

Architecting for Scale: Enterprise Technical Architecture Best Practices

FEATURING



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AGENDA

Architecture
Pain Points

Architecture
Considerations

Architecture
Examples

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Industry is Undergoing a Radical Transformation

The Landscape is **Shifting**



Increasing Complexity



Rapidly Evolving Technology



Shifting Consumer Demand

Manufacturers Need to **Adapt**



Optimize Production



Accelerate Innovation



Maintain Stringent
Quality & Safety Standards



Where the market is getting stuck

Analysis Paralysis

Many companies know they're behind technologically, but fear of cost, disruption, or making the wrong choice keeps them from starting.

Risky rollouts

Many companies still issue RFPs for "big bang" site-wide deployments. They ask for unrealistic timelines and complete transformation in one go

Trend Chasing

Some manufacturers jump straight to "AI" or "predictive" without first investing in reliable connectivity, contextualization, and governance.



Traditional scale strategies and architecture are keeping manufacturers stuck

Monolithic systems → inflexible, hard to adapt to new needs.

Vendor lock-in with proprietary solutions → limits future integrations.

Siloed data → undermines real-time visibility and analytics.

Underestimating governance in modular/composable systems → leads to fragmentation.

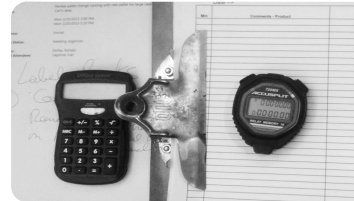
"Big bang" rollouts without phased testing → increases risk of large-scale failure.



Legacy Systems



Point Solutions



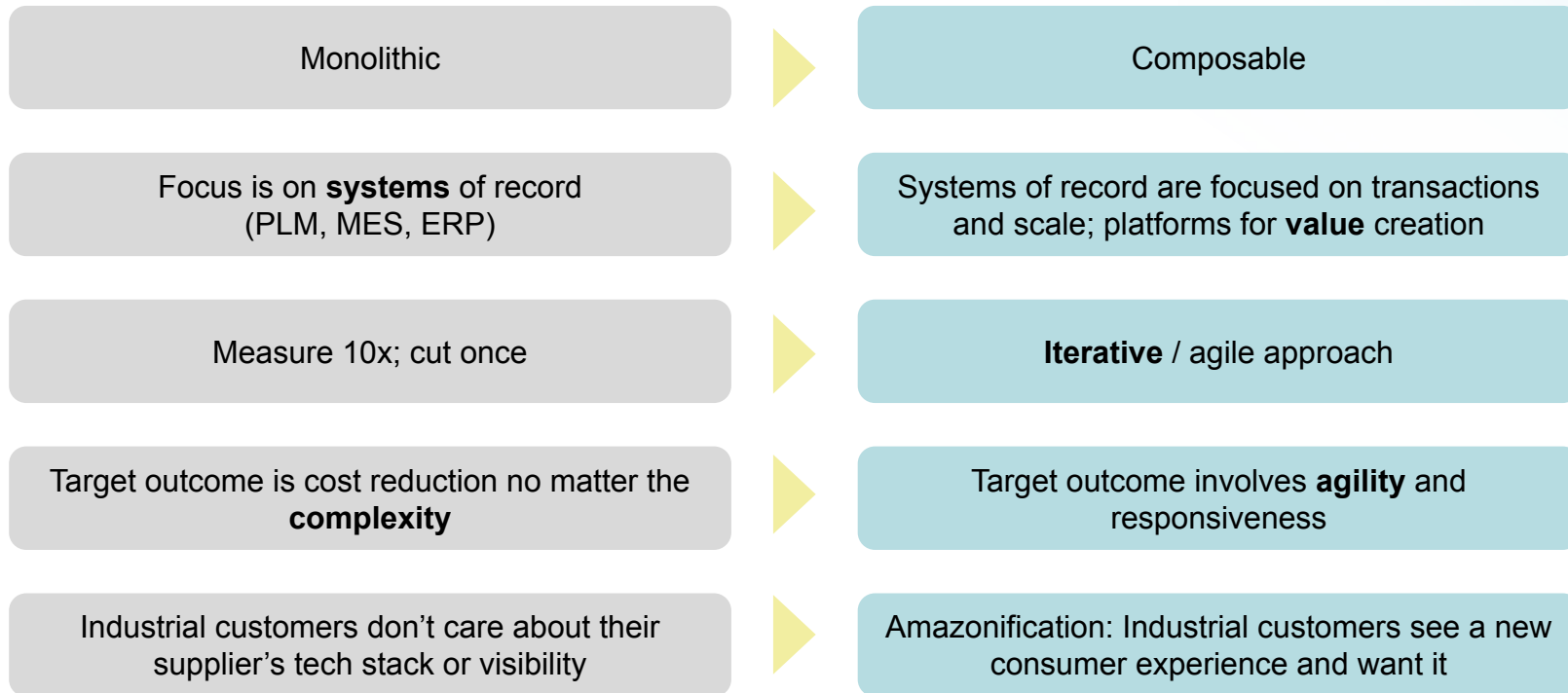
Paper Processes



Excel



Big Idea: A Paradigm Shift is Required for Scale



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Recommendations





What is “Composability” and why does it matter? Two definitions exist

1. **Composable architecture** is a modular approach to software design and development that builds **flexible, reusable and adaptable software architecture**.

- ✓ Open API
- ✓ Modular
- ✓ Modern Architecture

2. **Composability** is a design approach that enables systems — IT systems, organizations, products, etc. — to **adapt quickly to changes** while staying resilient. (Gartner)

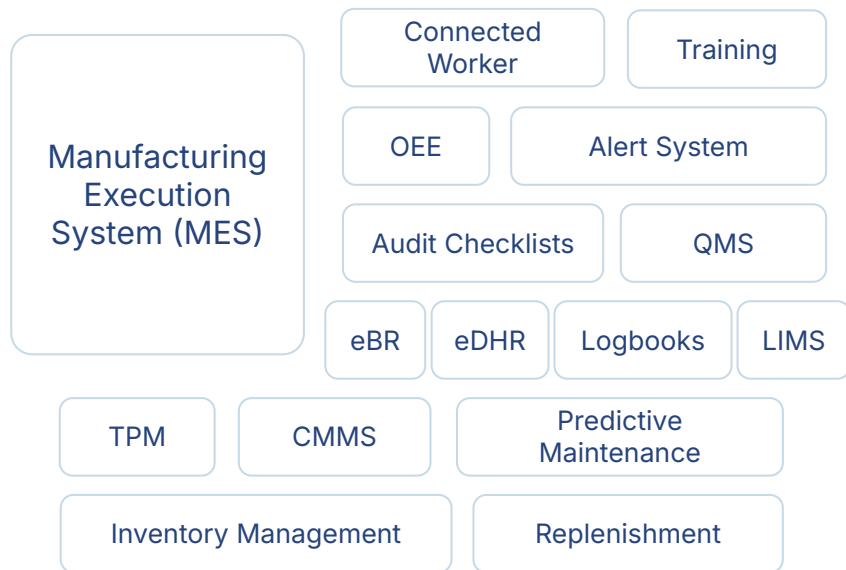
- ✓ Ability to compose (*no-code*)
- ✓ Iterative rollout (*apps, widgets, solutions*)

