Compliance and Performance Analysis of Procurement Processes Using Process Mining
BPI Challenge 2019

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Abstract. Procurement processes are essential part of the value chain of an organization to provide services and products. A regular analysis and optimization of these processes is beneficial for companies to increase quality, reduce costs, and identify process risks. Process mining techniques provide insights into the common flows of activities, detect deviations and compliance issues, and report process performance. In this paper, we present the analysis and evaluation of procurement processes of a company in the area of coatings and paints from the Netherlands. Applying filtering and discovering techniques, the paper presents six process models for handling different types of purchase orders. In addition, deviations of these flows and compliance violations, their frequencies, and root causes are described. Finally, key performance indicators regarding throughput time are defined and measured.

Keywords: BPI challenge · Procurement · Process Mining · Compliance.‘

1 Introduction

Business Process Intelligence (BPI) Challenges, organized annually, aim at advancing the field of process mining through providing real-life data sets and problems. By involving the process mining community from both academia and industry, the BPI challenges showcase the power and value of process mining, and trigger the development of new techniques and novel solutions. This year the data is provided by a multinational company located in the Netherlands in the area of coatings and paints. The data refers to the *Purchase-To-Pay* process as part of the procurement process of the company. Procurement processes are crucial to the value chain of organizations. These processes can be subject to business risks, such as the risk of long delivery times, decreasing efficiency of production or increasing costs, or more severely, risk of potential fraud. Analyzing these processes regularly provides insight on improvement potentials and prevention of potential risks.

Process Mining as the main component of process intelligence provides techniques for the analysis of processes based on recorded data, such as the provided

event log for the BPI challenge. Real process flows can be automatically discovered, revealing the behavior of the recorded process execution. Conformance of the recorded behavior to the expected behavior can be checked, and deviating cases can be detected, exposing violations to compliance rules. Root causes of violating cases can be explored. Performance metrics can be measured, unusually long cases be detected, and bottlenecks identified. These can lead to identification of process diagnostics, insights for process improvement, and preventive action for potential risks and fraud.

This report outlines the details and results of a process analysis on the provided data for the *Purchase-To-Pay* process, focusing on the three questions posed by the process owners. These questions are related to the three aspects of process mining, namely process discovery, conformance (compliance checking), and performance analysis. In order to organize the analysis flow and take a step towards a standardized and repeatable process mining analysis, we have followed a methodology inspired by works in the literature [5, 4, 2]. In the context of this BPI challenge, our methodology consists of five phases of *data and process understanding*, *discovery and design*, *Conformance and compliance checking*, *Performance analysis*, and *report*.

Section 2 details the understanding phase and provides statistics and models necessary for understanding the process, in addition to identification of data quality issues existing in the data. Section 3 zooms into specific analysis focusing on process discovery and design, before section 4 outlines deviations and compliance issues, while Section 5 details performance analysis of the process. Finally, section 6 summarize the main results, and suggestions for process improvement, and concludes the report.

2 Data and Process Understanding

In this part, we report the result of exploration and inspection of the data and the underlying processes.

2.1 The Data

The data is recorded for the execution of *Purchase-To-Pay* processes (possibly of an ERP system) of purchase orders submitted in 2018. The log contains 1,595,923 events, belonging to 251,734 traces (cases). The case notion adopted for the log is individual purchase order item. Each purchase order item is part of a purchase order (PO) document. Each PO document can consist of multiple items. There are 76,349 PO documents in total.

The data contains several attributes. A number of attributes are on the event level including:

- `Case ID`: A combination of PO ID and item ID as the case identifier,
- `Activity`: The name of the activity that the events refer to,
- `Timestamp`: of activity completion, and

– `User`: the resources recording the activity.

Majority of attributes, however, are on the case level recorded for each item including:

– `Company`: The anonymized ID of the respective subsidiary that the case relates to,
– `Name`: Anonymized name of the vendor,
– `Spend area text`: The purchasing area,
– `Cumulative net worth`: The value of the item in Euro,
– `Document type`: The type of purchasing document,
– `Item category`: The invoicing procedure is determined based on this attribute, and
– `Item type`: the type of the item.

