (RBAC) allows granular control such that a role can be limited to specific actions and users only get those permissions via role assignment[58]. A best practice in BI integration is to use pass-through credentials or single sign-on, so that the user's identity and roles in the warehouse are respected when they query from the BI tool. For example, Tableau supports Kerberos and OAuth delegation so that when a viewer opens a dashboard, the query to the database runs under that viewer's credentials[59] [60]. Power BI also supports single sign-on for many data sources[61]. Row-level security (RLS) and column-level security (CLS) also restrict which data rows or columns a user can see, based on some condition (like their region or department)[62] [63]. Traditionally, BI tools like Power BI and Tableau often implemented RLS and CLS within their models[64] [65]. However, warehouses now provide native RLS so that all queries, including those from any BI tool, automatically apply the filter. For instance, Amazon Redshift and BigQuery have support for defining RLS and CLS policies to a table that filters rows or columns for certain roles/users[66] [67].

Although all warehouses provide audit logs for queries and logins, understanding the lineage of data (where it came from, how it flows through transformations into BI) is also crucial for trust and compliance. While data lineage is often captured in data tools outside the warehouse[68], some warehouses are integrating lineage tracking. Databricks' Unity Catalog automatically captures lineage of data as it's transformed, and this can be visualized or queried via their lineage API/tables[69]. Azure Synapse can be connected to Microsoft Purview to automatically capture and track data lineage from pipelines and data flows, allowing users to monitor data movement and transformations, though some features like column-level lineage and certain copy options are not supported[70].

Data Sharing Frameworks

A distinct but related aspect is how warehouses share data externally in a standardized way. For example, Databricks Delta Sharing is a secure platform for sharing data and AI assets across organizations, whether or not recipients use Databricks[71]. It supports sharing for any platform using tokens and a customer-managed open-source server. Providers can control access, monitor usage, and share dynamic views or streaming

[56] https://docs.snowflake.com/en/user-guide/views-semantic/overview
[57] https://docs.databricks.com/aws/en/metric-views/
[58] https://docs.aws.amazon.com/redshift/latest/dg/t_Roles.html
[59] https://help.tableau.com/current/server/en-us/kerberos_delegation.htm
[60] https://help.tableau.com/current/server/en-us/protected_auth.htm
[61] https://learn.microsoft.com/en-us/power-bi/connect-data/service-gateway-sso-overview
[62] https://docs.aws.amazon.com/redshift/latest/dg/t_rls.html
[63] https://cloud.google.com/bigquery/docs/column-level-security-intro
[64] https://datatako.com/implementing-row-level-security-rls-in-power-bi/
[65] https://crgsolutions.co/a-comprehensive-guide-to-row-level-security-rls-in-tableau/
[66] https://docs.aws.amazon.com/redshift/latest/dg/t_rls.html
[67] https://cloud.google.com/bigquery/docs/column-level-security-intro
[68] https://airbyte.com/top-etl-tools-for-sources/data-lineage-tools
[69] https://docs.databricks.com/aws/en/data-governance/unity-catalog/data-lineage
[70] https://learn.microsoft.com/en-us/purview/data-map-lineage-azure-synapse-analytics
[71] https://learn.microsoft.com/en-us/azure/databricks/delta-sharing/

tables. Tableau and Databricks have expanded their partnership with two key updates to enhance data sharing and analytics. The new Tableau Delta Sharing connector enables secure, real-time collaboration between Tableau and Databricks, allowing organizations to share live data without duplication while improving governance and integrating with Delta Lake and Tableau's data management tools. Explore in Tableau streamlines insight discovery by connecting users to real-time data sources directly in the browser, eliminating manual file transfers and keeping workflows seamless. Additionally, the Databricks SQL connector now supports advanced authentication and improved SQL performance. Together, these updates simplify collaboration, accelerate analytics, and provide a more seamless, secure, and integrated data experience[72].

Sharing Dataset Metadata and Data Dictionaries

Providing a data dictionary or glossary alongside a dashboard addresses a critical need: users often have questions about what the data means or how it can be used. Even seemingly simple fields can prompt confusion (for example, does "Sales" include taxes, or how exactly is a "crash" defined?). Rather than leave these questions unanswered, incorporating definitions and context in the dashboard (or via an accessible link) ensures that every user can interpret the visuals correctly. This builds trust by making the data self-documenting and avoids misinterpretation[73]. A fillable Microsoft Excel template[74] is provided by California open data portal to help users create metadata and a fillable Microsoft Word template[75] is also provided to create the data dictionary. Many government agencies, especially in transportation, have recognized the importance of presenting metadata alongside their data dashboards[76] [77] [78].