You need both for a truly composable MES



Modularity: A Platform Approach Avoids the Sprawl of Multiple Point Solutions

Digitalization with Point Solutions

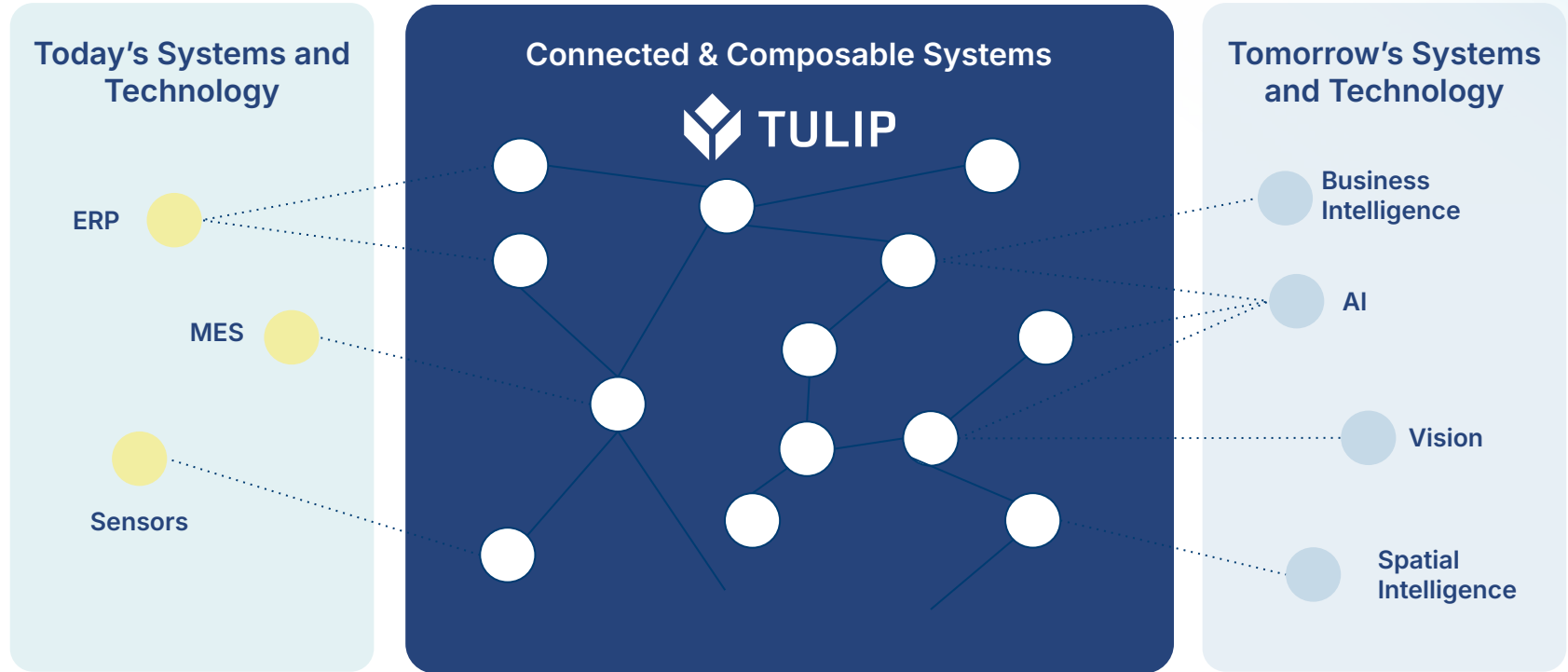


Composable, Platform Approach





Open API: Future-Proof Your Technology Investments with Openness





Key Pitfalls to Avoid

Wait for a Perfect ERP

Deployment of new ERP (or other solutions) can have a major impact, but it's not required; Don't wait for the ERP to get value

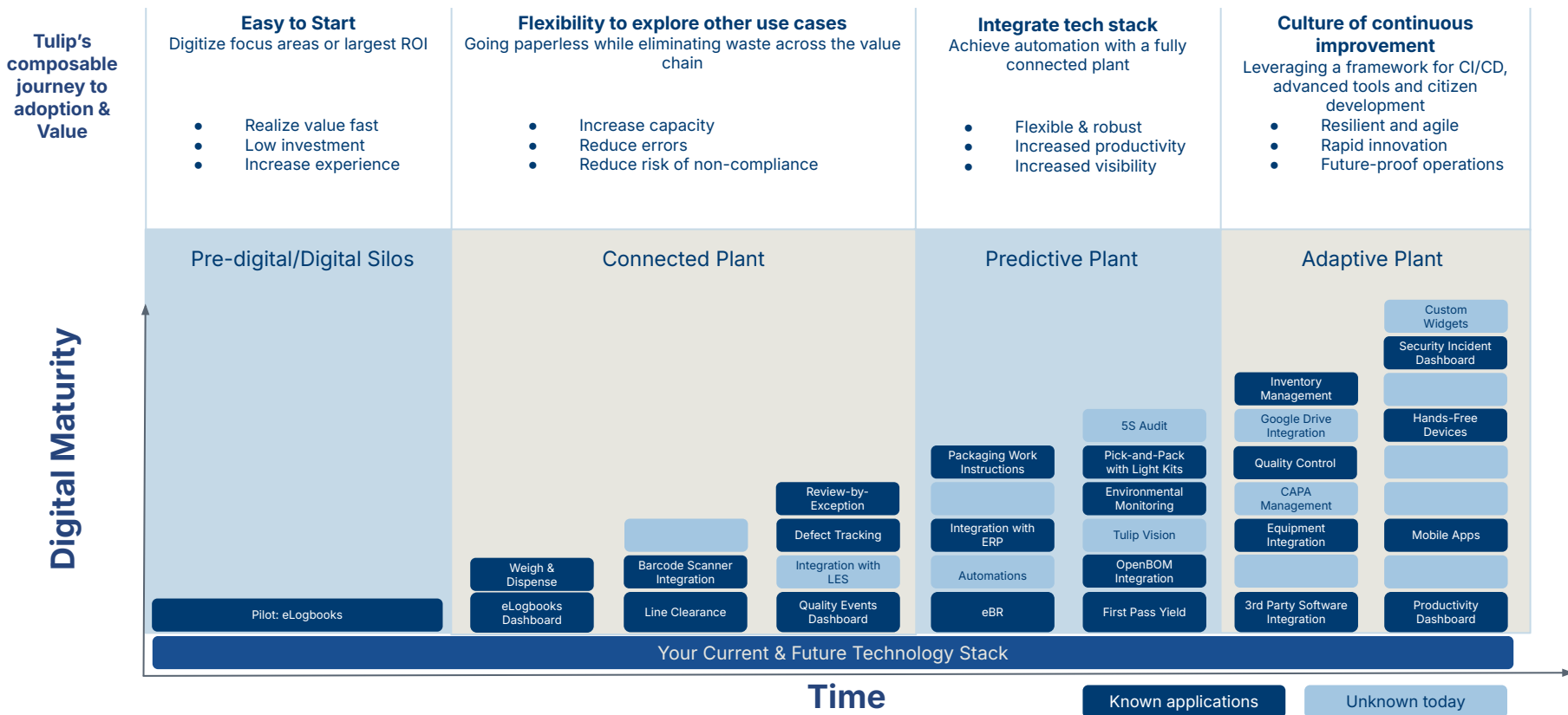
Tight Integrations (Point to Point)

Any integration has a cost. Deep integrations will bring marginal gains for high costs to deploy, and even higher costs to maintain or scale

Big Bang Rollouts

Complete solution rollouts are risky, and don't allow you to react to new constraints and requirements (priorities might change throughout a 6 months project), they also delay value and potential for improvement

Tulip's Unique Approach: Build what you need, roll it out fast, and adjust it as needed





Enterprise Architecture Recommendations

1. **Start small, scale fast**
2. **Focus on use case, then select technology**
3. **Invest in people and processes**
4. **Understand data requirements for selecting protocols**
5. **Plan for data analytics and AI**



Recommendation: Start small, scale fast

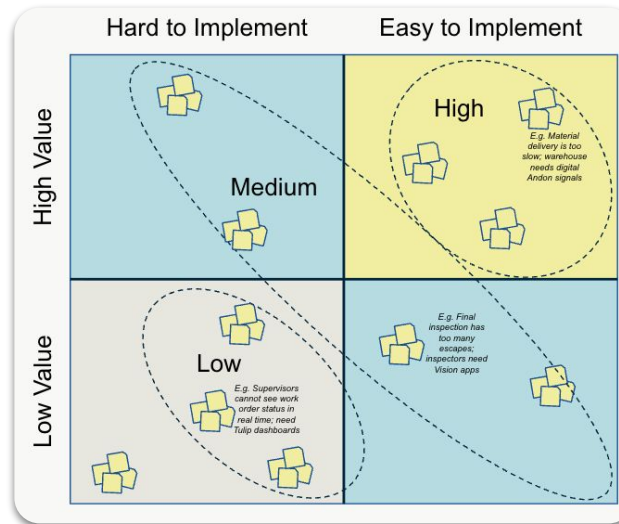
- Pilot with one production line, 2 to 3 use cases.
- Start with data collection even manual, light/limited integrations.
- Expand once the foundation proves stable.