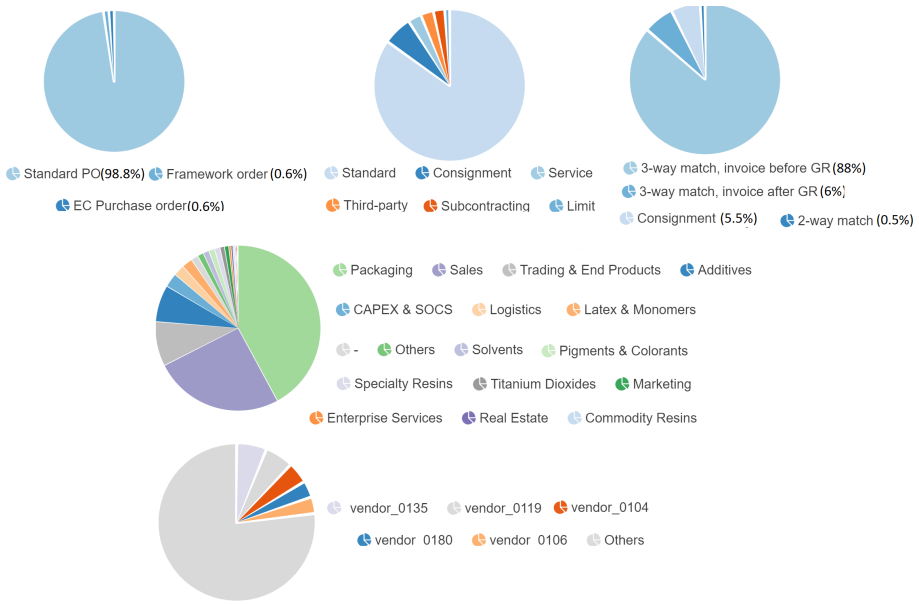

Fig. 1. Proportion of values of five case attributes in the log

Statistics on attributes: Figure 1 displays the proportion of the different values for a number of attributes. Majority of PO documents are of type "standard PO", while "framework", and "EC purchase orders" are together around 1% of the documents. The most frequent `item type` is "standard" followed by "consignment" and "Service". `Item category` is dominated by "3-way match, invoice before Goods Receipt (GR)" (88%), whereas the "2-way match" constitute a small proportion (0.5%). The biggest proportion of items are in the

area of "packaging". The other frequent areas are "sales", "trading & end products", and "additives". There are around 1900 unique vendors recorded in the log and the last chart in figure 1 reveals the top 5 frequent vendors (vendor_0135, vendor_0119, vendor_0104, vendor_0180, vendor_01060).

There are 42 different `activities` in the log. The five most frequent activities are: "Record goods receipt", "Create purchase order item", "Record invoice receipt", "Vendor creates invoice", and "Clear invoice". For each case, there is exactly one instance of "Create purchase order item", while the other activities can happen an arbitrary number of times for each case (e.g. several goods receipt might exist for one item). In total there are 627 different `Users` recorded, divided into batch and human users. Data related to 4 of the subsidiaries are recorded in the log. However, two of which ("Company-0001", and "Company-0002") only contain 2 cases each which are eventually deleted, one paid before deletion.

	Standard PO			Framework order	EC purchase order	∑	%
	Company_0000	Company_0001	Company_0002	Company_0003	Company_0000		
3-way match after GR	14,077	2	0	494	611	15,182	6%
3-way match before GR	221,008	0	2	0	829	221,010	88%
2-way matching	0	0	0	1,044	0	1,044	0.5%
Consignment	14,498	0	0	0	0	14,498	5.5%
∑	249,583	2	2	1,538	2,484	251,734	251,734

Table 1. Item category distribution across all companies and document types (created in Celonis).

Table 1 provides an overview to the number of cases belonging to each item category, and document type in their respective subsidiaries. As shown in the table, "3-way match, invoice after goods receipt" items comprise around 6% of all cases originating from "Company-0000" and from all three document types but mostly "standard PO". "3-way match, invoice before goods receipt" compose the biggest part of the log at around 88% all from "Company-0000", mostly "standard PO" with a few EC purchase order and 1 exceptional, incomplete case recorded as framework order. "consignment" order items constitute around 5.5% of the total number of items and are all originated from "Company-0000" and are as document type of "standard PO". Around 0.5% of cases are of category "2-way match", all coming from "Company-0003" and from "framework order" purchase documents.

