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Inventory Optimization using State-Aware Object-Centric Process Mining: An Industrial Case Study

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Highlights

How does this work contribute to systems science?

- Linking procurement, stock movements, and sales to the changing state of a shared plant-material object supports inventory diagnosis across these interacting parts of the industrial system.

What are the main findings and their implications?

- Persistent overstock warrants reviewing procurement that continues during overstock, while movement between unfavorable states warrants reviewing replenishment stability and planning parameters.

Abstract

Inventory management requires balancing product availability and inventory costs. Object-centric process mining (OCPM) links procurement, stock movements, and sales to the same material at a given plant. State-aware OCPM makes explicit whether those activities coincide with entry into, persistence in, or recovery from an unfavorable inventory state. We operationalize this approach at a large multinational industrial manufacturing company using an existing object-centric data foundation of more than 22 million events over three years. We classify inventory as *Understock*, *Normal*, or *Overstock* and examine two plant-material histories across two warehouses. For a comparison of scale, we divided the two warehouses' combined revenue at risk from understock at the time of analysis by their combined value of avoidable purchase orders associated with overstock over the previous twelve months. The ratio was 21.11%. One material shows persistent overstock without observed recovery, while the other moves between unfavorable states with reported recovery into *Normal*. These patterns motivate different priorities for reviewing procurement, replenishment quantities, and planning parameters. The proposed interventions were not implemented or evaluated.

Keywords: state-aware object-centric process mining; industrial case study; inventory diagnosis; process analysis; decision support

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1. Introduction

Inventory indicators help organizations identify excessive stock and inventory levels below selected thresholds. Enterprise systems also record the procurement, stock movement, and sales activities surrounding these situations. Process mining uses such event data

to investigate how business processes are executed [1]. Process discovery, conformance checking, and performance analysis are broader capabilities of process mining. Process discovery derives a picture of observed behavior. Conformance checking compares recorded behavior with specified expectations. Performance analysis examines frequencies and elapsed times. Rather than considering only aggregate outcomes, process mining examines the recorded sequences, frequencies, and timing of activities, helping analysts investigate how operational behavior relates to performance problems. The present case study is a descriptive inventory diagnosis. It examines how observed process behavior relates to unfavorable inventory states.

Inventory processes involve interacting business objects. Several purchase order items can concern the same material at a given plant. A purchase order item perspective describes individual procurement positions, whereas a plant-material perspective captures the inventory history shared by those positions and stock movements. Traditional case-centric process mining organizes an analysis around one selected case notion, and therefore keeps only one of those groupings. Object-centric process mining retains the relationships between events and multiple business objects, so both perspectives remain available [2].

The availability of inventory attributes does not make their operational interpretation explicit in an activity-based process view. For example, the same goods receipt activity may leave one material within the selected inventory band and another above its maximum stock threshold. For inventory diagnosis, the relevant distinction is therefore not only which activity occurred, but also the resulting inventory condition and whether the activity coincided with *entry* into, *persistence* in, or *recovery* from an unfavorable state. The activity of creating a purchase order item does not show which of those conditions holds for the associated material.

A current overstock indicator can accompany different histories. One material may remain overstocked without an observed return into *Normal*. Another may experience both *Understock* and *Overstock* with observed recoveries. These histories suggest different questions about procurement commitments, replenishment quantities, and planning assumptions.

Figure 1 summarizes the diagnostic questions raised by a current inventory warning and their role in motivating evidence-linked review priorities.

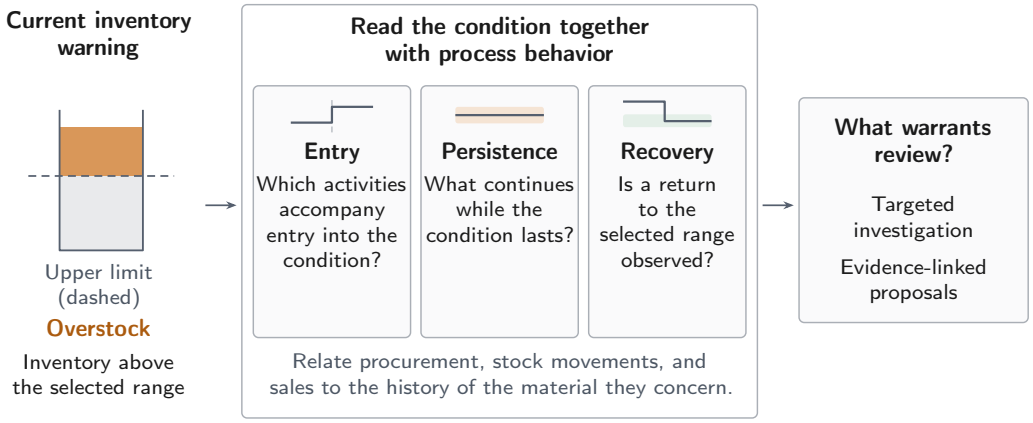

Figure 1. From an inventory warning to state-aware diagnostic questions. A current inventory classification identifies a condition but does not describe the process history that led to it. Reading procurement, stock movement, and sales activities together with the associated material's state history supports questions about entry, persistence, and observed recovery, which can motivate targeted investigation and improvement proposals.

State-aware object-centric process mining (SA-OCPM) makes object states and their transitions explicit in the process representation [3]. An object-centric log can already

carry a stock level as an attribute. SA-OCPM makes an explicit operational reading of that information available beside the activities. Section 2 defines the concepts. Building on this existing approach, the present study operationalizes an inventory diagnosis workflow on an industrial object-centric data foundation that contains more than 22 million events over three years. Materials are classified as *Understock*, *Normal*, or *Overstock* using selected inventory thresholds. The resulting object states are made explicit through state-aware event labels and transitions.

The study examines two plant-material histories from two warehouses at the company. It uses the state-aware representation to connect inventory indicators with process behavior and identify review priorities. The analysis contrasts *persistent overstock without observed recovery* with a history that contains both unfavorable inventory states and observed recoveries into *Normal*.

The overarching objective is to examine how explicitly representing inventory states and their transitions supports the diagnosis of inventory problems in an existing industrial object-centric process model. The paper makes the following contributions.

- **Industrial operationalization.** It documents how inventory states, state-aware event labels, and state transitions are integrated into an existing object-centric data foundation.
- **Comparative empirical diagnosis.** Two contrasting plant-material histories are characterized. Procurement behavior is related to *entry* into unfavorable states, to activity within those states, and to observed *recovery*. The comparison also motivates transferable diagnostic lessons and identifies the conditions under which they may be relevant to other organizations and object-centric processes.
- **Evidence-linked improvement proposals.** It derives improvement priorities and candidate controls from the observed patterns. The proposals distinguish reviews of continued procurement during persistent overstock from reviews that emphasize replenishment stability and planning assumptions. These are reasoned proposals. Section 7 records that they were not implemented or evaluated.

The paper answers three questions.

- **RQ1. How can inventory states and their transitions be operationalized on the existing industrial object-centric data foundation?**
- **RQ2. What contrasting patterns of inventory state evolution and procurement behavior are observed in the two plant-material histories?**
- **RQ3. What improvement priorities and proposals are motivated by the observed differences?**

Section 2 introduces process mining, object-centric event data, and state-aware analysis, and then positions the study relative to previous work. Section 3 describes the industrial setting, data, and study design. Section 4 addresses **RQ1** by presenting the inventory state-aware operationalization. Section 5 reports the empirical findings underlying **RQ2**. Section 6 synthesizes the answers to the research questions and develops the improvement proposals associated with **RQ3**. Section 7 discusses the limitations, and Section 8 concludes with the achieved contributions and directions for future work.

2. Background and Related Work

This section introduces process mining, object-centric event data, and state-aware analysis, then positions the study within related research.

2.1. Process Mining and Event Data

Process mining analyzes event data recorded by information systems to understand how processes are executed [1]. An *activity* is a type of action, such as creating a purchase order item. An *event* is one occurrence of an activity at a particular time. An *event log* collects these records, together with the business identifiers and attributes needed for the analysis.

In general, process mining supports process discovery, conformance checking, and performance analysis. Process discovery derives a representation of the behavior recorded in the log. Conformance checking compares that recorded behavior with specified expectations. Performance analysis examines how often activities occur and how much time passes between them.

In case-centric analysis, the analyst selects one identifier as the *case notion*. That identifier groups events into process instances. The ordered sequence of events in one instance is a *trace*.

The present study describes procurement behavior and the evolution of inventory states. It does not evaluate conformance against a prescribed process model.

2.2. Object-Centric Process Mining and OCEL 2.0

An *object type* is a kind of business entity. An *object instance* is one entity of that kind. One instance of the *plant-material* object type represents a particular material at a particular plant. One instance of the *purchase order item* object type represents an individual procurement position.