Recommendation: Focus on use case, then select technology

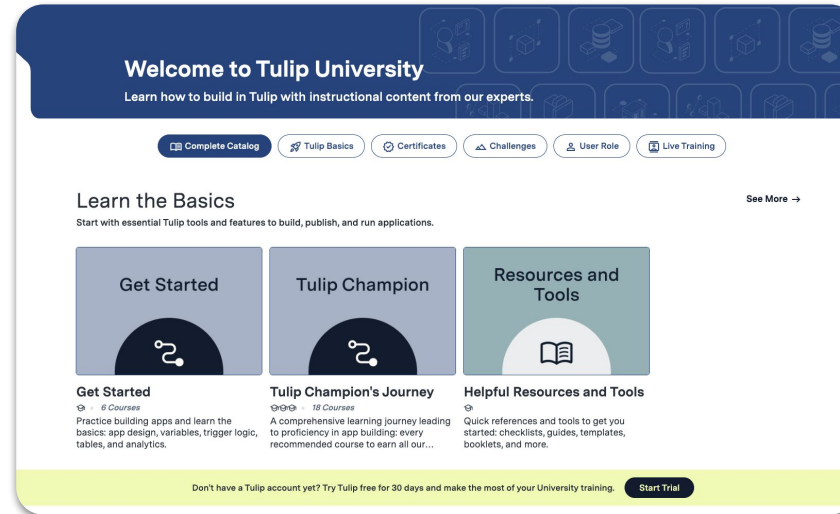
- Value creation drives the design and architecture
- Applied technology instead of standardized solutions





Recommendation: Invest in people and processes

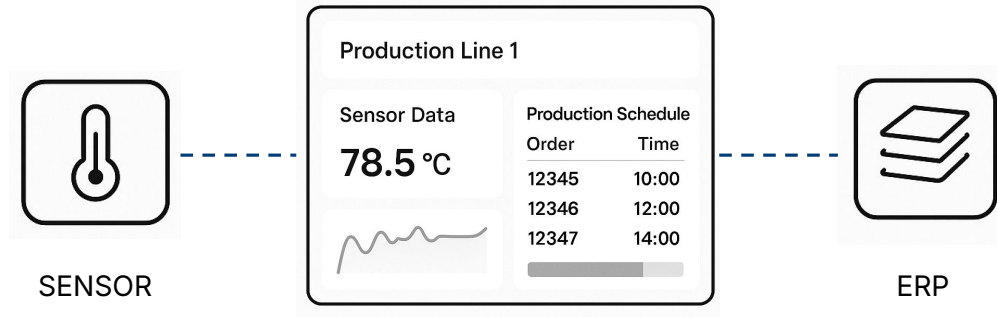
- Train teams for modular architecture and different technologies.
- Solution Architects, Digital Transformation consultants
- Establish clear ownership and governance.





Recommendation: Understand data requirements for selecting protocols

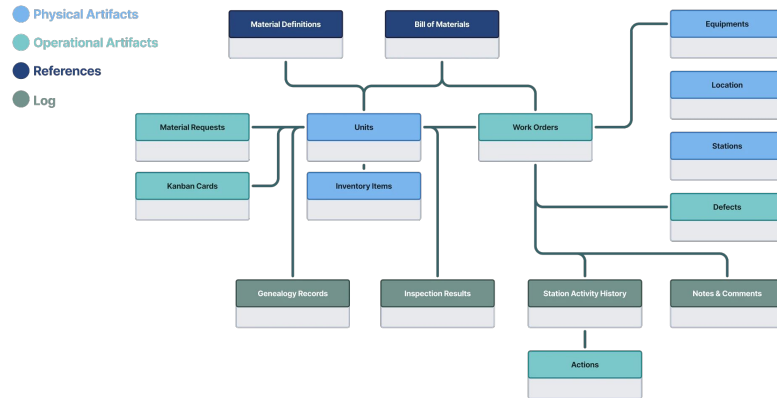
- Data frequency (real-time vs. batch) needs to be determined from business needs
- REST APIs for on-demand integration.
- Event streaming for real-time visibility.





Recommendation: Plan for Data Analytics and AI

- Data model inspired by Industry Standards (ISA95, IS88)
- Store historical data in scalable platforms (data lakes/warehouses).
- Keep architecture flexible to integrate future AI/ML pipelines (Data Ops)



Tulip → Enterprise Recommendations





Data Models

Tulip

- Build **your own data model**: Start from *Tulip Common Data Model* and follow Tulip Artefact Model on data storage..
- Document what needs to be common for all sites and instances vs. what can be flexible
- Understand that data models are not static artifacts but constantly evolving



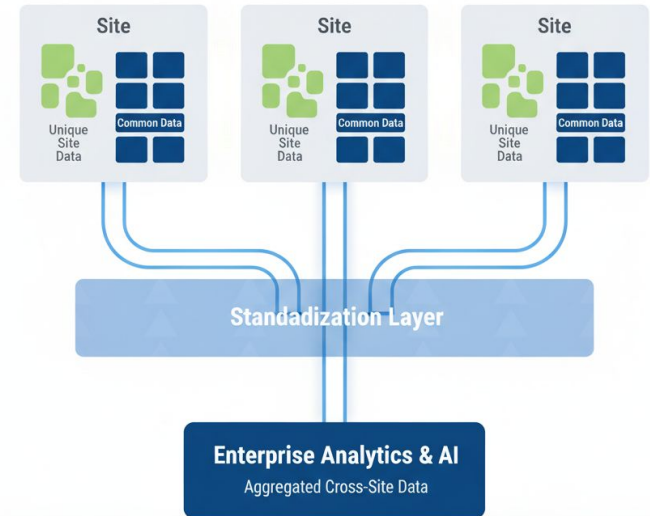
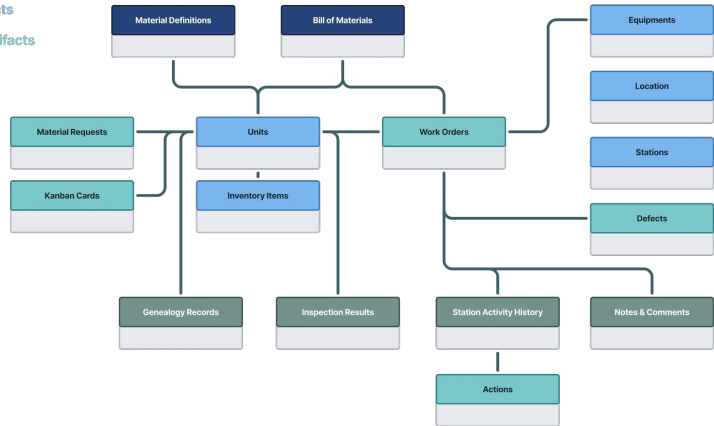
Enterprise Architecture

- Make use of the existing data models only if helpful (Don't feel the need to rigidly adopt ISA-95, ISA-88 but use elements as helpful)
- Understand what data will be analyzed cross-site and what is unique to sites; focus only on that data for cross-site standardization



Data Models

- Physical Artifacts
- Operational Artifacts
- References
- Log





Governance

Tulip

- Define a Center of Excellence to gather and share best practices internally.
- Leverage common templates across multiple sites (enterprise app exchange)
- Organize workspaces, apps, and stations by physical hierarchy (site, line, station, etc.)
- Selecting the right instances configuration application lifecycle: for DEV / TEST / PROD



Enterprise Architecture

- Own your solutions, architecture and roadmap, define and share standards
- Build repository of templates for sites to accelerate digital transformation
- Understand what analytics need to be enterprise-standard vs. site-specific
- Clearly isolate DEV / TEST / PROD environments and workloads