Relation between attributes: The classification trees in the figure 2 reveal relations between attributes `item category`, `document type`, `item type`, and`spend area text`. "EC purchase order" documents can contain items from categories, "3-way match, invoice before GR", and "3-way match, invoice after

GR". "Framework orders" are either "3-way match, invoice after GR" or "2-way match". "standard PO" contain, all three except "2-way match". On the other level, "3-way match, invoice before GR" items are of item types "standard", "subcontracting", or "third party", while "3-way match, invoice after GR" are mostly "services". "2-way match" are type "limit" , and "consignment" obviously "consignment" types. Furthermore, "Invoice before GR" are mostly (around 65 %) production (direct procurement) materials such as "packaging", and "trading and end products". "3-way match invoice after GR" on the other hand are mostly (88%) non production (indirect procurement) such as "logistics". "2-way match" items are almost always indirect procurement, mostly in the purchase area of "real state" and "energy", and "consignment" almost always(98.64%) direct procurement mostly "titanium dioxides", and "latex & monomers.

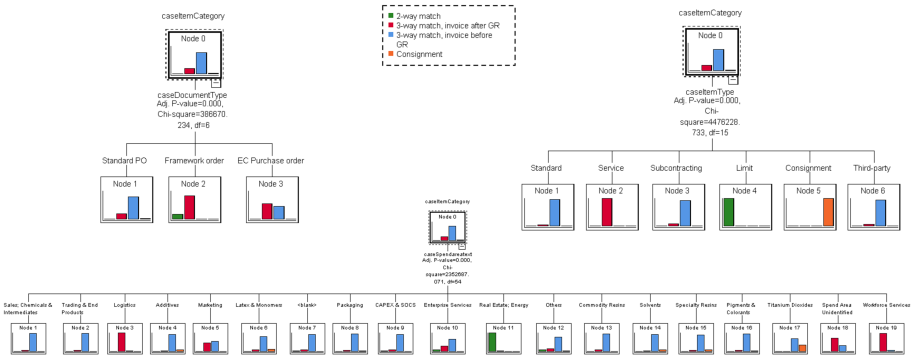

Fig. 2. relation between item category with item type, document type, and spend area

2.2 The process

The process is the *Purchase-To-Pay* process of a company with more than 60 subsidiaries. Since the case notion is purchase order items, the process describes the flow that items go through, since creation to payment. The purchase order items are divided into four categories (identified by `Item Category` attribute) based on the procedure for matching the invoice before payment. Therefore, items from each category go through a different flow. The categories are as follows:

- *3-way match, invoice after goods receipt* These items follow the classical invoicing approach when the value of an invoice is matched against the value of the goods receipt message and the value at its creation.
- *3-way match, invoice before goods receipt* The same matching procedure is applied with an only difference that invoices can be recorded before the goods are received but they must be blocked until the goods have been received. Only then the invoice can be paid after removing the payment block.

- *2-way matching (no goods receipt needed)* For these items, the goods receipt is not required. Before payment, the value of the invoice(s) is matched with regard to value at creation. These items are part of framework order documents (so called "blanket PO) which refer to items with recurring invoices over a period of time.
- *Consignment* for these items, the product is received and stored in the warehouse, but not paid until only after it has been used for production. Due to the fact that invoices are handled in a different process, the data do not contain information about their invoices.

Beside the essential activities contained in the normal flows, four other types of activity can be performed in *Purchase-To-Pay* processes which affect the performance of the process.

- Changes: change activities such as "change price" and "change quantity" can cause rework, decrease efficiency and therefore, can be candidates for process improvement.
- Cancellation and deletion: These activities often imply waste of time and resources.
- Release workflows: Activities such as "release PO" and "reactivate PO" can also lengthen the throughput times and decrease efficiency.
- Messages: Events such as "order confirmation" and overdue notices such as "vendor creates debit memo" can become potential bottlenecks of the process.

2.3 Data quality issues

There are a number of data quality issues in the event log which could influence the analysis result.

- *Incorrect timestamps*: there are a few cases with events dating back to outside of the scope of the event log (e.g 1948), or to a future date. As most of this cases show a regular behavior in terms of process flow and were even complete cases, we kept them for the discovery and conformance checking, while neglecting them in the performance analysis which results would be biased with the incorrect timestamps (e.g. unusually long duration would impact the average).
- *Incomplete cases*: Incomplete case, not ending with an expected end event (e.g. "clear invoice"), affect the result of analysis. The reasons for incompleteness might vary and is up to domain expert to identify them, however, for some cases is simply the snapshot effect, i.e. the case was still open at the time of data extraction and will possibly end in the future.
- *Multiplied events*: Another data quality issue is the fact that some events happen at PO document level but are copied in the traces of each item. Since this event is copied with the same timestamp into each trace, while items have different creation times and their events have different timestamps, these events are positioned wrongly in the traces. (For example if

PO document x is created at 2 pm with two items, y created at 2pm and z at 4pm (it is specially the case for framework orders). now imagine a change approval activity is performed for PO x at 3 pm. While the change approval event would appear after creation of item y, indicating a sequence from create purchase order item to change approval, the creation of item z would be positioned after the change approval, indicating the sequence from change approval to create purchase order item. This will impact the result of process discovery negatively.