An event can be linked to the objects that take part in it. That link is an event-to-object relationship. A goods receipt, for example, is connected to the relevant purchase order item and plant-material object. An object can also be linked to another object. That link is an object-to-object relationship. Several purchase order items can refer to the same plant-material object.

A single case notion keeps one of these perspectives and drops the other from the grouping. Grouping by purchase order item keeps each procurement position intact and splits the shared plant-material history across cases. Grouping by plant-material keeps the inventory history together and can mix events whose individual procurement relationships still matter. Object-centric process mining retains the event-to-object and object-to-object relationships, so both perspectives can be examined [2].

Object-centric process mining is the analysis approach. An object-centric event log is the data foundation of that approach. The Object-Centric Event Log (OCEL) 2.0 specification states how events, objects, their relationships, and time-varying object attributes are represented [4].[1] A stock level can be stored as one of those time-varying attributes.

2.3. State-Aware Object-Centric Process Mining

An *operational state* is a domain-specific interpretation of an object's attributes relative to an analysis objective. State-aware object-centric process mining (SA-OCPM) makes this interpretation explicit [3]. It enriches business event labels with state information, and it introduces derived events that record changes between states. These two mechanisms connect activity behavior with the operational conditions of the objects involved.

A state-aware business event such as *Post Goods Receipt (Overstock)* records a goods receipt together with the inventory condition that results from it. A derived transition such as *State Change from Normal to Overstock* records the change from one state to the next. The state-aware object-centric event log (SA-OCEL) is the enriched data representation that

[1] https://www.ocel-standard.org/

contains these labels and derived transitions. SA-OCPM is the analysis approach that uses a SA-OCEL.

Figure 2 illustrates that contrast for one set of activities. The left panel is a state-blind object-centric directly-follows graph. The right panel is the state-aware graph of the same activities.

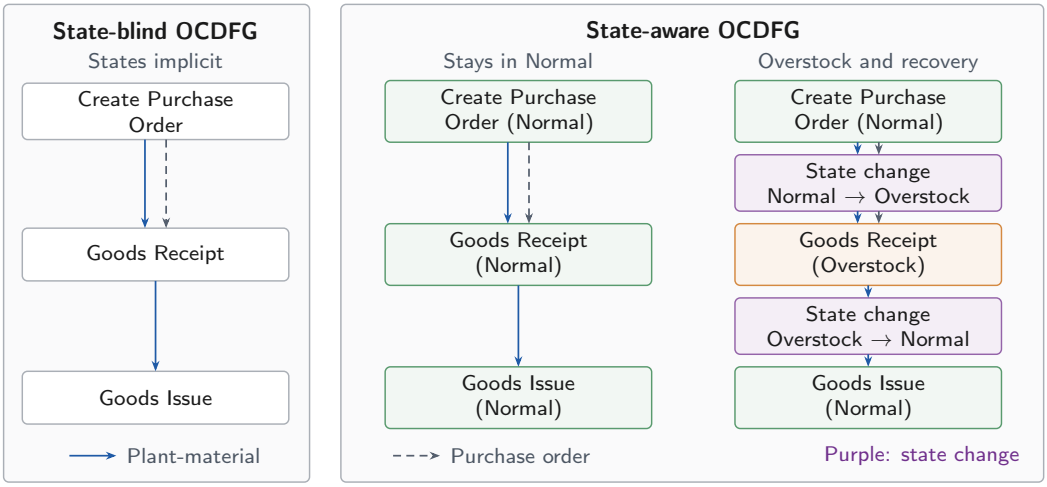

Figure 2. Schematic comparison of a state-blind object-centric directly-follows graph and a state-aware graph of the same selected activities. The state-aware panel distinguishes a history that stays in Normal from one that enters and recovers from Overstock. Blue solid arrows follow the plant-material object, and gray dashed arrows follow the purchase order. State transitions precede the associated business events. These illustrative paths do not describe the investigated materials.

OCEL 2.0 already supports time-varying object attributes, and a stock level can be one of them. SA-OCPM uses that stored information. It makes a domain-specific interpretation of it explicit, through object states, state-aware activity labels, and state transitions, so that the operational meaning is visible alongside the process behavior.

The inventory names used in this paper are a configuration for an inventory objective. The study classifies inventory as *Understock*, *Normal*, or *Overstock*. Those three states are not the general definition of SA-OCPM. Another objective could define other states.

A state is not an activity. *Overstock* describes a condition that can persist across multiple events. A derived transition is not an extra warehouse action. It records a change inferred from the relevant data and from the state definition. Section 4.4 states how this implementation records that change.

2.4. Related Work and Position of This Study

Process mining is used across supply chain management to investigate operational performance [5]. Applications include analyzing warehouse material movements to identify deviations and bottlenecks [6], and combining multidimensional process mining with value stream mapping to identify waste in internal logistics [7]. These studies emphasize material flows and logistics performance. The present case examines procurement behavior in relation to the inventory conditions of individual materials and how those conditions evolve over time.

Multi-object analysis provides the foundation for retaining the relationships needed for this diagnosis. Artifact-centric research examines interacting business objects and their lifecycles in ERP systems [8], while graph-based representations integrate structural and temporal relations across multiple entities [9]. Industrial applications also use multi-object analysis to study material-handling-system performance and support operational decisions [10]. The present case builds on this perspective by evaluating inventory conditions

alongside the activities of related procurement objects. An inventory classification such as *Overstock* evaluates a material against a chosen threshold, whereas a lifecycle describes its recorded progression.

Process analysis also uses information beyond activity sequences. Context-aware methods enrich logistics events with information learned from the data [11]. Event data preparation addresses the broader tasks of extraction, correlation, and abstraction [12]. Object-centric decision mining discovers decision structures and rules involving relevant activities and object types [13]. This case uses predefined inventory state rules and examines the resulting state histories together with procurement behavior; it does not discover classification rules.

The closest foundation is state-aware object-centric process mining, which already provides the representation used here and includes a logistics demonstration [3]. Earlier object-centric work also diagnoses overstock in a purchase-to-pay process and proposes improvements [14]. Thus, neither industrial application nor overstock diagnosis alone distinguishes this study. A more recent preprint automatically groups and ranks recurring state-aware behavioral patterns [15]. In comparison, this case interprets two selected material histories and links their differences to investigation priorities.

The contribution is a documented industrial operationalization and comparative diagnosis using an existing state-aware representation. The two histories differ in their persistence in unfavorable inventory states and their observed returns to *Normal*. Examining *entry*, *persistence*, and *recovery* helps explain why they suggest different review priorities. These concepts organize the observations; they are not a new general framework or discovery algorithm. In relation to research on business-value creation through process mining [16], the study connects analytical findings to proposed actions. It does not report implemented interventions or realized benefits.

3. Materials and Methods

The study is one industrial case. This section states the setting, the data, the workflow, and the rules for reading the indicators. The analysis covers one organization, two warehouse contexts, and two plant-material histories.

3.1. Industrial Setting and Business Objective

The study was conducted within a large multinational industrial manufacturing company. Company, site and material identifiers have been anonymized, and selected quantitative values have been generalized to protect commercially sensitive information. The company uses a commercial platform for object-centric process mining to analyze inventory management.

Purchase-to-pay runs from an internal request to buy, through the purchase order and the goods receipt, and on to supplier payment. Order-to-cash runs from a customer sales order, through the goods issue, and on to customer payment. The company analyzes both processes in that platform. This case uses only the portions that bear on the inventory question. Section 3.2 names those portions. Payment activities lie outside the selected event types.

The case uses two warehouse contexts, Warehouse A and Warehouse B. The practical task is to investigate inventory imbalances and to identify process behaviors that warrant review. The state-aware analysis supports a diagnosis and a set of proposals. Implementation of those proposals lies outside the reported study (Section 7).

3.2. Data and Scope of Analysis

The real-life event log covers three years and contains more than 22 million events. That count is the size of the existing data foundation. The detailed diagnosis covers two plant-material objects. Warehouse indicators summarize both warehouses. Section 7 states the boundary this scope places on the findings.

The analysis uses *plant-material* and *purchase order item* objects. The plant-material object carries the inventory history for a material at a specific plant. Each purchase order item refers to one such object.

The selected event types, and the business meaning used in this paper, are as follows. *Create Purchase Requisition Item* records an internal request to procure a quantity of a material. *Create Purchase Order Item* records a procurement commitment to a supplier for that material. *Post Goods Receipt* records that the ordered quantity has arrived in the warehouse. *Create Sales Order Item* records customer demand for a material. *Goods Issue* records that a quantity has left the warehouse. *Change Reorder Point* and *Change Planned Delivery Time* record updates to planning parameters. These events are the portions of purchase-to-pay and order-to-cash selected for the inventory question. Other activities in those processes are outside the analyzed scope.