There are different types of metadata: descriptive metadata (like titles and keywords) helps identify and find data; structural metadata explains how data is organized and related, which is useful for combining different datasets; and administrative metadata includes details like who can access the data and where it came from. To keep metadata consistent and usable across systems, standards are used. For example, Dublin Core is a simple set of elements for describing resources, and ISO standards offer detailed rules for managing and sharing metadata, especially in technical and global contexts[79] [80]. A review found that metadata suffer from inconsistent definitions, too many competing standards, and low usability. Key fixes include standard harmonization, better tools, lifecycle management, and automation, supported by a new schema that adds context and links metadata across systems[81].

Data Guide in Tableau is a feature that helps users better understand dashboards by providing contextual information, such as descriptions, data summaries, links to resources, and insights powered by Explain Data (like detected outliers and possible explanations). Dashboard authors can customize this guide at the dashboard, viz, and mark levels to improve usability and accessibility. Users can explore these layers to gain a deeper understanding of the data and how it's being filtered or affected[82]. In Tableau, you can also enhance dashboard usability by creating an interactive instruction button, even though it's not a built-in feature. By using a worksheet labeled Instructions and linking it via a dashboard action to a separate

[72] https://www.tableau.com/blog/tableau-databricks-delta-sharing-connector
[73] https://atlan.com/data-governance-data-dictionary/
[74] https://data.ca.gov/uploads/page_images/2019-08-29-211135.259354Publishing-Metadata-Template.xlsx
[75] https://data.ca.gov/uploads/page_images/2019-08-29-211153.010691DATA-DICTIONARY-TEMPLATE-2017-03-16.docx
[76] https://rideuta.com/Rider-Tools/dashboard-definitions
[77] https://www.texastransitdashboard.com/glossary/
[78] https://www.transportation.gov/mission/office-secretary/office-policy/freight/flow/flow-data-dictionary
[79] https://atlan.com/metadata-standards/
[80] https://datacalculus.com/en/knowledge-hub/data-analytics/data-identification-and-acquisition/metadata-standards-and-protocols/
[81] https://www.jmir.org/2022/1/e25440
[82] https://help.tableau.com/current/server/en-us/data_guide.htm

dashboard containing user guidance, you can direct users to helpful content like data definitions, usage instructions, or data source details[83]. Another Tableau technique is using show/hide containers to create an on-demand info panel overlay[84]. In Tableau Desktop, it is possible to add a manual comment to any field and enter notes like business definitions, formulas, or governance details[85].

To display measure descriptions in Power BI reports for end users, you can create a table with measure names and descriptions. This method lets report consumers view measure definitions directly in visuals without accessing the semantic model, though text alignment and long description formatting remain minor challenges[86]. The simplest approach in Power BI is to create a report page that serves as a data dictionary or info hub. This page can contain text boxes or tables listing each relevant field name with its definition, along with any data source info or usage notes. For a public-facing dashboard, the page might be titled "About the Data" or "Definitions". You can then add a visible button or tab navigation so that users know where to find it. Power BI's visual and page tooltips[87] can also be cleverly used to show data definitions on hover or click. In the October 2024 Power BI update, four new functions added to help report authors easily access metadata about their model. These functions create tables that update automatically when the model is refreshed, making it easy to build a dynamic data dictionary. The functions provide details like table names, column descriptions, and relationships, helping users better understand the structure of the report[88].

Audience Considerations

Different audiences require different levels of detail and explanation. The Metadata for All Guide[89] helps NYC Open Data Coordinators produce clear, consistent, and user-friendly metadata so the public can use datasets without direct assistance. Developed in 2018 and addresses shortcomings in the 2016 Data Dictionary (such as missing context, unclear definitions, and incomplete field information) by introducing two required resources for each dataset: a User Guide that explains the dataset's purpose, context, limitations, and sample questions, and a Data Dictionary that clearly defines each column, values, and data types. The new standards stress plain language, consistent formatting, and complete metadata, supported by templates, a rubric, glossary, and engagement tools.