- *Missing events*: In cases that goods are receipt before invoices, a payment block has to be set to prevent early payments without having the goods. However, these event has not been properly recorded and reflected in the log. Although the event "Remove payment block" exist 57,136 times, "Set payment block" is recorded 124 times.
- *Missing attributes*: Another rather minor problem is that the value for a number of attributes are missing for some cases. For example, in the "spend area text" or "Users" sometimes the value is not recorded.
- *Case data on event level*: Lastly, the fact that majority of attributes are at case level but copied for each event not only creates overload, but leads to incorrect statistics (e.g. frequencies of certain type of items). To avoid this, for collecting statistics on this attributes we grouped the events and considered on event per each case.

3 Process Discovery of the Common Flow

Process discovery is one of the three main types of process mining and aims at constructing process models based on event logs [1]. It can be seen in various perspectives like the control-flow, the organizational, and case perspective. In this section, we focus on discovery of control-flow. The discovered process models should capture the behavior recorded in the event log. However, there is a need for a trade-off between desired and undesired behavior. The latter, also called noise, may occur in several ways, such as missing data, perturbed order of events, or additional events. Especially for processes with high variance, as observed in this year's log, this trade-off between noise and desirable behavior can be challenging. In general, the discovered model should represent the recorded events, therefore it should be precise. At the same time it should fit the log.

In this challenge we roughly followed the steps below, to handle infrequent behavior but retain most of the observed events:

1. Filter out artificial start and end events,
2. filter out incomplete cases,
3. filter out infrequent cases[1],
4. use inductive miner[2] and heuristic miner[3] with appropriate thresholds,

[1] Eric Verbeek, Filter Out Low-Occurrence Traces (Single Log), ProM Plugin
[2] S. J. J. Leemans, Mine Petri net with Inductive Miner, ProM Plugin
[3] F. Mannhardt, Ineractive Data-aware Heuristic Miner, ProM Plugin

5. create and check activity to resource mapping,
6. Design a BPMN process diagram based on the discovered model.

To accomplish the steps above, we used different process mining tools like Disco, Celonis, ProcessGold, ProM, and Apromore. In this section, especially Celonis and ProcessGold were used to obtain more in-depth insights into the data and to understand root causes for certain control-flow deviations. In the following the result of process discovery for each `item category` is presented.

3.1 3-way Match, Invoice after Goods Receipt

This section describes the models which depict the process of items falling into the first category. For such items, the value of the goods receipt message should be matched against the value of a corresponding invoice received message and the value put during the creation of the item. However, the invoice should be received after the goods have been received. As stated in Table 1, 15,182 cases belong to this group. After exploring the event log, we decided to distinguish between EC purchase orders and all others. Since the former ones are partly processed by a supplier relationship management (SRM) system, we separate these process instances.

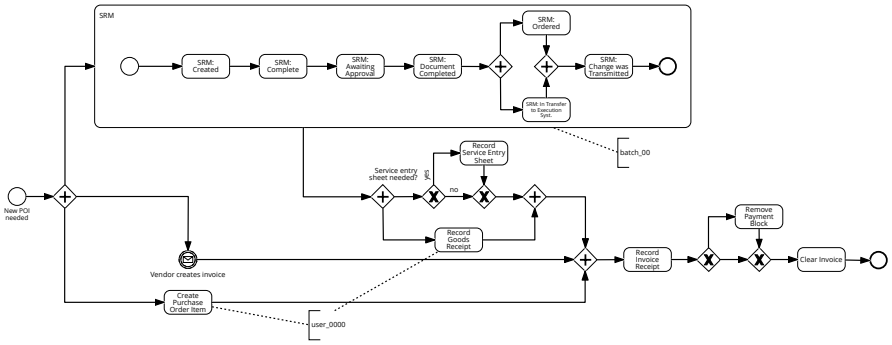

Fig. 3. Designed model for item category *3-way match, invoice after GR*, and document type EC purchase order.