The unit of analysis is one organization, two warehouse contexts, and two detailed plant-material histories. Aggregate inventory indicators are reported for both warehouses. We use Material A and Material B as labels for the plant-material objects examined at Warehouse A and Warehouse B, respectively. Section 7 explains why these histories are not read as a representative sample.

3.3. Analytical Procedure

The work follows an adaptation of the PM^2 methodology [17] shown in Figure 3. PM^2 organizes a process mining project from an objective, through data and analysis, to a closing stage. In this adaptation, the conceptualization includes object relationships and inventory states, and the closing stage produces improvement proposals. It does not report implemented improvements.

The enrichment of the existing data foundation provides the operationalization for **RQ1**. Inspection and comparison of the two material histories support **RQ2**. Linking those observations to operational concerns supports **RQ3**.

The inventory objective was defined first: investigate imbalances and the process behavior around them. Objects, events, and the inventory state representation were then specified. The existing object-centric data foundation was the source, and the state-aware enrichment was implemented on that foundation. Indicators and process behavior were inspected for the two warehouses and for the two material examples. Improvement proposals were formulated by linking those observations to operational concerns. The final stage in Figure 3 is that set of proposals.

3.4. Interpretation of Indicators

The numbers in Section 5 use three time horizons. The event log is the three-year observation period. Avoidable purchase order value is reported for the last twelve months. Current overstock, current revenue at risk, and the material-level overstock and holding cost figures are current indicators, reported at the time of analysis.

The manuscript does not disclose the calculation of these reported indicators. They remain reported indicators on the horizons above. Twelve-month purchase-order value, current overstock, and current revenue at risk describe different quantities. They are separate indicators. They are not realized savings from the state-aware analysis. No textbook formula is substituted for the undisclosed company calculation.

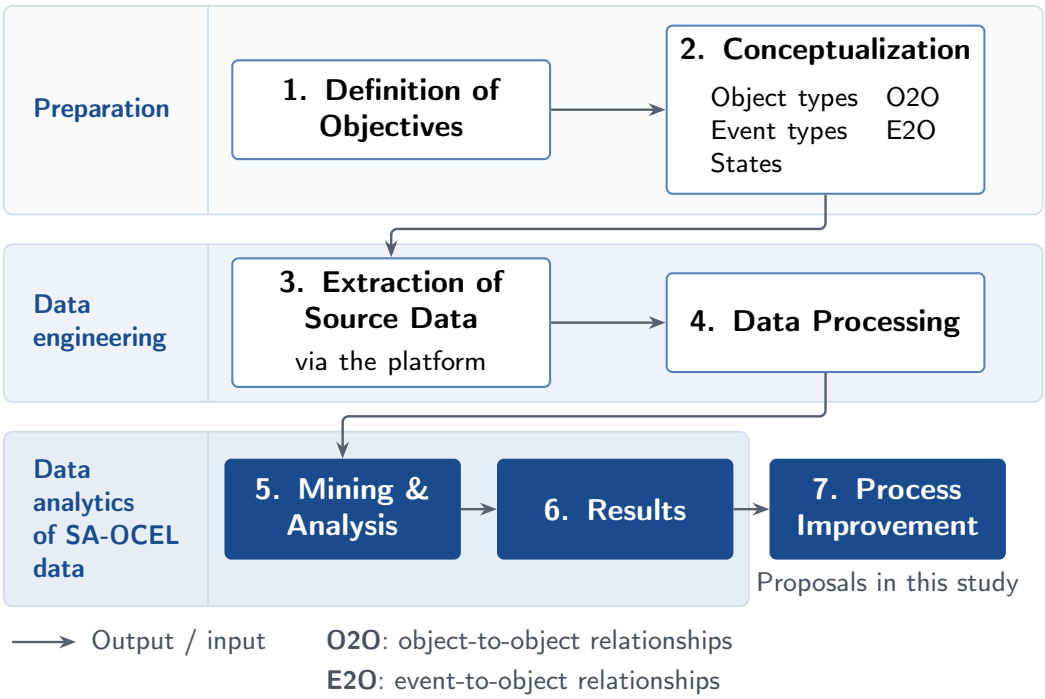

Figure 3. Adapted PM^2 workflow for this study. PM^2 is a methodology for organizing process mining projects. The conceptualization in this adaptation includes object relationships and states. Stage 7, "Process Improvement," produces improvement proposals in this study. The paper formulates the proposals and does not report them as implemented.

The warehouse-level operational reports also include recovery time in overstock, average time in overstock, the corresponding understock times, and counts labeled *Normal*, *Overstock*, and *Understock*. The manuscript does not disclose how those times differ from one another or how those counts are calculated. The paper does not use them as evidence.

4. Operationalizing Inventory State-Aware Analysis

This section addresses **RQ1**. The input is the existing object-centric data foundation, including business events, object relationships, and inventory-related attributes. The enrichment evaluates the inventory state definition for each material, adds the resulting state to relevant business event labels, and records changes between states as derived transition events. The enriched representation is then used to examine activity behavior, state evolution, and the two material histories. The three inventory equations below are the chosen definition for this case.

4.1. Existing Data Foundation and Enrichment

Figure 4 separates the existing foundation from the enrichment added in this study. Transactional data for purchase-to-pay and order-to-cash processes are extracted from the ERP system into an object-centric representation. In this implementation the ERP system is SAP, and the object-centric model is maintained in the commercial platform. That representation already contains events, objects, relations, and dynamic attributes. Stock level is one of those attributes, as the simplified log in Section 4.4 also shows. The implementation contributes the state-aware enrichment of this existing object-centric data model. The enrichment adds inventory states, state-aware event labels, and explicit state change events. The result is a SA-OCEL. The analysis of that log is the SA-OCPM application reported here.

The enrichment uses data transformations in the commercial platform and calculations in the Process Query Language (PQL). PQL evaluates the inventory state definition on

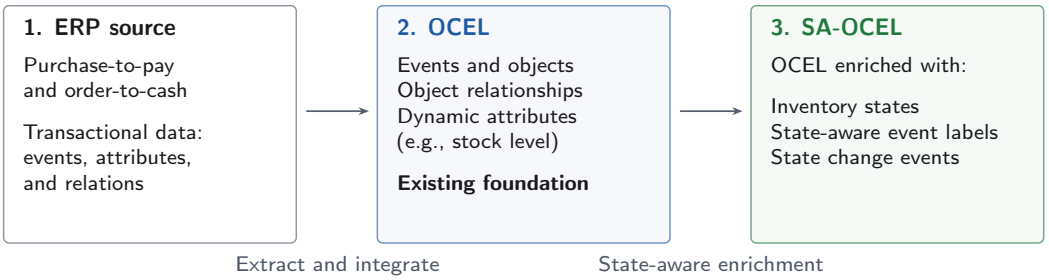

Figure 4. Path from ERP transactional data to an object-centric log and then to a state-aware log. The middle layer is the existing foundation, an object-centric event log (OCEL). The enrichment on the right produces the state-aware object-centric event log (SA-OCEL), in which inventory states and state changes are explicit. The figure labels the source processes purchase-to-pay and order-to-cash.

the existing data model at the relevant event timestamps. The query syntax itself is not required to follow the study.

For each plant-material object and event timestamp, the implementation reconstructs the inventory situation and evaluates the state condition defined in Section 4.3. The state is re-evaluated when an event affects the inventory situation or a relevant planning parameter. In this case, *Post Goods Receipt* and *Goods Issue* are the only selected event types that directly change the physical stock level. They are the primary drivers of stock-level-induced state transitions. *Create Purchase Requisition Item* records an internal request, and *Create Purchase Order Item* records a commitment to a supplier.

4.2. Objects, Events, and Relationships

Figure 5 shows that one plant-material object can be associated with zero to many purchase order items. Each purchase order item refers to exactly one plant-material object. Several procurement commitments can therefore share one inventory history.