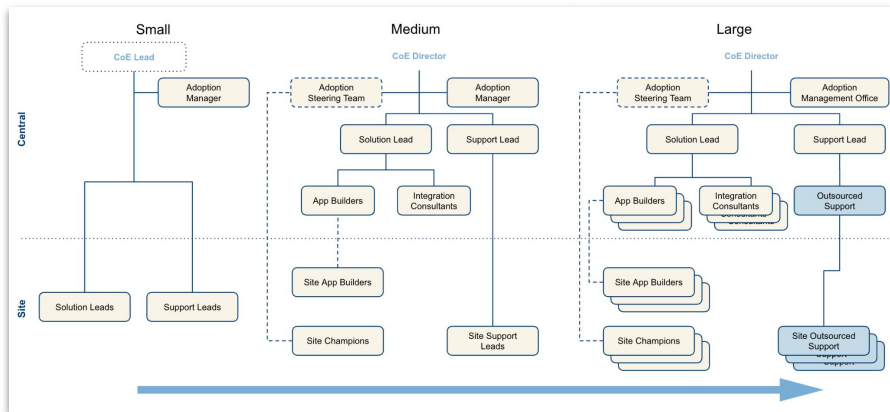
Governance

Platform

The Platform section displays four screenshots of the Tulip application interface, each with a descriptive label in a blue box:

- Version tracking and change log:** A screenshot of the 'Yoyo Inspection' page showing a table of versions with columns for version number, date, and description.
- Permission management:** A screenshot of the 'Yoyo Assembly' page showing a table of permissions with columns for role, permissions, and status.
- Centralized best practice content:** A screenshot of the 'Create New App' dialog box showing a list of templates and a 'Create New App' button.
- Central connector management:** A screenshot of the 'SiteNetworkCloud' page showing a table of connectors with columns for name, status, and last update.

CoE





Agile & Iterative Development

Tulip

- Start Small (Value-focused pilots) and iterate
- Design starts with deep understanding of operational flow and physical environment
- Solution CREDO (Simplicity, Adoption, Human Centric, Focus)
- Involve SMEs and End Users throughout the process - test early and often

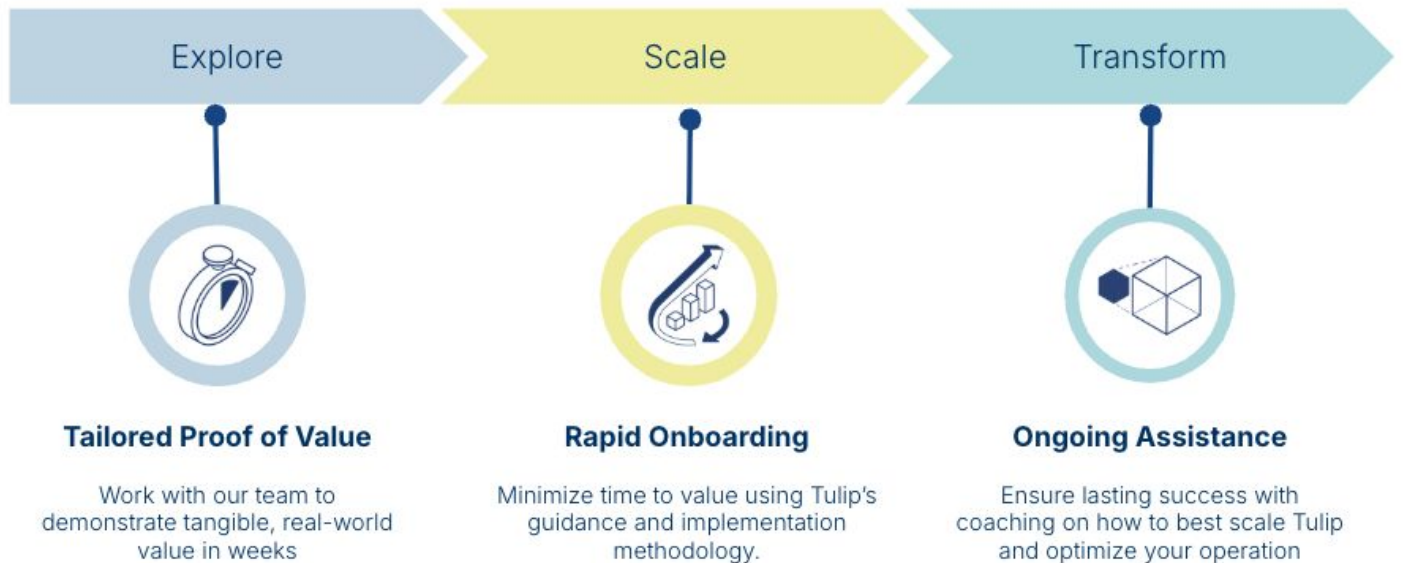


Enterprise Architecture

- Start Small (Value-focused pilots) – site-level pilots do not need to immediately consider rigid enterprise standards
- Enterprise architecture design starts with deep understanding of operational flow and process flow
- Human-Centric and adoption still matter for Enterprise solutions
- Iterate on your recommendations / best practices & keep learning from standards