EC purchase order Initially, this sublog contains 610 cases with 279 variants. After filtering out incomplete instances, we filtered out very infrequent variants. In the next step, we applied the inductive miner discovery algorithm to obtain a process model. We improved the resulting model by grouping activities into a subprocess and adding resource information. Figure 3 depicts the discovered process as BPMN process diagram. The discovered model has a trace fitness of 84% on the original log.

A batch resource executes all activities in the subprocess across all process instances. Once the subprocess ends, two activities are concurrently executed. On one side, the receipt of the goods gets recorded while on the other side a service entry sheet gets registered. The later one is optional and only observed for service-oriented purchase order items which holds for 47% of all variants. Since the model reflects the common flow, it does not contain infrequent loops. However, in 11% of all cases, a vendor creates invoice at least three times. In at least 24% of all cases in which this activity is executed at least three times, the vendor_0040 creates the invoice. In addition, 50% of these cases belong to the "Workforce Service". We observed similar findings in section 4 with violations of business rules.

While several different resources execute most of the activities which do not belong to the subprocess, only one user creates the order items and also registers the receipt of the goods. Further, many different resources execute most of the user tasks, therefore we did not model the resource allocation with pools and lanes but added comments to highlight activities which are connected to specific resources.

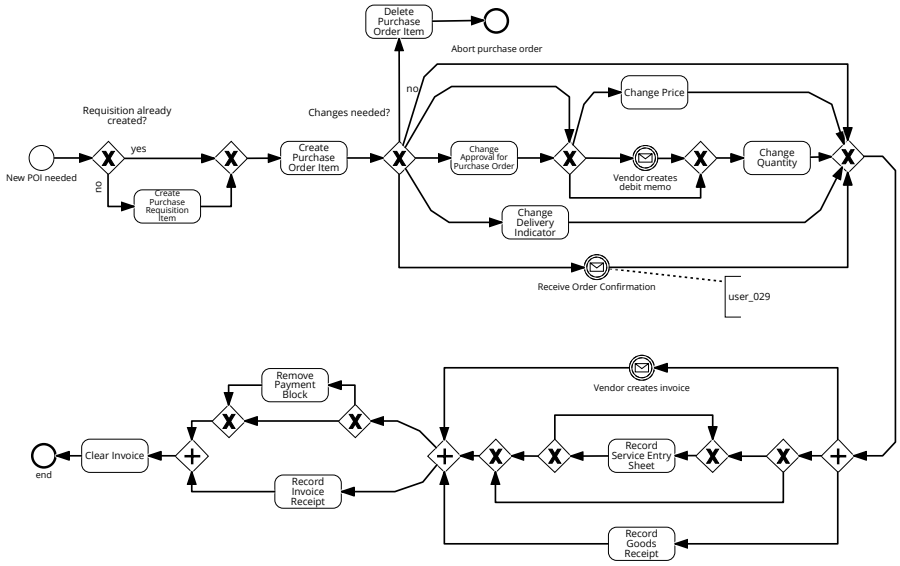

Fig. 4. Designed model for purchase orders of item category *3-way match, invoice after GR*, excluding EC purchase order documents.

Standard and Framework Orders While the previous process model describes only EC purchase orders, the model in Figure 4 depicts all other document types, as there are framework orders and standard purchase orders. Similar

to the former process, we observe a high variance of cases. Nevertheless, the discovered model has a trace fitness of 83% on the original log.

While the activity "Create Purchase Requisition Item" is optional in the model, we observe a process drift, which is indicated by a more frequent execution of this activity since September 2018. Like the previous process model, this model only reflects the common behavior and only one loop. However, there are activities in the log which are executed multiple times, even if the model does not allow for this. One example is the "Change Price" activity. In 68 cases it happens at least two times and in 79% of cases in the Logistics area. For example, vendor_0388 participates most in cases where the price has changed multiple times. "Change Quantity" is another activity that occurs at least two times in 115 cases, even if the model does not allow for that. Other than in the previous example, the activity is repeated the most in "Packaging" (61%), especially by vendor_0264 (24%). Again, we observe similar behavior concerning violation of cardinality rules as described in section 4. Based on domain knowledge the process owner should decide whether this exceptional behavior should be reflected in the model in the future or not. Maybe it would also make sense to keep cases of certain spend areas in separate process models, like logistics.

Another activity which stands out is the "Remove Payment Block" activity. It is present in 15% of all cases. Following the description of the item category, this activity does not belong to this process. It mostly occurs in "Packaging" and "Sales".