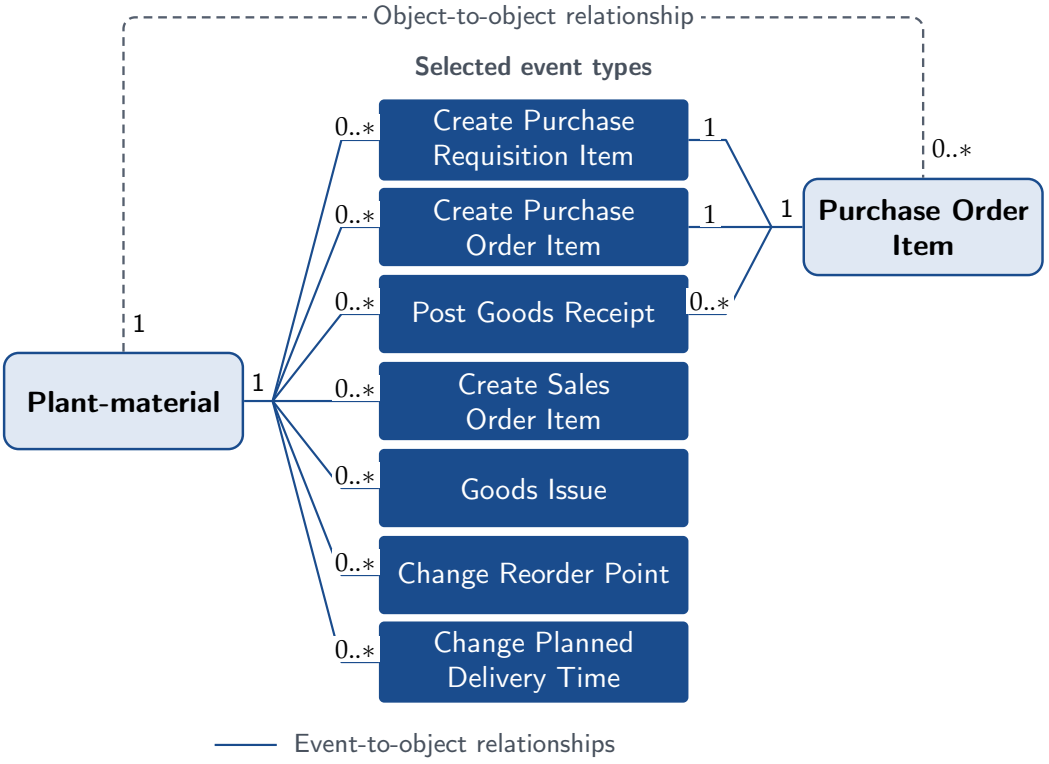

Figure 5. Object types and selected event types in the analyzed scope. The plant-material object links inventory history to purchase order items. Its inventory state is used in the event labels.

The inventory state belongs to the plant-material object. A state-aware purchase-order event label uses the inventory state of that associated object. For example, *Create Purchase Order Item (Overstock)* records order creation while the associated plant-material object is in *Overstock*.

Each detailed result follows one plant-material history in its reported warehouse context. A succession in that history records the order of events. Linking a receipt to a specific purchase order item requires the corresponding object relationship.

The dark blue boxes in Figure 5 are the selected event types. The light blue boxes are the two object types. The lines show event-to-object and object-to-object relationships. Each event is related to the corresponding plant-material object and, where applicable, to the respective purchase order item. A plant-material object can be associated with zero to many *Create Purchase Requisition Item* events. Each purchase order item is associated with exactly one *Create Purchase Requisition Item* event. The same figure includes *Create Sales Order Item* and *Goods Issue*, which are the demand-side events in the selected scope.

4.3. Inventory State Definitions

Three states are defined for each plant-material object with the Min-Max method [18,19]. The metrics below are inputs to that definition. They are the chosen operational definition for this case. This paper does not expand them into a broader inventory optimization model.

For each plant-material object m, the metrics are as follows.

- *Economic Order Quantity (EOQ)*: The order quantity that minimizes ordering and holding costs, defined as $\mathrm{EOQ}_m = \sqrt{\frac{2D_m S}{H}}$, where D_m denotes annual demand, S the fixed ordering cost, and H the holding cost per unit per year [20]. The holding cost period is the year, so that H uses the same time unit as annual demand. This formula defines the metric. It is an input definition, and it is not a measured result of the case.
- *Safety Stock (SS)*: A buffer against demand variability during the lead time, calculated as $\mathrm{SS}_m = z \times \sigma_m \times \sqrt{l_m}$, where z represents the service-level factor, σ_m the standard deviation of demand, and l_m the lead time [21]. The formula combines a demand deviation with a lead time, so those two inputs need compatible time units. The manuscript does not disclose the time unit stored for them.
- *Reorder Point (ROP)*: The inventory level at which replenishment is triggered, given by $\mathrm{ROP}_m = d_m \times l_m + \mathrm{SS}_m$, where d_m denotes average demand [19]. The product of average demand and lead time likewise requires compatible units. The manuscript does not disclose the demand period stored for d_m.
- *Maximum Stock Level (Max)*: The upper inventory limit used to control excess stock, defined as $\mathrm{Max}_m = \mathrm{EOQ}_m + \mathrm{SS}_m$ [19].

The input parameters for these metrics are derived from the event log or computed from attributes contained in the event log. The manuscript does not disclose whether safety stock and maximum stock stay fixed for the whole observation period or are recomputed when an input changes, and it does not disclose how a historical value would be selected in the latter case. The state of plant-material object m at time t is defined as follows.

Understock: $\text{Inventory Level}_{m,t} < \mathrm{SS}_m$.

Normal: $\mathrm{SS}_m \leq \text{Inventory Level}_{m,t} \leq \mathrm{Max}_m$.

Overstock: $\text{Inventory Level}_{m,t} > \mathrm{Max}_m$.

Understock means that the inventory level is below the selected safety stock threshold. It does not, by itself, mean that a stockout has occurred. *Normal* means that the inventory level is within the selected band. *Overstock* means that the inventory level is above the selected maximum. The literature treats understock and overstock as unfavorable relative to a chosen band, because understock may result in lost sales and overstock binds capital

[22–24]. That literature gives the reason for treating the two outer states as unfavorable. This case does not report a measured loss of that kind.

Two consequences follow for the diagnosis. Ordering while the material is *Normal* can still be followed by a later move above Max, so the diagnostic question concerns quantities, timing, and the subsequent inventory trajectory. The reorder point is not a state boundary. The states depend on the inventory level, safety stock, and Max. A planning parameter update changes the classified state only when it changes one of those inputs. A *Change Reorder Point* event changes the reorder point, which is not an input of the classification, so that event does not by itself change the classified state. Such an event can still be observed beside a state transition. That pair is an observed association.

4.4. State-Aware Events and Transitions

Figure 6 is a schematic example of the enrichment. The upper table is an object-centric event log with an activity, a timestamp, the related objects, and the stock level. The lower table adds an inventory state label and inserts a synthetic state change event when the labeled state changes. The safety stock of 1,400 and the maximum stock of 3,000 are illustrative thresholds for this figure. They are not parameters of the company, and they are held fixed inside the example. A reader can check the displayed classifications against them. A level below 1,400 is *Understock*. A level from 1,400 through 3,000 is *Normal*. A level above 3,000 is *Overstock*.

Object-centric event log (OCEL)

Event	Activity	Timestamp	Plant-material	PO item	Stock
E001	Create Purchase Requisition Item	02.06.2026 11:19	M100	POI1	1,500
E002	Create Purchase Order Item	02.06.2026 15:06	M100	POI1	1,500
E003	Change Planned Delivery Time	02.06.2026 15:10	M100	POI1	1,500
E004	Post Goods Receipt	05.06.2026 09:03	M100	POI1	4,800
E005	Create Sales Order Item	17.06.2026 10:48	M200	–	2,300
E006	Goods Issue	18.06.2026 08:00	M200	–	1,300

State-aware object-centric event log (SA-OCEL)

Event	State-aware activity	Timestamp	Plant-material	PO item	Stock
E001	Create Purchase Requisition Item (Normal)	02.06.2026 11:19	M100	POI1	1,500
E002	Create Purchase Order Item (Normal)	02.06.2026 15:06	M100	POI1	1,500
E003	Change Planned Delivery Time (Normal)	02.06.2026 15:10	M100	POI1	1,500
E007	State Change from Normal to Overstock	05.06.2026 09:03	M100	POI1	4,800
E004	Post Goods Receipt (Overstock)	05.06.2026 09:03	M100	POI1	4,800
E005	Create Sales Order Item (Normal)	17.06.2026 10:48	M200	–	2,300
E008	State Change from Normal to Understock	18.06.2026 08:00	M200	–	1,300
E006	Goods Issue (Understock)	18.06.2026 08:00	M200	–	1,300

Illustrative thresholds: safety stock 1,400; maximum stock 3,000.

PO item = purchase order item; – = no related purchase order item.

Figure 6. Simplified object-centric event log (upper table) and its state-aware extension (lower table), using an illustrative safety stock of 1,400 and maximum stock of 3,000, not company parameters. Business event labels report the resulting inventory state. Synthetic transitions are inserted at the same timestamp immediately before their associated business events as an ordering convention. Transition labels describe changes between states, not additional inventory states.