Agile & Iterative Development



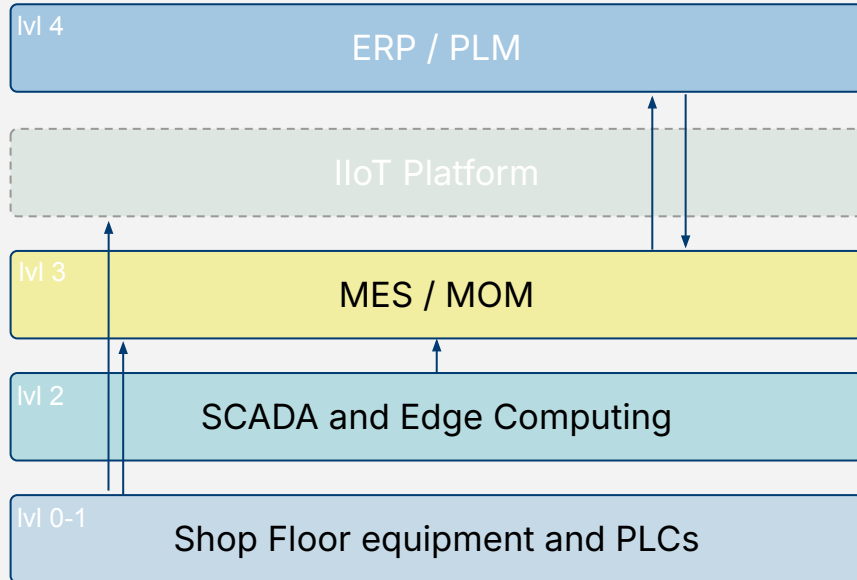
Technology





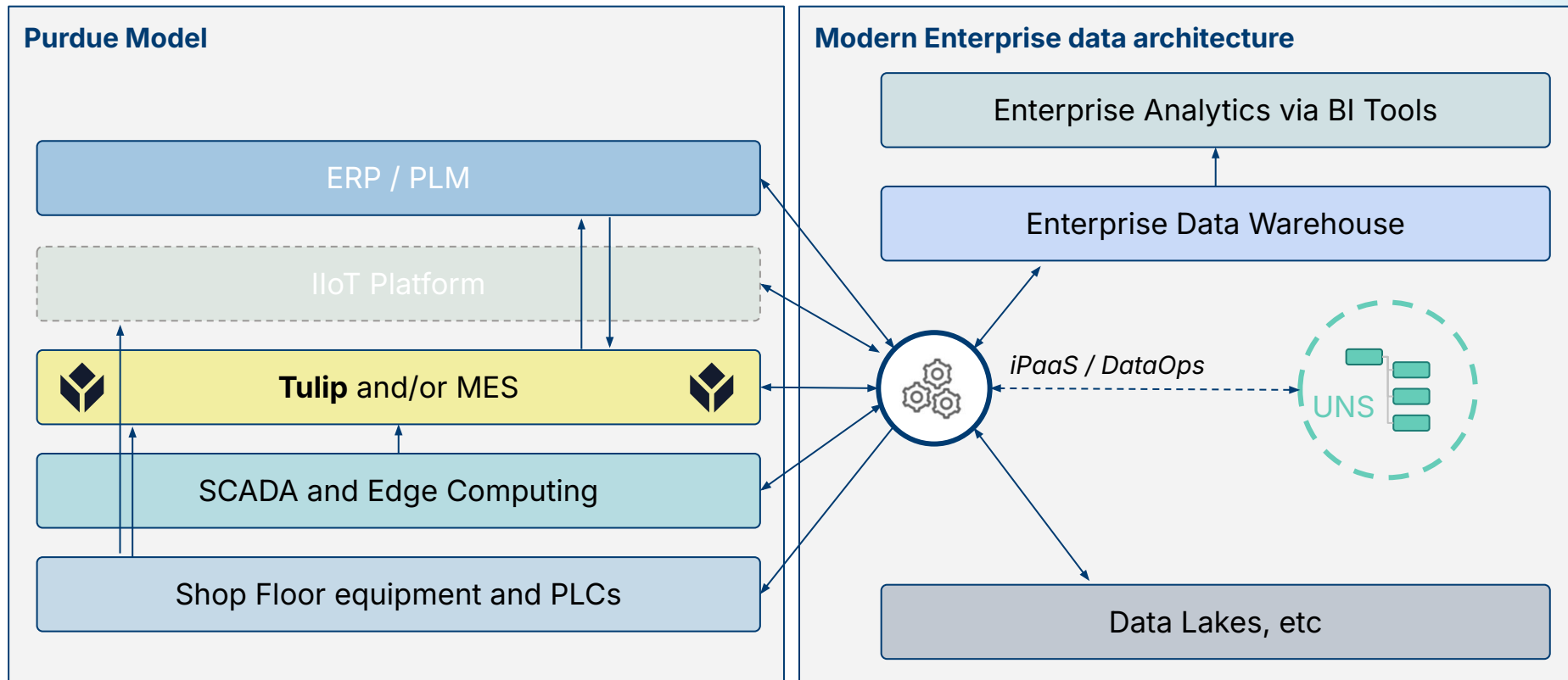
Traditional Model

Traditional approach (often used at site level)