3.2 3-way Match, Invoice before Goods Receipt

This category of items go through the same matching procedure as the previous category (the value of invoice, goods receipt and at PO creation time). However, the invoice can be received and recorded before the goods are received. In this case the invoice should be blocked for payment until the goods are received. This category of items are the most common category in the log constituting around 88% of cases and contain items from standard, and EC purchase documents. In the same manner as the previous category we have divided the process based on the PO type. In the following we detail the process for each part.

Standard PO These cases compose 87% of cases in the log. The model for this category is shown in figure 5. A purchase requisition item is created prior to the creation of PO item; or create purchase order item is performed first. Next an order confirmation can be received (based on the log this is optional) in case vendor has not sent the invoice yet this event might happen next, before goods and invoice are receipt (in any order). Finally, the payment block needs to be removed (if exist) before the invoice can be paid. The designed model based on the recorded behavior in the log, and adjusted by the logical (desired) process flow maintains the fitness of around 85 percent compared to the complete log and of 91 percent against the log with only completed cases. This implies that although there are various variants and deviations in the log (which will be

investigated in detail in the next section), most cases can be explained by the model depicted in figure 5.

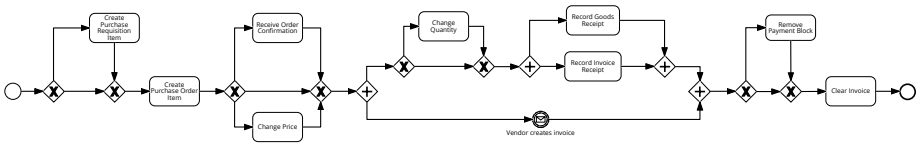

Fig. 5. BPMN process diagram for PO items following the *3-way match, Invoice before Good Receipt Standard Po*

EC purchase order There are 829 cases belonging in this category and the process model describing them is depicted in figure 6. The process start with the SRM system events (or by vendor sending a debit memo), followed by creation of purchase order item. Afterwards, receiving the goods can happen after the creation and recording the invoice. If the invoice is recorded before goods are received a payment block has to be set, which is not reflected in the log properly. After the goods are received and the invoice is recorded the payment block can be removed (if set previously), which, unlike setting the block, is reflected in the log (57,136 times) and then invoice can be cleared.

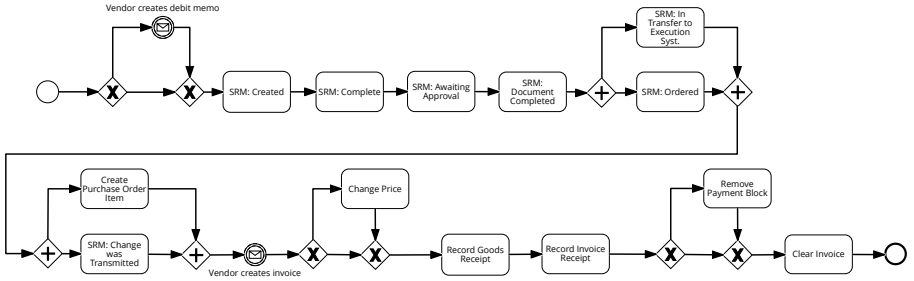

Fig. 6. BPMN process diagram for PO items following the *3-way match, Invoice before Good Receipt EC Po type*

3.3 2-way match

The 2-way matching process executed only by Company0003, in which no goods but an invoice is received, is shown in Fig. 7.

This part of the event log has a major data quality issue; the event "Change approval for Purchase Order" is occurring multiple times for each item, although

it happens on a PO document level, it is copied for each item in the document. This means, although an item was created much later, the change approval activity which was executed previously for the PO, was added to its trace. The logging of every change approval for each purchase item leads to the pattern that items had multiple "Change approval for Purchase Order" events at the beginning or end of the trace. Thus, we filter this event type out from the traces prior to discovery (as it indicates wrong sequences), and added the activity in the designed BPMN model after "Create Purchase Order Item" where it occurs in 96% of the traces.

Additionally also infrequent behaviour was filtered out (traces less than 10%) resulting in 935 traces (originally 1,044 traces). Based on the filtered log, the inductive miner could produce a model with a trace fitness of 97.2% on the original log without the "Change approval for Purchase Order" events. The result was improved in a designed model in Fig. 7 by visualizing the "Vendor creates invoice" as a BPMN start event and by adding several end events. Besides, the invoice handling is often only captured in one of the PO items, although it might cover several items. This means that an invoice by a vendor can initiate the creation of several PO items, but only in one of them the invoice creation, its receipt and clearing is shown. Thus, we added a multiple-instance activity which captures this pattern that one or more purchase orders can be created and get approved. Additionally, we extended the diagram by adding common users executing an activity in its annotation.