One goods receipt row shows the full step from the object-centric log to the SA-OCEL. For plant-material object M100, the events before the receipt record a stock level of 1,500. That level lies between the illustrative thresholds, so the classification is *Normal*. The goods receipt, event E004, records a stock level of 4,800. That level lies above the illustrative maximum, so the classification changes from *Normal* to *Overstock*. The business event is therefore labeled *Post Goods Receipt (Overstock)*. The enrichment adds a derived transition,

event E007, *State Change from Normal to Overstock*, at the same timestamp, immediately before the receipt.

The goods issue for plant-material object M200 illustrates a downward transition. The preceding sales order row records a stock level of 2,300, which the same illustrative thresholds classify as *Normal*. The goods issue, event E006, records 1,300, which lies below the illustrative safety stock. The business event is labeled *Goods Issue (Understock)*, and the enrichment adds event E008, *State Change from Normal to Understock*, immediately before that issue.

Business event labels report the resulting inventory state. A goods receipt labeled *Post Goods Receipt (Overstock)* may be the receipt that moves the material into *Overstock*, or a receipt that leaves an already overstocked material in that state. The transition event distinguishes these situations. A transition is present when the resulting state differs from the preceding state. A receipt that remains inside *Overstock* carries the *Overstock* label and has no new transition into that state.

The same-timestamp rule is an ordering convention in the enriched log. The synthetic transition is placed immediately before the associated business event. That order is not evidence that the physical inventory changed before the receipt occurred. The manuscript does not disclose a further rule for ordering several business events that share one timestamp. Placing the transition before its associated event does not, by itself, resolve every such tie.

A directly-follows relation means that one event comes immediately next to another in a specified ordered history. It is not a causal relation [1]. On the enriched log, that adjacency includes the synthetic transition immediately before the associated business event. The receipt therefore follows the synthetic transition, and the preceding business event is no longer adjacent to the receipt. The synthetic transition and the business event are one state change. They are not independent business actions. Section 5.3 uses this relation in a graph.

4.5. State Episodes

A *state episode* is a contiguous interval during which a plant-material object remains in the same classified inventory state. *Entry* marks a change into that state. *Persistence* concerns the subsequent interval spent there. *Recovery* denotes an observed return from an unfavorable state into *Normal*. Movement that remains outside *Normal*, including movement closer to the band without entering it, is not *recovery* under this definition. Throughout this paper, a recovery into *Normal*, a return into *Normal*, and an observed recovery are this same event: a transition into *Normal* is present in the reported history.

The length of an episode is the length of that interval. The manuscript does not disclose how an episode that meets the start or the end of the observation window is included in a reported average duration. An episode that is still open at the end of the log can appear in a duration report while *recovery* has not been observed. The absence of observed *recovery* is then bounded by the finite observation period, as Section 7 states. A reported duration and the absence of *recovery* therefore answer different questions.

Figure 7 contrasts activity during persistence, stock reduction without recovery, and an open episode with an unknown later outcome.

5. Results

Following the operationalization presented for **RQ1**, this section addresses **RQ2**. Warehouse-level indicators establish the context. The two plant-material histories show how procurement behavior and inventory states evolved together. The comparison provides the empirical basis for the improvement proposals developed for **RQ3**. Each plant-material

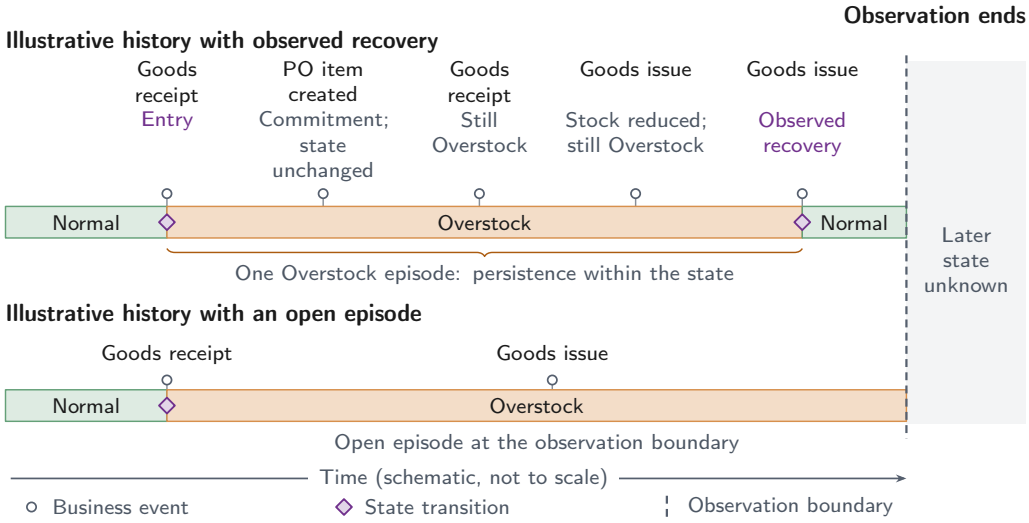

Figure 7. Schematic interpretation of inventory state episodes. The upper history distinguishes entry into Overstock, activities occurring during persistence, and an observed return to Normal. A goods issue that reduces stock without leaving Overstock is not a recovery. In the lower history, the episode remains open at the observation boundary, so later recovery is unknown. The histories are illustrative and are not scaled to the reported material durations.

history uses the same dimensions, defined in Section 4.5: *entry* into an unfavorable state, *persistence* in that state, and observed *recovery*.

5.1. Warehouse-Level Inventory Indicators

The warehouse indicators motivate the plant-material analysis. Revenue at risk from understock is measured at the time of analysis. The value of avoidable purchase orders associated with overstock covers the previous twelve months (Section 3.4). To compare the scale of these two indicators, we divided the combined current revenue at risk from understock by the combined twelve-month avoidable purchase-order value for both warehouses. The ratio was 21.11%.

Warehouse A accounts for 94.60% of the combined twelve-month avoidable purchase-order value and Warehouse B accounts for the remaining 5.40% (Figure 8). Using each warehouse's own twelve-month avoidable purchase-order value as the reference, current overstock was 23.43% at Warehouse A and 33.27% at Warehouse B. Current revenue at risk from understock was 21.64% at Warehouse A and 11.70% at Warehouse B on the same basis.

Reported warehouse indicators

Warehouse A	Warehouse B
Share of the combined twelve-month avoidable purchase-order value **94.60%**	Share of the combined twelve-month avoidable purchase-order value **5.40%**
Current overstock, relative to that warehouse's twelve-month value **23.43%**	Current overstock, relative to that warehouse's twelve-month value **33.27%**
Current revenue at risk from understock as a share of own twelve-month value **21.64%**	Current revenue at risk from understock as a share of own twelve-month value **11.70%**

Figure 8. Warehouse indicators for Warehouse A and Warehouse B. The first row shows each warehouse's share of the combined twelve-month avoidable purchase-order value associated with overstock. The other rows compare each warehouse's current overstock and current revenue at risk from understock with its own twelve-month avoidable purchase-order value.

5.2. Warehouse A, Material A: Persistent Overstock without Observed Recovery

The plant-material object examined at Warehouse A is Material A. We report the inventory outcome, entry into *Overstock*, activity during that state, and whether recovery was observed.

Observed outcome. At the time of analysis, Material A accounted for 1.59% of Warehouse A's current overstock value. Its reported holding cost was 19.96% of its own overstock value. The average time spent in *Overstock* is longer than one year. The history contains no *Understock*. It also contains no return from *Overstock* to *Normal*, so no *recovery* was observed within the reported observation. The history is read as *persistent overstock without observed recovery*.

The duration above is the reported average for this material. It is separate from the warehouse time fields that Section 3.4 leaves unused. Section 4.5 records that the manuscript does not say how an episode touching the start or the end of the observation window enters that average. The average answers how long *Overstock* lasted. The missing recovery answers whether a return to *Normal* was seen. An episode can remain open, and can still contribute to the average, when that return has not occurred.

Process evidence: entry into Overstock. Material A's history records purchase-order item creation while stock was *Normal*. A later goods receipt accompanied the transition into *Overstock*. This succession is observed on the plant-material history. Linking the receipt to a specific purchase order item requires the object relationships described in Section 4.2.

Process evidence: activity within Overstock. *Create Purchase Requisition Item* in *Overstock* accounts for 2.77% of all executed activities. Creating a purchase order item in that state accounts for 0.97% of all executed activities. These events record internal requests and commitments to suppliers, respectively, while the material is classified as *Overstock*. The stock itself changes at *Post Goods Receipt* and at *Goods Issue*.