The guide recognizes that different audiences require different levels of detail and explanation, with some benefiting from a narrative overview while others rely on concise technical references. Additional recommendations include using web-friendly formats, automating documentation, and enhancing dataset pages. This dual-documentation approach improves both accessibility for new users and precision for experienced analysts.

Agency officials and domain experts are concerned with accuracy, consistency, and proper use of data. Metadata for this group should include any official definitions (possibly aligned with standards or legal definitions), caveats or limitations of the data, and methodology notes. For example, the Massachusetts Department of Correction publishes a Glossary, Definitions, and Caveats[90] document for its dashboards. Clear metadata helps officials ensure that the public or other departments draw correct conclusions from the data. Transportation agencies might explain, for example, the scope of a dataset and also define each metric (e.g., FHWA Safety Data Dashboards[91]).

[83] https://medium.com/@narula.rashmi888/creating-and-utilizing-instruction-buttons-in-tableau-dashboards-7eecad845bc7
[84] https://datavis.blog/2019/03/10/show-hide-containers/
[85] https://dabblingwithdata.amedcalf.com/2015/04/16/data-dictionary-functionality-in-tableau-server-9/
[86] https://medium.com/microsoft-power-bi/how-to-display-measure-descriptions-directly-in-power-bi-reports-c87e3579eb6a
[87] https://learn.microsoft.com/en-us/power-bi/create-reports/desktop-custom-tooltips?tabs=powerbi-desktop
[88] https://telefonicatech.uk/blog/data-dictionary-in-powerbi/
[89] https://opendata.cityofnewyork.us/wp-content/uploads/2018/12/Metadata-for-All-Guide-for-Open-Data-Coordinators.pdf
[90] https://www.mass.gov/doc/data-dictionary-1/download
[91] https://highways.dot.gov/safety/learn-safety/understanding-safety-data-dashboards

Centralized vs. Dashboard-Specific Metadata

Centralized metadata management involves collecting and storing all metadata in a single central repository, which serves as the main source for all metadata use, queries, and applications. This approach provides a single source of truth, improving data consistency, trust, and governance across an organization, while also allowing for enhancements to metadata that support better understanding and efficiency. However, if the central repository goes down or becomes outdated, the whole system suffers. In addition, keeping it up to date with source systems requires significant effort. Alternatives include distributed metadata management, where each system manages its own metadata and provides real-time access, and hybrid (or federated) metadata management, which combines real-time access with a central repository for enhanced metadata and backup (offering a balanced solution for most enterprise needs)[92].

Recommendations

- Effective metadata management requires more than just technology and processes. One essential step is creating a clear metadata strategy that aligns with business goals and is easily shared with stakeholders. This strategy should answer questions about the data asset, such as what it is (including descriptions and tags), why it exists (its source and purpose), where it comes from (location and domain), who is responsible for it (owners and experts), when it was created or updated, and how it can be used (licensing and use cases)[93] [94].
- The metadata should be one click or one hover away from the main view. Good metadata should be easy to read and access, but many current platforms make this difficult, causing users to get tired or confused[95]. Use conspicuous info icons, buttons, or tabs labeled in plain language (About the Data, Definitions, Help). If users have to hunt for a separate document or website, many will not bother, leading to misinterpretations. Instead, embed cues in the dashboard itself that additional information is available. Write definitions and descriptions in terms that your broadest audience can understand. Spell out acronyms and avoid assuming domain knowledge. Where possible use standard definitions. Transportation data often has nationally or internationally accepted terminology (e.g., the U.S. DOT's Highway Performance Monitoring System metrics, or transit definitions from NTD, or safety definitions from AASHTO).
- There is a balance to strike between providing complete information and overwhelming the user. A recommended approach is to layer the information. Provide a short explanation in the dashboard (e.g., in a tooltip or brief description) and allow users to drill down or read further for the full details[96]. Ensure that the metadata content is accessible to all users. If using interactive elements (like hover tooltips), also provide a clickable or static alternative for users on mobile devices or using assistive technology (since hover doesn't work for everyone). For those with disabilities that prevent using the interactive dashboard, providing the data dictionary in a separate accessible PDF or HTML page.
- Whenever the data is updated or the dashboard is updated, ensure the metadata is also reviewed and updated[97]. In practice, maintaining a data dictionary can be as important as maintaining the dataset itself. Some agencies version their data dictionaries which is a good practice for telling users which version of metadata they're looking at[98]. Be transparent about data limitations in the metadata. If the dashboard is based on preliminary