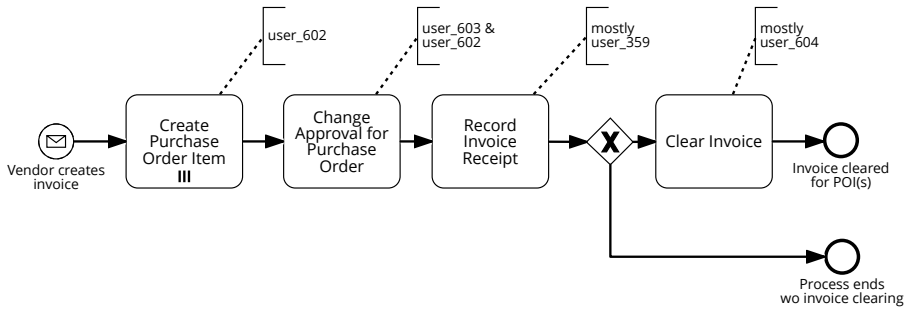

Fig. 7. BPMN process diagram for PO items following the *2-way matching*

If a vendor creates an invoice, then user_602 can create one or several PO items at the same time. Next, the user_603 changes the approval of the PO. Then, the invoice receipt is recorded, mostly by user_395 and also usually the invoice cleared, mostly by user_604.

The most common variant in this part of the log, with 22%, consists only of the two activities "Create Purchase Order Item" and "Change Approval for Purchase Order". Those are the cases which were created together with several others based on one incoming invoice where the invoice handling is not recorded.

The second most common variant 21% covers the exactly the described process, without having the activity "Clear invoice".

3.4 Consignment

The consignment process, where a good is received in the warehouse and is paid only after usage, is shown as BPMN process diagram in Fig. 8. The actual usage of the product is not anymore part of the process log, such that the net value of all purchase order items is zero.

Filtering out incomplete cases (not ending with "Record goods receipt", "Delete purchase order item", "Cancel goods receipt") and infrequent behavior (traces less than 10%), left 12,172 traces from the original 14,498 traces (cf. Table 1). On this filtered log, we ran the inductive miner which resulted with a model having a trace fitness of 97% by replaying the complete log for consignment. The resulting process model of the inductive miner was minimally corrected by showing different end events and a loop activity.

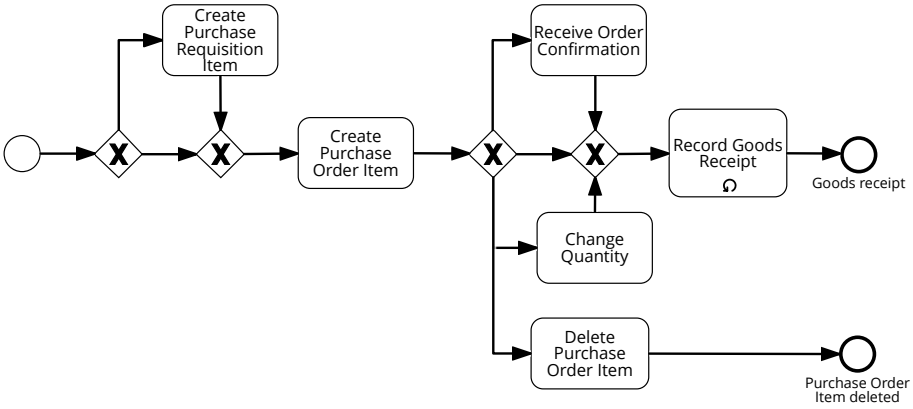

Fig. 8. BPMN process diagram for *Consignment*

Most commonly in consignment, first a purchase order item is created and then the goods are received covering 61% of the traces (8,776 traces). Goods can also received multiple times. This is visualized in the BPMN process diagram as a loop activity, which is finished as soon as all ordered goods were obtained. In 9% of the traces, it could be observed that the goods were received more than two times.

Since September 2018, we could observe a slight drift. Since then, first Create Purchase Requisition Item is executed before the purchase order item is created. This is the second most common variant with 12% of the traces.