Post Goods Receipt accounts for 16.12% of the activities recorded in the *Overstock* state. The requisition share and the purchase-order share use all executed activities as the denominator. The goods-receipt share uses only the activities recorded in *Overstock*. The treatment of derived transition events in these denominators is undocumented. A receipt label states the state after the receipt, so this goods-receipt share includes receipts that carry the material into *Overstock*. Section 4.4 keeps that entry, which has its own transition event, apart from a later receipt that leaves the material in *Overstock*.

Process evidence: observed recovery. After Material A entered *Overstock*, its stock did not return to *Normal* during the observation period.

Interpreted. Order quantities vary substantially, and actual lead times vary strongly. The *minimum order quantity* is the smallest quantity that can be ordered for the material. The reorder point is small relative to that minimum and to the economic order quantity. Orders placed in *Normal* are followed by quantities that are high relative to demand over the planning horizon. Rework activities and changes to the reorder point are associated with transitions into *Overstock*. *Change Reorder Point* is one of the selected event types. The reorder point is not a boundary of *Understock*, *Normal*, or *Overstock*. Section 4.3 sets those states from the inventory level, safety stock, and maximum stock, so the classified state changes only when one of those inputs changes. The candidate contributing factors are quantity variability, planning parameters, and lead times.

5.3. Warehouse B, Material B: Movement between Unfavorable Inventory States

The plant-material object examined at Warehouse B is Material B. We report the inventory outcome, entry into an unfavorable state, activity during that state, and whether recovery was observed.

Figure 9 summarizes the reported findings. Each arrow in the upper panel shows a directly-follows relation between two event labels in the aggregate graph [1]. The lower panel summarizes procurement during *Overstock* and the broader state history.

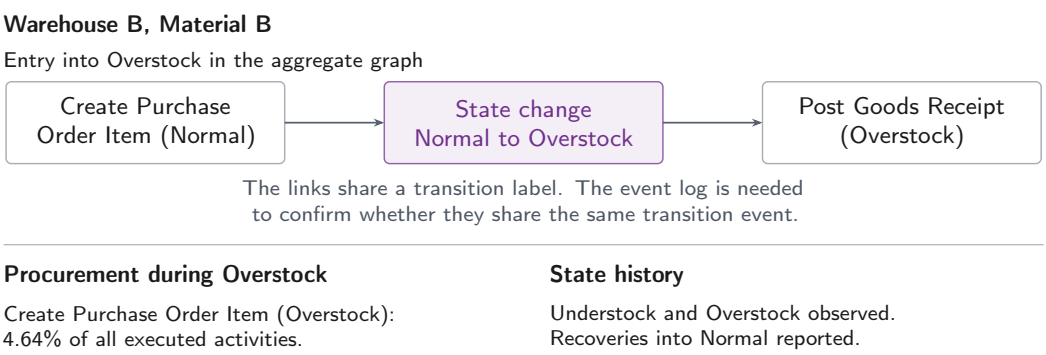

Figure 9. Simplified state-aware view of Material B at Warehouse B. The upper panel shows two selected directly-follows links from the aggregate graph. The lower panel summarizes procurement during Overstock and the broader state history.

Observed outcome. At the time of analysis, Material B accounted for 13.71% of Warehouse B's current overstock value. Its reported holding cost was 2.68% of its own overstock value. The history contains both *Understock* and *Overstock*, and it contains returns to *Normal*. Section 4.5 defines a recovery as one of those observed returns. The pattern is movement between unfavorable inventory states, together with the reported recoveries. That trajectory is distinct from the *persistent overstock without observed recovery* of Material A.

Process evidence: entry into an unfavorable state. The aggregate graph shows a link from *Create Purchase Order Item (Normal)* to the synthetic transition from *Normal* to *Overstock*. It also shows a link from that transition label to *Post Goods Receipt (Overstock)*, consistent with receipt-associated entry into *Overstock* under the ordering convention in Section 4.4. The two links share a transition label. Establishing that they share the same transition event requires checking the ordered event log.

Process evidence: activity within an unfavorable state. *Create Purchase Order Item* while Material B is in *Overstock* accounts for 4.64% of all executed activities. The same caveat about the treatment of derived transitions applies here (Section 5.2). The percentage counts events. It does not measure the share of time spent in *Overstock*. These purchase orders are commitments recorded while the material is classified as *Overstock*. Stock changes at *Post Goods Receipt* and at *Goods Issue*.

Process evidence: observed recovery or later movement. Both *Understock* and *Overstock* appear in the history, and so do recoveries into *Normal*. The observed pattern is movement between unfavorable states, together with those recoveries.

Interpreted. Order quantities vary widely. The study describes that spread through low, typical, and high configurations of the reorder point and the economic order quantity. Actual lead times differ from the lead times stored in the master data. The *master-data lead time* is the planning value stored for the material, and the observed lead time is compared with that value. Order-quantity variability and the gap between observed and master-data lead times are the candidate contributing factors for this movement between states. Section 6.3 develops those planning observations into review priorities.

5.4. Comparison of the Two Plant-Material Histories

The same kind of inventory warning can come from different process histories, and those histories call for different investigations. The comparison covers Material A at Warehouse A and Material B at Warehouse B, in the context of the warehouse indicators in Section 5.1.

Entry. For Material A, a goods receipt associated with entry into *Overstock* came after purchase-order item creation in *Normal*. For Material B, the aggregate graph shows a receipt-associated entry and a separate link from purchase-order item creation in *Normal* to the same transition label (Figure 9).

Persistence. Purchase-order item creation in *Overstock* accounts for 0.97% of all executed activities for Material A and 4.64% for Material B. Material A's requisition creation share of 2.77% also uses all executed activities as the denominator. Its goods-receipt share of 16.12% uses only activities recorded in *Overstock*. These shares describe the activity mix in each history. Comparing the proportion of orders placed in *Overstock* would require the total number of purchase-order item creation events for each material. A requisition records an internal request, and a purchase order records a commitment to a supplier. A goods receipt or a goods issue records a change in stock.

Recovery. After the entry into *Overstock*, Material A stayed in that state through the end of the observation period. The *Normal* state in the entry analysis was the state before the overstock episode began. Material B shows both unfavorable states and subsequent returns to *Normal*.

RQ2 is answered by that distinction. Procurement commitments during *Overstock* appear in both histories. The state trajectories differ, and that difference sets the priorities for further investigation.

6. Discussion: Answers to the Research Questions and Improvement Implications

This section synthesizes the answers to the research questions, develops improvement proposals from the findings, and considers how the diagnostic reasoning may transfer to other organizations and processes.

*6.1. Answer to **RQ1**: Industrial Operationalization*

RQ1 is addressed through the inventory state-aware enrichment of the existing object-centric data foundation (Section 4). The implementation maps selected inventory attributes to the operational states *Understock*, *Normal*, and *Overstock*. It connects those states to business events through state-aware labels and synthetic transitions. The contribution is the documented configuration and use of this representation in the industrial setting. This paper does not introduce a new general state-aware method.

This is a reported implementation. Section 7 states the assessment bounds on effort, performance, and portability.

*6.2. Answer to **RQ2**: Diagnostic Findings and Their Significance*

RQ2 is answered by the contrast between the two plant-material histories. Purchase-order items were created during *Overstock* for both materials. Material A remained overstocked through the end of the observation period. Material B showed both unfavorable inventory states and reported recoveries into *Normal* (Section 5.4). The different state trajectories motivate different reviews.

A shared inventory classification does not imply a shared process history or an identical priority for investigation. This is a lesson illustrated by the two material histories in this case. Section 7 states the scope of that lesson.

The existing object-centric foundation connects procurement events with the plant-material objects they concern. The state-aware enrichment makes the inventory condition associated with those events explicit and distinguishes transitions into unfavorable states from activity occurring while those states persist. In the investigated examples, this representation supports a comparison between persistent overstock without observed

recovery and a history containing both unfavorable states and recoveries into *Normal*. The resulting review priorities therefore reflect the observed state trajectories rather than the current inventory classification alone.

No conventional object-centric baseline was evaluated. The study shows what the state-aware representation supports in this case. It does not show that the same observations would be impossible from another analysis of the same data, and it does not show that the representation produces more accurate or faster diagnoses than conventional object-centric analysis.

*6.3. Answer to **RQ3**: Improvement Priorities and Proposals*

RQ3 is addressed by deriving different improvement priorities from the observed histories. For Material A, the principal emphasis is reviewing continued procurement commitments and quantities associated with *entry* into *Overstock*. For Material B, the principal emphasis is replenishment stability, including order-quantity variability and differences between observed and master-data lead times. Purchasing exceptions and quantity reviews remain relevant to both materials. The two sets of controls are not disjoint. Their difference is the primary emphasis and the evidence that motivates it.