Moving a distributed/scalable model





Moving a distributed/scalable model

Enterprise Data & Analytics

Enterprise Data Warehouse

Enterprise Analytics via BI Tools



iPaaS / DataOps



Site 1

Site 2

Site 3

ERP/PLM

Tulip and/or MES

SCADA and Edge
Computing

Shop Floor equipment and
PLCs

Tulip and/or MES

SCADA and Edge
Computing

Shop Floor equipment and
PLCs

ERP/PLM

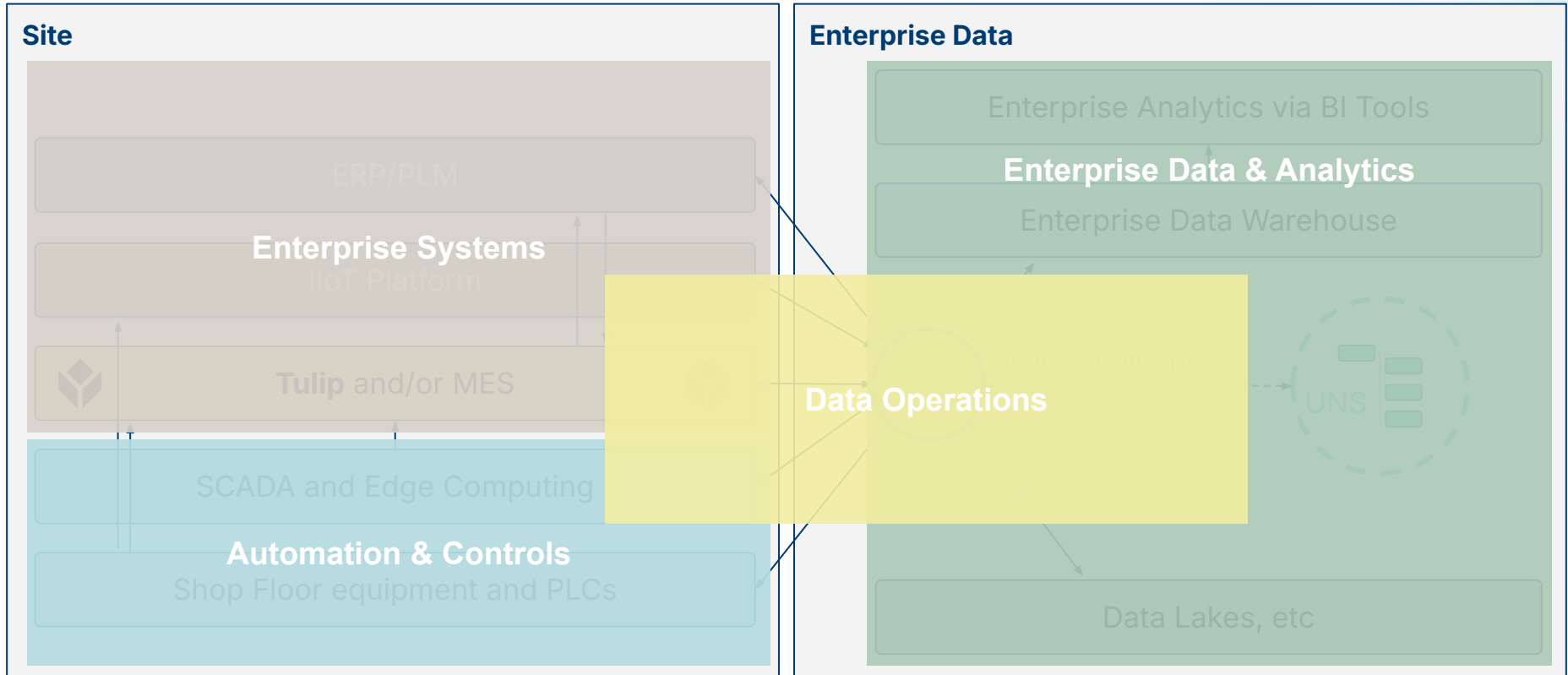
Tulip and/or MES

SCADA and Edge
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PLCs



From Purdue to a distributed model

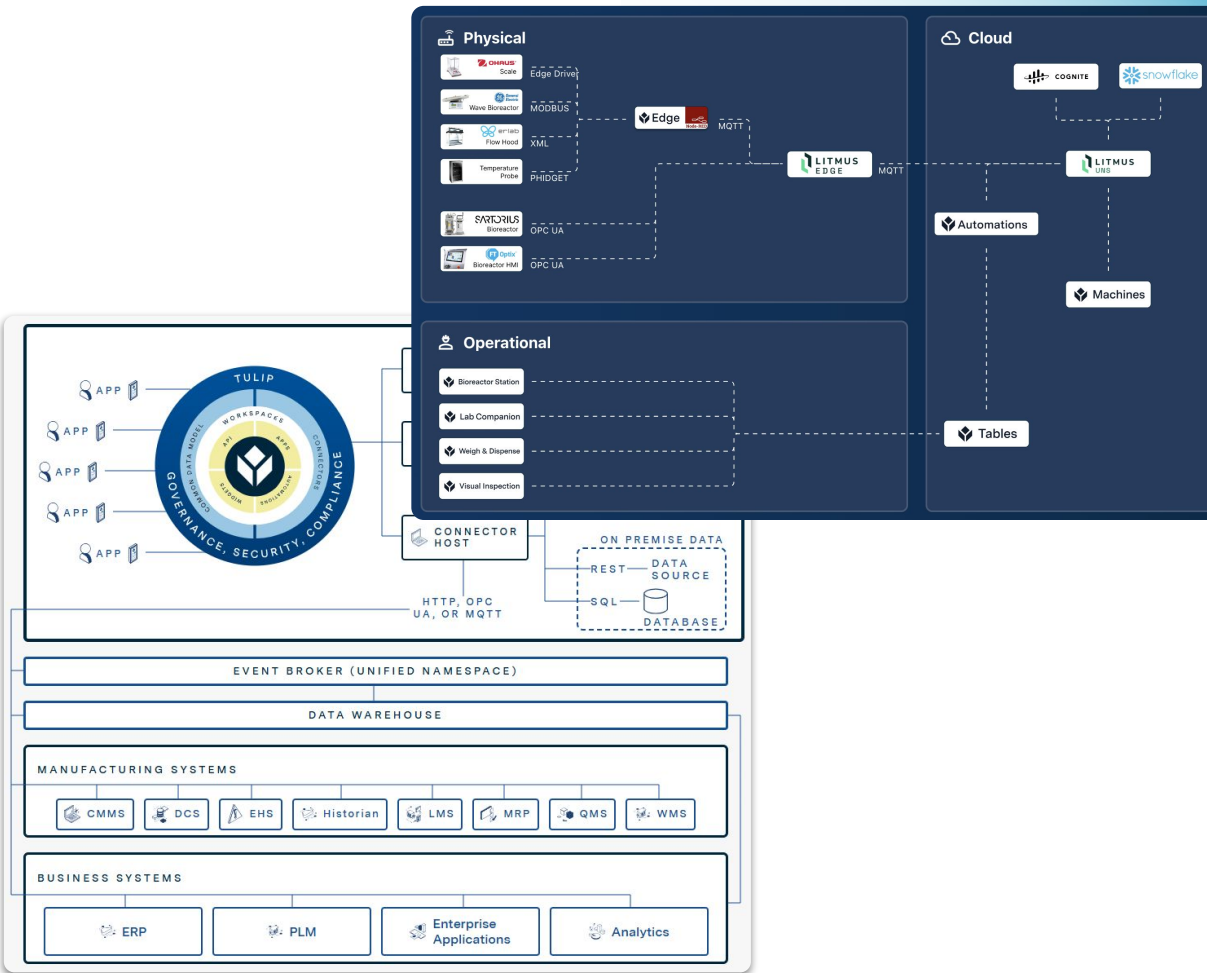


Enterprise Architecture

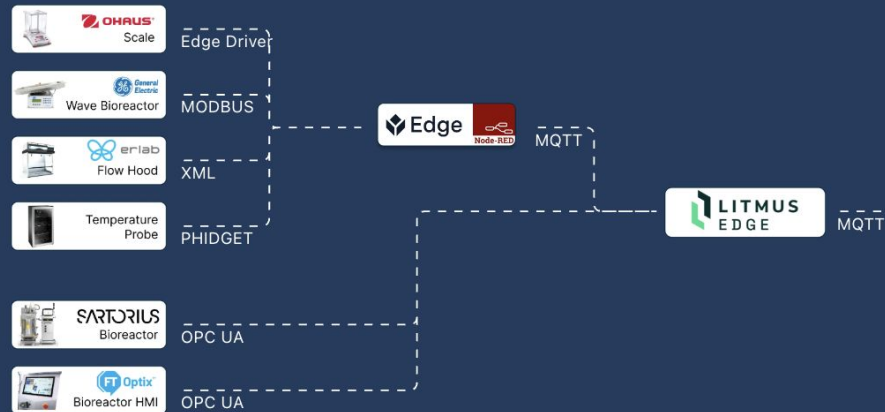
An **open ecosystem** architecture is the key to a resilient and agile future.

Data can flow freely between disparate systems to unlock data and promote **interoperability**.

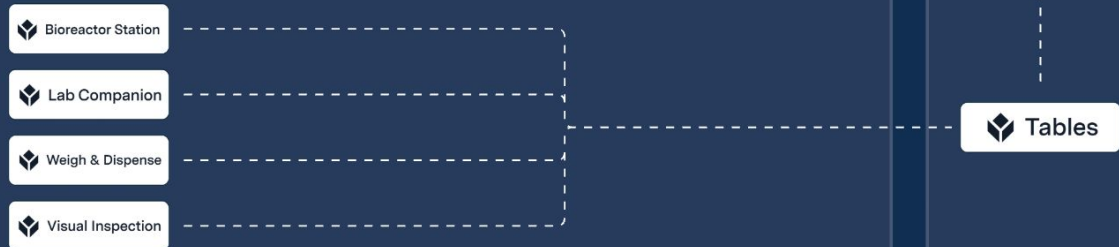
Tulip's Connector Framework can be **configured to exchange data** and messages via Web APIs, SQL MQTT, OPC UA



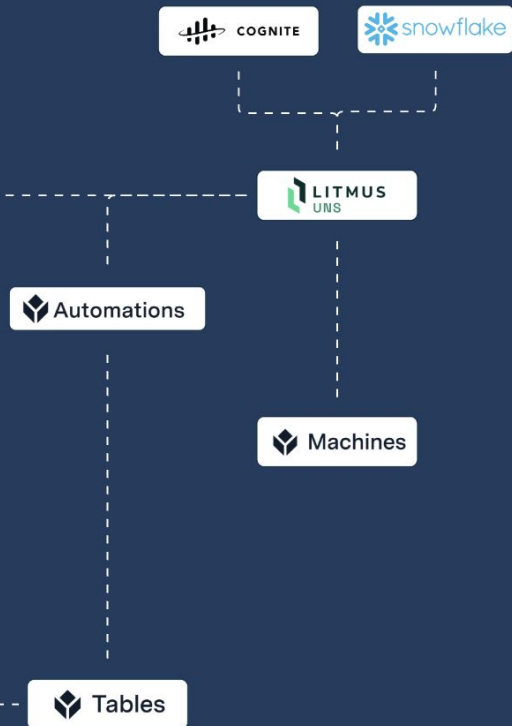
Physical



Operational



Cloud





Automation and Controls

Why this matters to Tulip builders and architects

- Data needs context!
- IT and OT make decisions in silos; MES + controls data needs to be joined
- Ops needs the full picture of performance

Architecture Considerations

- Start with first principles; *why do you need the data on the cloud or analyzed at all?*
- Center around action: *what actions will supervisors, and managers take from this data?*
- Prioritize event based technology to connect these systems to the rest of the stack: **OPC UA, MQTT**

Risk: limited interoperability with proprietary protocols.



OPC Server: Kepware, Matrikon; **DCS:** PCS7, Experion, DeltaV, Yagawa; **SCADA:** AVEVA, WinCC, Ignition;
IIoT: Thingworx, Azure IoT, AWS IoT Core, Litmus; **Historian:** PI, GE Proficy



Data Operations

Why this matters to Tulip builders and architects

- It gets very difficult to read data from machines and systems into Tulip and write back data to these systems
- Complicated point-to-point integrations won't scale

Architecture Considerations

- Know when to leverage standard iPaaS platforms
- Know when to use IT standards (Kafka) or OT standards (MQTT)
- Understand what really requires UNS vs. simple APIs

Risk: Complicated Data Ops slows down future integrations

Risk: governance gaps if standards aren't enforced: silos, latency, duplication.



MuleSoft, Boomi, Kafka, Azure Data Factory, Microsoft Fabric, AWS Glue, Amazon Event Bridge, HighByte, Litmus, HiveMQ, etc



Operations & Enterprise Systems

Why this matters to Tulip builders and architects

- Integrating to systems of record enables Tulip to be a robust, flexible system of engagement
- Source of truth is important! ERP integration accelerates value creation

Architecture Considerations

- Are there existing integration patterns for ERP, PLM, QMS
- How can you start simple? E.g., Basic Work Orders from ERP or defects from QMS?

Risks: misalignment between Automation, MES, ERP, QMS, creates gaps and inefficiencies/waste.

Risk: Slowing down MES, QMS, PLM integrations limits scalable value



AVEVA



Microsoft
Dynamics 365

ORACLE®



windchill®

Honeywell

SIEMENS

SAP, Oracle, Dynamics, Dassault, Arena by PTC, PTC Windchill



Enterprise Data and Analytics

Why this matters to Tulip builders and architects

- Important to understand what to analyze in Tulip vs. what to analyze with Enterprise BI tools and dashboards
- Balance multi-site insights without hampering each site to fit a rigid schema

Architecture Considerations

- What actions will be driven from what insights from what data from what processes?
- Who is reviewing these reports and for what purpose?