[92] https://www.octopai.com/glossary/centralized-metadata-management/
[93] https://atlan.com/metadata-management-101/?ref=/hub/content-hub-demo/
[94] https://www.ewsolutions.com/metadata-strategy-overview/
[95] https://arxiv.org/pdf/2403.15861v2
[96] https://docs.data.ca.gov/california-open-data-publishers-handbook/3.-create-metadata-and-data-dictionary
[97] https://www.usgs.gov/data-management/data-dictionaries
[98] https://www.transportation.gov/mission/office-secretary/office-policy/freight/flow/flow-data-dictionary

data or a sample, say so. If definitions changed over time or data for a certain year is incomplete, note that.

- Finally, treat the presentation of metadata as an evolving aspect. If possible, get feedback from users on whether the data dictionary provided is meeting their needs. Are there terms still unclear? Is the info easy to find? Web analytics can show if users click on the "About" page or not – if not, maybe the link isn't prominent enough. A usability study[99] shows how user feedback helped improve clinical research data dictionaries.

BI Governance Strategies in Transportation Agencies

Transportation agencies, such as state Departments of Transportation (DOTs), have been early adopters of data visualization for improving operations and transparency. Many DOTs use Tableau or Power BI for dashboards on topics like safety, asset conditions, project delivery, and performance management. In doing so, they have started to formulate Business Intelligence governance strategies tailored to their needs.

Some DOTs have formalized their approach. For example, Maryland DOT's Data Governance and Data Hub Action Plan[29] can be seen as a BI governance roadmap. It outlines a vision to make timely, relevant, and trusted data available for decision- making, and sets goals to improve data quality, accessibility, and consistency across the agency. Objectives in this plan include clear data guidelines, standardizing data organization across divisions, and providing intuitive, accessible reports (including in formats like PDF/CSV for users of varying technical skill). MDOT's plan also highlights reducing redundant data efforts and ensuring leadership is aware of how data is used in reports[100]. This kind of plan is essentially a governance strategy to support BI: it ties data management improvements directly to better analytics and dashboards.

The WisDOT Data Governance Phase II[101] final report presents a comprehensive plan to establish an enterprise-wide Data Governance Framework tailored to the Wisconsin Department of Transportation's (WisDOT) evolving data needs. As transportation technologies like connected and automated vehicles generate unprecedented volumes of data, WisDOT faces critical challenges, including inconsistent data classification, multiple redundant datasets without a clear system of record, and the absence of a centralized repository documenting applications and data assets. To address these issues, the Institute for Physical Infrastructure and Transportation (IPIT) at the University of Wisconsin-Milwaukee worked with WisDOT staff and surveyed all 50 state DOTs (receiving 27 responses) and conducted in-depth interviews with six DOTs (including Caltrans, FDOT, and IowaDOT) to gather best practices. Successful programs emphasized executive leadership, formal structures, defined roles and responsibilities, data cataloging tools, and cultural change management to improve data sharing, quality, and security.

Based on this research, the project team developed five foundational documents for WisDOT: (1) a governance structure aligned with the department's organizational chart; (2) a charter for both a Data Governance Board and Council, defining oversight and operational roles; (3) detailed role descriptions for data stewards, custodians, and users; (4) a process flow diagram outlining data intake procedures; and (5) a data intake form to guide submission, evaluation, and implementation of new datasets. These tools support harmonized data management across divisions, increase clarity and consistency, and provide mechanisms for documenting ownership and metadata. The report recommends establishing a Chief Data Officer and a Data Catalog Administrator to lead implementation and oversee ongoing data governance efforts. It underscores the importance of aligning governance initiatives with technology, involving stakeholders across all levels, and institutionalizing change through communication, training, and engagement.