Each proposal follows one structure. An observation from Section 5 raises an operational concern, and a review or control is proposed in response. An order that is contractually unavoidable, and an order needed to satisfy confirmed demand, would remain outside a blanket stop. Other orders could be postponed, reduced, or cancelled. The proposals were not implemented or evaluated (Section 7).

6.3.1. Material A.

Observation. For Material A, a goods receipt associated with entry into *Overstock* came after purchase-order item creation in *Normal* (Section 5.2). During the ensuing *Overstock* episode, requisition and purchase-order item creation accounted for 2.77% and 0.97% of all executed activities, respectively. No return to *Normal* was observed.

Operational concern. Continued procurement commitments during *Overstock*, and the quantities associated with *entry* into *Overstock*, are the review priority for this material.

Proposed review. Purchase requisitions and purchase orders raised while the material is in *Overstock* could be routed to an exception workflow that asks for an explicit business justification. The workflow could separate contractually unavoidable orders, orders needed to satisfy confirmed demand, and orders that could be postponed, reduced, or cancelled. A quantity review is proposed for *entry* into *Overstock*. Planned quantities could be compared with demand variability, current inventory, open purchase orders, safety stock requirements, expected consumption during the replenishment lead time, and the economic order quantity. *Post Goods Receipt* could be reviewed for the inventory state the receipt produces. These controls are proposed from the commitments in *Overstock* and from the succession out of *Normal*. The same purchasing exceptions and quantity reviews can also apply to Material B. Here they are the primary emphasis.

6.3.2. Material B.

Observation. Material B is reported in both *Understock* and *Overstock*, with reported recoveries into *Normal*. The aggregate graph shows a link between entry into *Overstock* and a goods receipt (Figure 9). *Create Purchase Order Item* in *Overstock* accounts for 4.64% of all executed activities. Order quantities vary, and actual lead times differ from the master-data lead time.

Operational concern. Replenishment stability is the review priority, including order-quantity variability and the difference between observed and master-data lead times.

Procurement during *Overstock* is also observed, so purchasing exceptions and quantity reviews stay in scope.

Proposed review. Purchase requisitions and purchase orders created while the material is in *Overstock* could enter an exception workflow, with the same separation of contractual obligations, confirmed demand, and orders that could be postponed, reduced, or cancelled. Goods receipts could be reviewed for the inventory state they are expected to produce. Order quantities could be reviewed against current demand, inventory, safety stock, open purchase orders, and expected consumption during the lead time. Before release, a planned quantity could be compared with the economic order quantity, and the resulting level could be compared with Max. Because actual lead times differ from the master-data lead time, those actual lead times could be monitored and used to update the master-data lead times. Where substantial variability persists, safety stock and the reorder point could be recalculated. A monitor could flag goods receipts associated with entry into *Overstock* and link each receipt to its purchase order item for review. The exception workflow and the quantity comparison overlap with the Material A proposals. The primary emphasis here is replenishment stability, order-quantity variability, and observed versus master-data lead times.

RQ3 is answered at the level of evidence-linked improvement proposals. Whether these proposals reduce inventory imbalance or improve service performance remains an implementation and evaluation question (Section 7).

Beyond the particular inventory controls proposed here, the case illustrates a reusable procedure for moving from diagnosis to improvement proposals. The procedure identifies activities associated with *entry* into an unfavorable condition. It examines commitments and physical changes while that condition persists. It assesses whether *recovery* is observed. It formulates review questions that reflect the resulting trajectory. This procedure supports the prioritization of further investigation. It does not determine an effective intervention without additional operational assessment and outcome evaluation.

Prospective controls would additionally require a decision-time implementation using information available before the action, rather than relying on retrospectively observed resulting states.

Figure 10 synthesizes the reasoning from the reported material-level observations to the primary review priorities and proposed reviews, including the controls relevant to both materials.

6.4. Transferability to Other Organizations and Object-Centric Processes

Scope of transfer.

The broader relevance of this case lies in its diagnostic reasoning. Case study and information systems research distinguish statistical generalization, which estimates patterns across a population, from analytical generalization, which develops insights for settings with corresponding characteristics [25,26]. This discussion follows the latter approach: other organizations may investigate how business activities relate to *entry* into, *persistence* in, and observed *recovery* from an unfavorable condition of a shared business object. The two investigated materials do not establish how frequently such patterns occur elsewhere.

Three levels of transfer should be distinguished. Diagnostic questions are candidates for reuse; their operationalization requires adapting object types, state definitions, historical reconstruction, event semantics, and queries. Empirical results and intervention effects require separate investigation. The reported frequencies, durations, financial indicators, and improvement priorities remain specific to this case, and the proposed controls were not evaluated. Reusing the reasoning therefore does not imply similar outcomes or benefits.

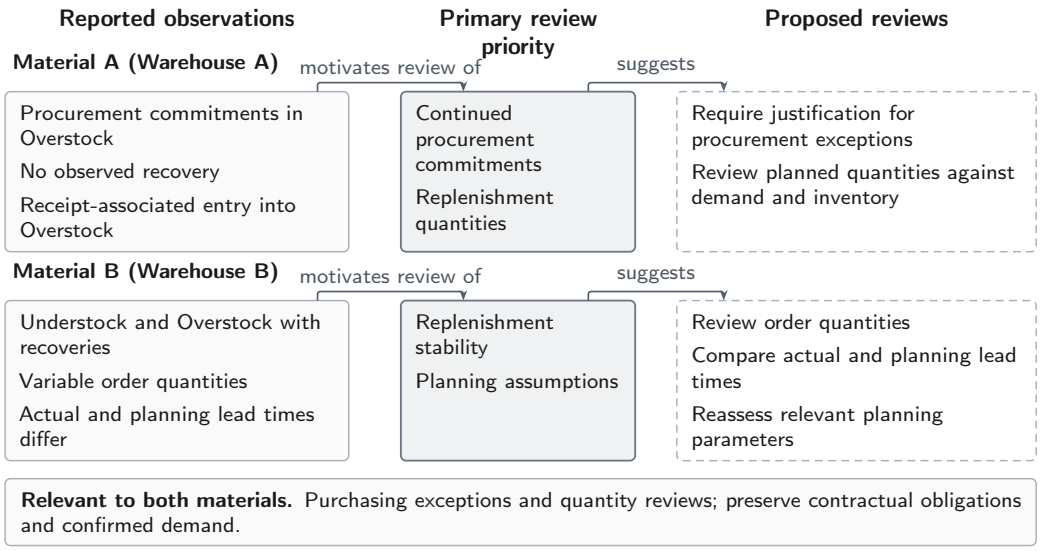

Figure 10. From material-level observations to proposed review priorities. Material A primarily motivates reviews of continued procurement and replenishment quantities, whereas Material B primarily motivates reviews of replenishment stability and planning assumptions. Arrows indicate reasoned links rather than established causal relations. Purchasing exceptions and quantity reviews remain relevant to both materials. The proposed controls were not implemented or evaluated.

Diagnostic lessons.

The case illustrates three lessons rather than a validated framework or taxonomy. First, objects with the same current unfavorable classification may warrant different investigations. Persistent overstock without observed recovery at Warehouse A motivates attention to continued procurement and replenishment quantities. The Warehouse B history, which includes unfavorable states and recoveries into *Normal*, emphasizes replenishment variability and planning assumptions (Section 5, Section 6.2). These priorities follow from the observed trajectories. They are not a universal mapping from a trajectory to a control: purchasing exceptions and quantity reviews remain relevant to both materials (Section 6.3).

Second, transaction-level behavior must be related to the object whose condition matters. A purchase order item records an individual procurement commitment, while the plant-material object carries the inventory history shared by multiple commitments and stock movements. Another process requires the same distinction between the object carrying the operational condition and the transactions that inform its evolution. Linking a particular receipt to a particular purchase order item requires the corresponding object relationship (Section 4.2).

Third, an activity's diagnostic meaning depends on the surrounding states. A goods receipt that accompanies *entry* into *Overstock* differs from one that leaves the material in *Overstock*, despite sharing the same activity name (Section 4.4). Examining the state before and after an activity distinguishes deterioration, persistence, and recovery. These associations support investigation, but adjacency does not establish causation, and an activity followed by recovery is not thereby a proven intervention.

Adapting the operationalization.

The reusable procedure connects object relationships, domain-defined states, and process behavior: identify the object and condition of interest, reconstruct its attributes over time, classify its states, retain links to events and other objects, and examine trajectories to formulate review questions (Sections 4.1 to 4.5). The inventory formulas and the three states used here are a configuration for this objective. Another application may use different

thresholds, object scopes, or categorical states without an upper and lower order. OCEL 2.0 supports object relationships and changing attributes without prescribing their operational interpretation [4]. The reasoning does not inherently depend on a particular ERP product or commercial process-mining platform, although the implemented transformations do. Reuse requires adapting and verifying the data reconstruction and state semantics; technical portability has not been demonstrated.