Risks: data sprawl and poor data governance.

Risk: Data duplication, real-time streaming, Agentic AI can get expensive without the right use case

AVEVA



databricks



AWS, MSFT, Snowflake, or Databricks for scalable storage/analytics; Power BI, Tableau, AWS Quicksight, etc for visualization

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"We need an MES": Phasing and Iteration is Important

Context

Despite a highly complex manufacturing process, currently rely on manual systems to create work instructions and "travelers", tracking products on the shop floor, collecting data, and managing quality control.

Challenges: Inefficiency, Lack of visibility, Data silos, Quality control

Goal: digitize and streamline their shop floor operations, leading to improved efficiency, visibility, and quality control.

Requirements

An MES that support the creation of detailed work instructions, track products and materials on the shop floor, collect and analyze data, manage NCRs and rework, and integrate with their existing ERP and PLM systems.



Improved efficiency | Enhanced quality control | Better decision-making | Increased visibility and traceability | Seamless integration



○

Recommended and approved project plan

PILOT - Digital Traveler Templates

Initial deployment to 2 lines for 5 models

- Production Tracking, Complete Process Visibility
- Quality Assurance and Compliance
- Early Detection of Non-Compliance
- Labor Tracking & Timekeeping
- Dashboards: Data Analytics and Continuous Improvement, Real-Time Monitoring of Production Progress

PHASE 2 - Roll out and new features

- Deployment for all 10 models for the 2 lines
- Non conformances and Rework
- Labor & Employee Performance Evaluation
- Integration with ERP

Phase 1 + Phase 2 can be rolled out to second plant.

PHASE 3 - Inventory & Integration to WMS

- Material Receptions & Inspection
- Material Movement
- FIFO and Shelf-Life Management

Data is aggregated in analytics tools:

- *Supplier Evaluation*
- *Compliance with Industry Standards*
- *Data-Driven Decision Making*

Integration to 3rd party systems

Teams work together to define the right integration level to support the business:

Initial ERP integration: pull schedule and push order and operations completions (triggers backflush)

WMS and Data Analytics tools integration
(Later phases: Timekeeping system, Document Control)



Tulip discussions extend beyond “Tulip”

Context

Global health and nutrition company - consumer transparency

Goal: harmonize manufacturing and quality processes across their production and supply points.

Challenges: Inadequate Traceability, Process Inconsistencies, Manual Processes and Data Entry, Lack of Real-Time Visibility attributed to Lack of a standardized modern MES

Requirements

Scalable MES for European dairy division, then global expansion. Robust, end-to-end traceability, from raw materials to finished products, and harmonize manufacturing processes across all sites and seamless integration existing ERP, WMS, and LIMS systems and a new Automation layer built on MQTT.



Enhanced Safety and Quality | Increased Operational Efficiency | Improved Transparency and Consumer Trust | Better Decision-Making | Future-Proofing the Business



Example Solution Architecture

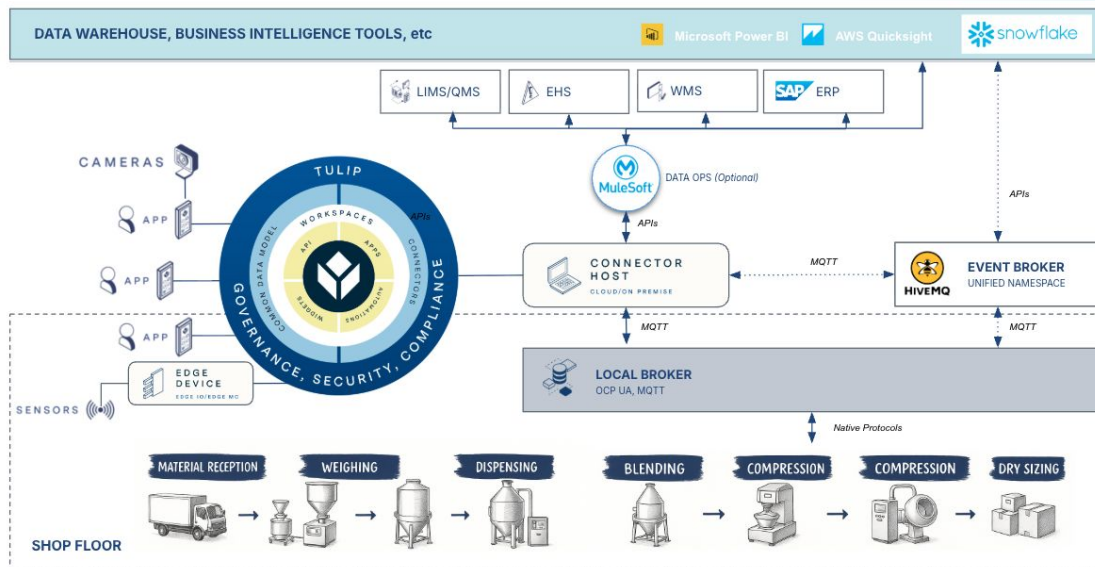
This reference architecture highlights how Tulip will be able to integrate with the systems described in customer requirements:

Tulip's [Connector Framework](#) can be configured to exchange data points and messages via **Web APIs, MQTT, OPC UA to Data Ops tools or Event Broker**; as well as any other 3rd party system supporting these technologies.

Event brokers are core to the event driven architecture that powers a Unified Namespace (on-prem for local/site + cloud for enterprise aggregation)

Data Warehouses are centralized repository designed to manage large volume of unstructured data to support advanced analytics and AI (Tulip recommends [Snowflake](#))

The services listed are part of [Tulip's partner ecosystem](#), Tulip is open to work with **your preferred suppliers** in these areas.

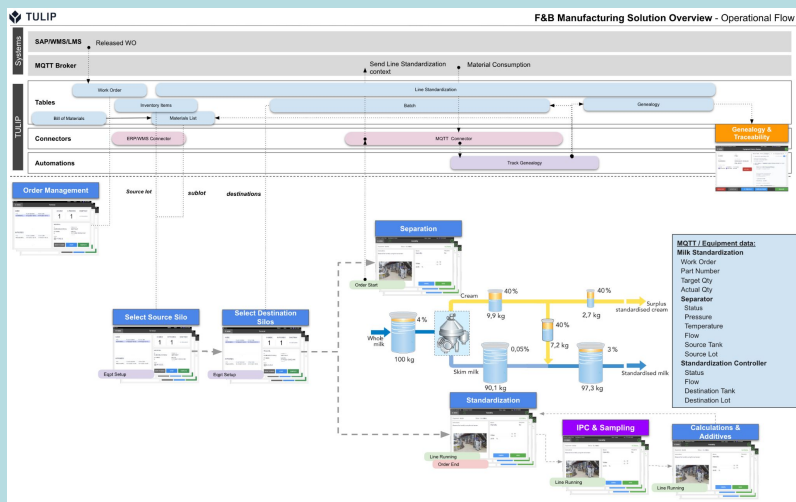


[interactive architecture reference](#)



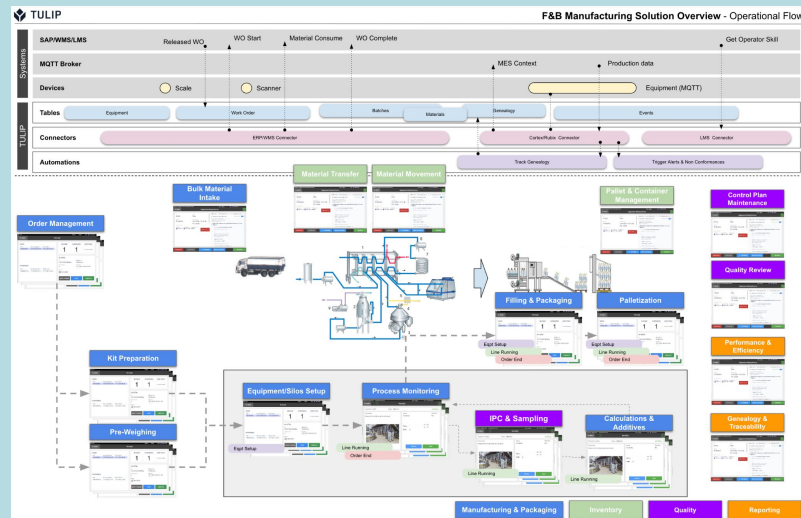
Recommended and approved project plan

PHASE 1: focus on one area, connect to Automation and ERP (enable genealogy, transparency and quality monitoring)