[99] https://humanfactors.jmir.org/2018/3/e10205/

[100] https://transops.s3.amazonaws.com/uploaded_files/MDOT%20Data%20Governance%20Action%20Plan_FINAL%20May%2020%202019_0.pdf

[101] https://wisconsindot.gov/documents2/research/Final-Report-WisDOT-Data-Governance-Phase-II.pdf

The Tableau Server Publishing and Deployment document[102] outlines the Arizona Department of Transportation's (ADOT) standards for publishing dashboards to its Tableau Development (DEV) and Production (PROD) servers. The DEV server is for testing and training, where developers have publishing access, while the PROD server is restricted to approved, production-ready dashboards and managed by the Tableau Support team. Before publishing, developers must follow security guidelines, especially when working with confidential or sensitive data. They are required to complete a checklist covering data security, usage approval, data refresh schedules, accuracy, and peer reviews. Only after these steps can dashboards be submitted for production deployment via a support ticket. Production dashboards must also meet additional standards, including visible disclaimers, approved ADOT branding, clean data sources, and no unauthorized sensitive information. Once published, developers remain responsible for accuracy and ongoing updates.

Texas Department of Transportation (TxDOT) emphasizes brand consistency in data visualizations[103], especially when using Tableau. Visuals should follow typography and color guidelines to ensure clarity and alignment. Data visualization helps reveal insights through charts, graphs, and diagrams. Following best practices, choosing the right visualization types, and designing clear dashboards are key. All visual content must also meet federal accessibility standards (more resources available on TxDOT's intranet).

At the federal level, the FHWA has published guidance to help state and local DOTs create data business plans. For example, The U.S. Department of Transportation Roadway Transportation Data Business Plan (Phase 3)[104] provides a structured framework to help state and local departments of transportation (DOTs) and metropolitan planning organizations (MPOs) develop and implement a Data Business Plan (DBP) specifically for roadway travel mobility data. This data includes vehicle, freight, bicycle/pedestrian, and transit-related information such as volume, speed, travel time, and connected vehicle data. It outlines a nine-step approach beginning with establishing needs and objectives, followed by stakeholder outreach, data assessment, and gap analysis. It then guides agencies through the development of improvement strategies, creation of data governance structures, and establishment of effective data management practices. The plan also develops an implementation roadmap and the formal DBP document. Key features include stakeholder engagement through surveys and interviews, the use of maturity models to assess agency capabilities, and guidance on setting up data governance councils, manuals, and data catalogs. The document provides practical examples from pilot agencies, showing how real-world applications can reduce duplicative efforts and support more efficient and informed decision-making. It highlights the importance of documenting roles, responsibilities, and data-sharing protocols, as well as ensuring privacy, security, and metadata standards. The document also includes a series of templates, sample agreements, and governance tools in the appendices to support implementation.

A recent National Cooperative Highway Research Program (NCHRP) report Business Intelligence Techniques for Transportation Agency Decision- Making[105] (2024) provides a state-of-the-art overview for DOTs. The report outlines how agencies are increasingly turning to data-driven solutions to improve efficiency, productivity, and responsiveness in the face of aging infrastructure, workforce challenges, and evolving user needs. Through real-world examples such as Pennsylvania DOT's transition to a mobile inspection app and Maryland DOT's predictive tool for incident duration, the report demonstrates that BI can lead to significant cost savings, better resource allocation, and faster, more informed decision-making. Discussed modern BI capabilities include real-time analytics, predictive and prescriptive modeling, text and image mining, and cloud-based data lakes. Based on this report, these enable agencies to move beyond traditional descriptive metrics toward a dynamic, interactive understanding of transportation systems and tools like Apache Kafka, Microsoft Azure Stream Analytics, and machine learning platforms

[102] This document is internal to ADOT and not available to the public online.
[103] https://www.txdot.gov/about/brand-guidelines/data-visualization.html
[104] https://ops.fhwa.dot.gov/publications/fhwahop18009/fhwahop18009.pdf
[105] https://nap.nationalacademies.org/catalog/27819/business-intelligence-techniques-for-transportation-agency-decision-making

such as TensorFlow support advanced analytics that can monitor and optimize performance in real time. However, the report stresses that technical tools alone are insufficient. Agencies must also invest in data governance, leadership engagement, and change management to build a culture that values data sharing, transparency, and continuous improvement.

The report highlights that BI maturity varies across agencies and suggests both top-down and bottom-up strategies for BI adoption. For successful implementation, agencies should choose tools that align with user skill levels, organizational needs, and long-term interoperability. Additionally, avoiding common pitfalls (such as vendor lock-in or flashy but ineffective products) is critical. As data sources proliferate and become increasingly complex, the report argues that now is the time to invest in BI, as the cost of inaction will be rising inefficiencies and missed opportunities. With strong leadership, decentralized but accountable data governance, and targeted workforce development, transportation agencies can transform into proactive, high-performing organizations capable of navigating uncertainty and advancing their missions more effectively.