Conditions for reuse.

Transfer is most plausible where several transactions relate to a shared operational condition, reliable historical data support its reconstruction, and domain experts can define meaningful states and review criteria. Manufacturers, distributors, retailers, and spare-parts operators are possible receiving settings when these conditions hold. The relevant similarities concern object relationships and available information, rather than industry membership. Plant-material objects keep inventory histories for the same material at different plants separate (Section 4.2). Another setting may require a different level of detail, such as a material at a specific warehouse or storage location.

A current status field is insufficient for reconstructing state trajectories. Reliable event relationships and historical attribute values are needed, and changes in thresholds should be distinguished from changes in the object's condition. State definitions must also express the local objective. For example, *Understock* here means inventory below the selected safety stock threshold, not an observed stockout (Section 4.3). Receiving organizations must assess their own thresholds and formulas instead of copying this configuration.

Event and measurement conventions must remain explicit: physical changes versus commitments, resulting state versus preceding state labels, and recorded business events versus synthetic transitions (Section 4.1, Section 4.4). Numerical comparisons across organizations additionally require compatible denominators, observation windows, and treatment of unfinished episodes (Section 4.5, Section 7). Proposed responses must respect operational constraints. Procurement during *Overstock* warrants investigation, but contractual obligations and confirmed demand can justify it and preclude a blanket stop (Section 6.3).

Other object-centric processes.

The same reasoning suggests applications beyond inventory. In production workload management, a work center or resource group could carry the condition, with production orders and operations as related objects. Workload states could distinguish an acceptable capacity-adjusted range from overload, supporting questions about whether additional releases accompany entry into overload, continue while it persists, or occur after workload returns to an acceptable range.

In accounts receivable management, a customer account could carry an exposure state linked to invoices, payments, and orders. The analysis could ask whether further transactions occur above a defined limit and whether payments merely reduce exposure or return it below that limit.

In asset maintenance, an asset could be classified as available, degraded, or unavailable and linked to maintenance orders, components, and inspections. The question would be whether completed maintenance coincides with restored availability or leaves the asset in an unfavorable condition. These three mappings are proposed illustrations, not evaluated applications. Each requires its own object model, state definitions, observation rules, and domain interpretation; the inventory states and improvement proposals would not transfer unchanged.

Figure 11 maps the related objects, condition-carrying objects, illustrative states, and diagnostic questions for these three proposed applications, separating reusable questions from the elements that require adaptation.

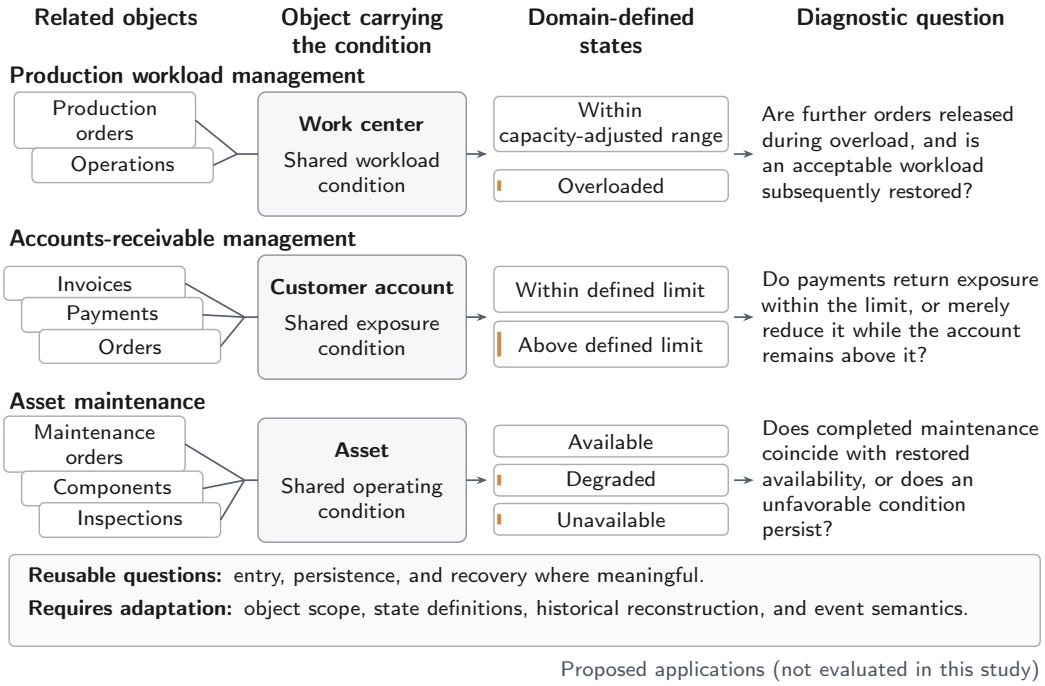

Figure 11. Illustrative applications of state-aware diagnosis beyond inventory. In each application, related transactions are interpreted against the evolving condition of a shared object. The object types, state definitions, and diagnostic questions require domain-specific adaptation. These mappings illustrate potential applicability; they were not implemented or evaluated in this study.

Further boundaries.

Some applications also require a different treatment of transitions and recovery. Overdue or deadline-based states can change as time passes without a recorded business event, requiring time-based evaluation in addition to the event-triggered reconstruction used here. For irreversible or terminal states, the relevant questions concern *entry*, *persistence*, and exit or resolution. A return to *Normal* is meaningful only where the domain supports that interpretation.

7. Limitations and Boundaries of Interpretation

The findings come from one organization, two warehouse contexts, and two plant-material histories, Material A at Warehouse A and Material B at Warehouse B. These two trajectories illustrate contrasting inventory problems. They are not a representative sample of either warehouse, of the plant-material objects in the event log, or of other organizations. The event log contains more than 22 million events over three years. That count is the size of the data foundation on which the operationalization was applied. Applying the operationalization at that reported scale is not a controlled assessment of computational performance or portability.

The results depend on the selected inventory state definitions and on the underlying data. The observation period is finite. When an unfavorable episode is still open at the end of the log, the absence of observed *recovery* is bounded by that period. The manuscript does not disclose how an episode that meets the start or the end of the window is included in a reported average duration, including the average *Overstock* duration for Material A, which is longer than one year.

The study does not establish causal effects. A reported succession from an activity to a later state is not identified as a cause of that state. Reported financial exposure is not realized savings. The improvement proposals were not implemented or evaluated. The paper therefore does not show that the proposals reduce inventory imbalance or improve service performance.

The limited empirical coverage constrains claims about the prevalence of the observed patterns, their distribution across organizations, and the effectiveness of the proposed controls. The discussion nevertheless identifies conditions under which the diagnostic reasoning may be relevant elsewhere (Section 6.4). This conditional transferability has not been empirically established across organizations or process domains.

Section 6.2 gives the positive account of what the state-aware enrichment contributes in the reported histories, and it states the full baseline boundary. Indicator meanings and time horizons are defined in Section 3.4. State and event label semantics, including resulting state labels and the same-timestamp ordering convention, are defined in Section 4.4. State episodes are defined in Section 4.5.

8. Conclusions

This study operationalized inventory state-aware analysis on an existing object-centric data foundation and used it to compare two plant-material histories. The analysis distinguished *persistent overstock without observed recovery* from a history containing both unfavorable inventory states and reported recoveries into *Normal*, and it motivated different priorities for reviewing procurement and replenishment planning. **RQ1** was answered through the industrial operationalization, **RQ2** through the comparative diagnosis, and **RQ3** through the derivation of evidence-linked improvement proposals. All three questions were answered within the stated descriptive scope of the case.

Section 7 states the boundaries of these findings, including the two-material scope, the absence of causal claims, the unevaluated proposals, and the absence of a demonstrated advantage over other analyses of the same data.

Beyond the investigated materials, the case illustrates the importance of interpreting transaction-level behavior within the evolving condition of the shared objects those transactions concern. This diagnostic reasoning may be transferable to other organizations and object-centric processes when meaningful states and sufficiently reliable historical relationships can be reconstructed. Its cross-context usefulness and the effectiveness of resulting interventions remain to be evaluated.

Future work should examine additional materials, repeat the analysis in another organization with comparable inventory dynamics, and subsequently investigate a different object-centric process using an adapted state definition. These are distinct extensions. Collecting more materials from the same existing data foundation would not by itself establish cross-company or cross-domain applicability. Further work can also assess the sensitivity of the diagnosis to state definitions, compare the diagnostic benefits of alternative representations, and evaluate the proposed controls through implementation and subsequent outcome measurement.

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