Basic ERP Integration, Integration with Automation

PHASE 2: Deploy across the shopfloor, connect to WMS, LIMS, etc

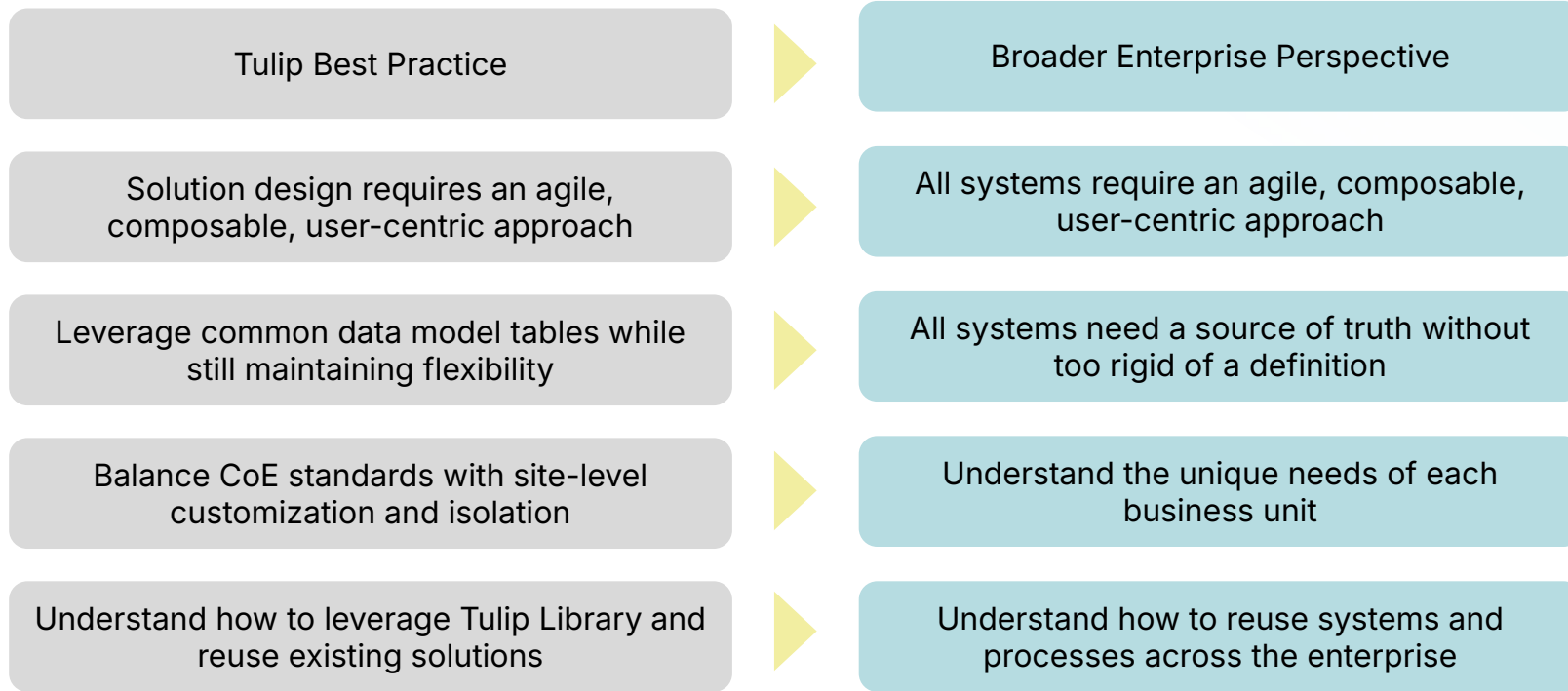


Advanced ERP Integration, Skill Management integration

While the Phase 2 is being delivered and validated, Phase 1 can be rolled out to other lines and sites.



Big idea: *Tulip best practices are really enterprise best practices*

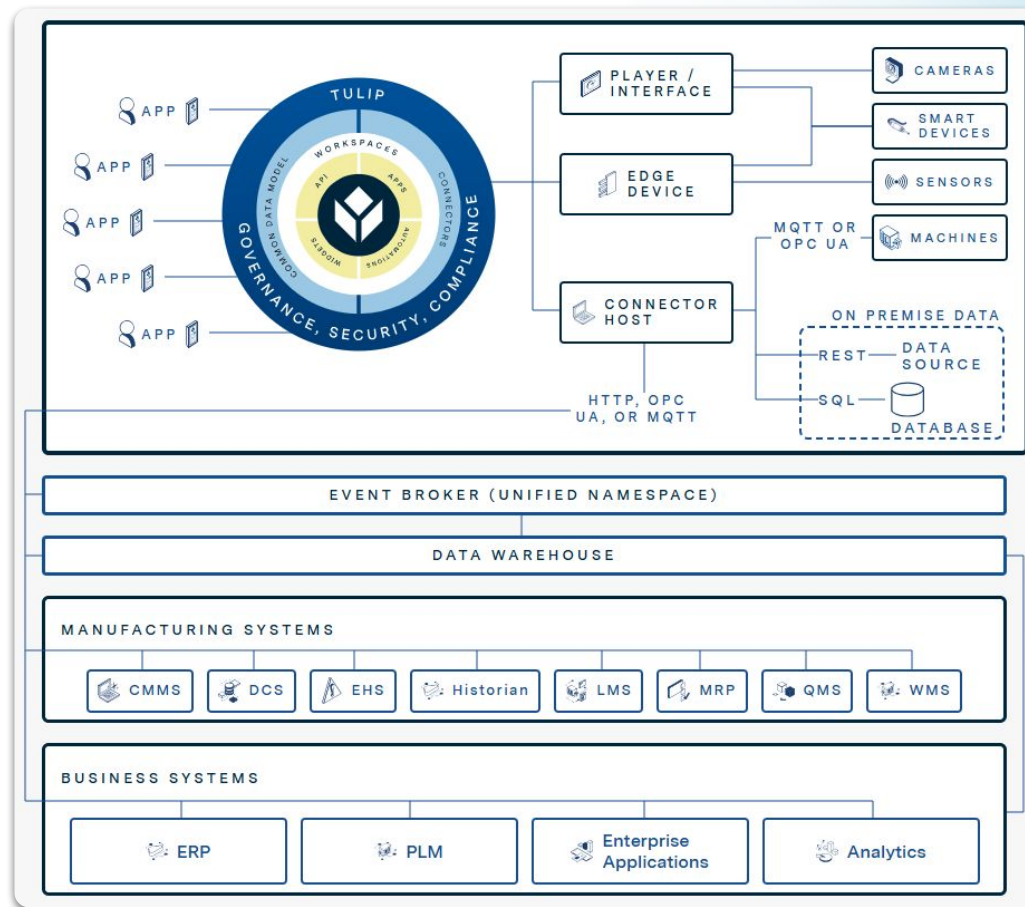


Enterprise Architecture

An **open ecosystem** architecture is the key to a resilient and agile future.

Data can flow freely between disparate systems to unlock data and promote **interoperability**.

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Next Steps

Identify business needs or pain points that can be improved upon with digital tools, build momentum and confidence.

Cross functional team (Operations, IT, etc) to define long term vision: define internal standards and governance, help sites evaluate and deploy solutions, and ensure alignment with company goals.

In controlled environments, test the technology and evaluate the potential ROI (define measurable success criteria)

Technology alone will not solve the problems. Bring in SMEs and end users early in your projects to discover what works and what doesn't.

Rollout to new areas and use cases iteratively and adjust your best practices

Pick low hanging fruit

Establish Digital Team

Start Pilots

Involve SMEs, End Users

Build a phased plan

QUESTIONS?



TULIP

THANK YOU