The NCHRP Report Implementation Plan[106] emphasizes that while most agencies already use BI to some extent, higher-level, integrated, enterprise-wide applications remain limited. The report identifies two main BI adoption pathways: bottom-up approaches, driven by local champions addressing specific operational pain points, and top-down strategies led by executive leadership focused on strategic alignment. Effective BI implementation depends heavily on leadership, governance structures, and organizational change management. The report also highlights the importance of selecting appropriate BI tools (ranging from basic data preparation to advanced analytics like machine learning and artificial intelligence) and improving data management by transitioning from siloed legacy systems to integrated, accessible data environments. It also addresses key barriers such as resistance to change, funding limitations, staffing constraints, obsolescence of tools, and political influences. Proposed solutions include starting with small pilot projects that demonstrate tangible benefits, building internal expertise, and choosing flexible, scalable technologies. The report emphasizes the need for metrics to measure impact, such as the number of automated processes, cost and time savings, data integration, and cross-functional data sharing. Additionally, the report identifies research gaps and recommends further studies on decision-making processes, building the business case for BI, tool selection guidance, data governance, and workforce development. It suggests creating a BI sharing platform to promote knowledge exchange and calls for research into the evolving skill sets needed to support BI-centric organizations. Overall, the implementation plan encourages transportation agencies to embrace BI strategically, invest in workforce capabilities, and collaborate across departments to realize the full potential of data-informed decision-making.

Transportation agencies often align with broad data management principles endorsed by bodies like AASHTO (American Association of State Highway and Transportation Officials)[107] [108]. The core principles[109] (treating data as an asset, making data open and accessible, ensuring data quality, keeping data secure, using common data definitions, eliminating duplication, and ensuring accountability from data (e.g., using it to drive decisions)) all support better BI outcomes. By embedding these principles into the governance plans, DOTs ensure that their Tableau/Power BI dashboards or other tools are fed by data that is high-quality, secure, and well-documented, and that the insights derived truly inform decision-making. In summary, many transportation agencies have created or are creating BI governance plans/ strategies, though they might be labeled as data governance or analytics plans. These strategies typically involve establishing data stewardship roles, setting data standards, choosing the right BI technologies, and ensuring every

[106] https://www.nationalacademies.org/webdocs/nchrprep1099-implementationplan/NCHRPRep1099-ImplementationPlan.pdf?channelToken=b9515dcea9b44b1caeec286a25accf32&download=false&tStamp=1710798578730
[107] https://transportation.org/data/about-us/
[108] https://transportation.org/data/policy-and-guidance/
[109] https://transportation.org/data/wp-content/uploads/sites/45/2023/01/Core-Data-Principles.pdf

dashboard aligns with the agency's goals and policies. The result is that DOTs and other agencies can confidently use Tableau, Power BI, or other tools to communicate performance and guide decisions, knowing that the visuals rest on a solid foundation of governed, authoritative data.

Summary of Findings

Government agencies, including state Departments of Transportation (DOTs), are adopting structured Business Intelligence (BI) governance strategies to ensure that Tableau, Power BI, and other visualization tools produce accurate, consistent, accessible, and secure insights. Key findings show that effective BI governance integrates clear visual design standards, accessibility compliance, open data practices, and rigorous privacy controls. Agencies emphasize the use of authoritative, vetted datasets sourced from centralized repositories, supported by defined governance roles, refresh schedules, and metadata documentation. Best practices to reduce data duplication include live connections to enterprise warehouses, shared semantic layers, and centralized extracts. Interoperability between BI tools and cloud data warehouses relies on standardized connectivity protocols, semantic alignment, and integrated security controls. Comprehensive metadata and data dictionaries, tailored to audience needs, are essential to user understanding and trust. Transportation-specific examples (from Maryland DOT's governance roadmap to WisDOT's enterprise framework) demonstrate that successful BI programs require leadership engagement, stakeholder collaboration, and alignment with broader data management principles endorsed by organizations like AASHTO. Collectively, these practices position agencies to improve decision-making, transparency, and operational efficiency while maintaining data integrity and compliance.

Gaps in Findings

While significant progress has been made in establishing comprehensive BI governance strategies and best practices across government agencies, some critical gaps remain.

Standardization and Interoperability

While there are many technical mechanisms for interoperability, adoption is fragmented, vendor-driven, and lacking a common, agency-wide or industry-wide standard.

Metadata standardization remains weak

The review notes inconsistent definitions, too many competing standards, and low usability indicating a need for harmonization, better tools, lifecycle management, and automation.

Inconsistent enforcement and monitoring of duplication controls

Although best practices exist (such as direct connections to central repositories, certified semantic layers, and centralized extracts) few agencies have systematic enforcement or automated monitoring. Without governance dashboards, alerts, or mandated review processes, ad-hoc data imports and redundant extracts can reappear over time.

Long-Term Sustainability and Scalability

Many BI governance strategies focus predominantly on immediate implementation without adequate consideration for long-term sustainability. More detailed guidance is needed on how to scale BI governance frameworks effectively as agency data and analytical needs grow.

Measurement of BI Impact

While agencies emphasize the importance of data-driven decision-making, there is a notable absence of clearly defined metrics and evaluation frameworks for assessing the impact of BI dashboards on agency operations, decision-making processes, and overall organizational efficiency.

Advanced Analytical Integration

Current governance practices largely focus on descriptive analytics. There is limited strategic direction regarding the integration of more advanced analytics, such as predictive and prescriptive analytics, machine learning, and artificial intelligence. Explicit guidance for integrating advanced analytical capabilities into BI governance frameworks would enhance future readiness.

Workforce and Skill Development

Despite acknowledging the necessity of workforce development, there is insufficient detail on effective approaches to upskilling staff or cultivating specialized BI roles within transportation agencies. Clear strategies for workforce training, skill enhancement, and recruitment specifically tailored to BI competencies are missing.

Community of Practice and Knowledge Sharing

Although isolated efforts exist, systematic mechanisms or platforms to promote continuous knowledge exchange and sharing of best practices among agencies are currently lacking. Establishing formalized communities of practice could significantly enhance collaborative learning and widespread adoption of successful BI governance strategies.

Guidance on Vendor Management and Procurement

Few agencies provide detailed guidance on vendor management practices, particularly concerning long-term vendor relations, licensing, and avoiding vendor lock-in. Explicit recommendations on best practices for procuring BI tools and managing vendor relationships would strengthen overall governance.

Next Steps

To effectively address these identified gaps, the following steps are recommended.

Develop Interoperability Standards

Convene a cross-agency working group to identify, evaluate, and agree on a standardized set of interoperability protocols and data exchange formats that can be applied across BI tools and data warehouses. Align with existing open standards where possible and publish implementation guidelines for consistent adoption.

Create a metadata governance standard

Define a common metadata model with agreed-upon field names, definitions, and data types. Implement organization-wide metadata management tools that support lifecycle tracking, version control, and automation. Provide training for analysts and developers to ensure consistent application.

Implement automated duplication controls and monitoring

Deploy governance dashboards and alert systems to track dataset lineage, detect redundant extracts, and flag non-compliant data connections. Establish formal review processes and integrate compliance checks into BI publishing workflows to ensure ongoing enforcement of duplication-minimization best practices.

Establish Scalable Governance Frameworks

Develop strategic plans and detailed roadmaps focused on the scalability and long-term sustainability of BI governance frameworks.

Implement Impact Metrics

Define and adopt clear metrics to systematically measure and evaluate the impact of BI initiatives on organizational outcomes and decision-making effectiveness.

Advance Analytical Capabilities

Integrate advanced analytics, including predictive modeling, prescriptive analytics, machine learning, and AI, into existing governance frameworks through pilot projects and strategic planning.

Enhance Workforce Training

Develop and implement targeted training programs, certifications, and continuous learning opportunities specifically tailored for BI skills.

Create Collaborative Platforms

Establish formalized communities of practice, forums, or platforms to encourage collaboration, knowledge exchange, and dissemination of best practices among government agencies.

Strengthen Vendor Management

Provide clear guidelines and best practices for vendor selection, management, and procurement processes to mitigate risks associated with vendor lock-in and ensure long-term flexibility and effectiveness.