After the purchase order was created also three other activities can occur: "Change Quantity" (3.7% of the traces) or "Receive Order Confirmation" (2.1%

of the traces), where the goods are still received, or "Delete Purchase Order Item" (1.2% of the traces) where the case is then terminated.

4 Detection of Compliance Issues with Rule-based Conformance Checking

Conformance checking aims to analyze the relationship between observed and desirable process behavior. The later one can be, for example, expressed as a normative business model or defined by rules. Rules can be derived from process models as a set of constraints given by the model's control flow. In a less technical perspective, such rules can also express business rules, like fulfilling the four-eyes principle, or more related to the given process, particular matching behavior. Compared to other conformance checking approaches, rule checking provides useful but straightforward insights into process conformance. In general, there exist five types of rules: (i) ordering rules, (ii) cardinality rules, (iii) exclusiveness rules, (iv) response rules, and (v) precedence rules [3].

Rules are always defined for a pair of activities. While the first three types are quite self-explanatory, response rules define whenever one activity occurs in a trace, there eventually has to be the other activity in the same trace. Similarly, precedence rules define activities, which have to occur in the same trace before the requesting activity takes place. By counting the violation and satisfaction of each rule, the conformance can be measured.

In the following, we analyze rules for each item type and point out violations which are strongly connected to compliance issues and therefore of particular interest. However, across all item types, response rules are frequently violated. One crucial factor for this could be a relatively large number of open cases. Therefore we do not consider them in our compliance analysis. Further, we will not report violations of cardinality rules in more detail, as we covered them in section 3 already. In general, these rules are strongly connected to rework and loops of activities, which are not modeled in our discovered process models since they only occur infrequently. In the context of the given process, such exceptional behavior may also not be considered as conformance checking problem since various goods and invoices could be received for single line items.

We implemented a Python library[4] to define and check rules for a given event log. We expand the given definition of precedence and response rules given in [3]. Since by default one occurrence of either the preceding or responding activity satisfies the respective rule, we allow enforcing the existence of a matching partner for all requesting activities, e.g. in one trace for each instance of "Record Goods Receipft" a "Record Invoice Receipt" activity has to exist. In the following, the default case will be marked with a "True" flag.

[4] https://github.com/bptlab/bpic19

Rule	Preceding activity	Requesting activity	# violations	% of traces	single occ.
	3-way match, Invoice after Goods Receipt with EC				
1	Record Goods Receipt	→ Clear Invoice	31	**5.80**	False
2	Record Invoice Receipt	→ Clear Invoice	3	0.67	False
3	Record Goods Receipt	→ Record Invoice Receipt	55	**6.88**	False
	3-way match, Invoice after GR without EC				
4	Record Goods Receipt	→ Clear Invoice	534	**4.58**	False
5	Record Invoice Receipt	→ Clear Invoice	91	0.87	False
6	Record Goods Receipt	→ Record Invoice Receipt	861	**5.02**	False
	3-way match, Invoice before GR with EC				
7	Record Invoice Receipt	→ Clear Invoice	3	0.28	False
8	Set Payment Block	→ Remove Payment Block	101	**100.00**	False
9	Record Goods Receipt	→ Clear Invoice	18	**2.36**	False
10	Record Goods Receipt	→ Clear Invoice	1	0.14	True
	3-way match, Invoice before GR without EC				
11	Record Invoice Receipt	→ Clear Invoice	1,670	0.91	False
12	Record Invoice Receipt	→ Clear Invoice	399	0.23	True
13	Record Goods Receipt	→ Clear Invoice	5,552	**2.83**	False
14	Record Goods Receipt	→ Clear Invoice	653	0.38	True
15	Set Payment Block	→ Remove Payment Block	54,532	**99.98**	False
	2-way matching				
16	Record Invoice Receipt	→ Clear Invoice	0	0	False

Table 2. Considered precedence rules for compliance analysis

4.1 3-way Match, Invoice after Goods Receipt

For this item category recording goods before recording the invoice is crucial and any violation a compliance issue.

EC purchase orders As shown in table 4, about 7% of all cases in this type, that contain "Record Invoice Receipt" at least once, violate this rule. Further in three cases, not all recorded invoices have been cleared and in about 6% of all cases invoices have been payed without recording the goods first. Paying an invoice without receiving goods may hint for fraud. The average amount of these items is 130,322.85€. The most common spend area (13 cases) is "Marketing", followed by "Workforce Services" (10 cases). The same observations can be made for the third rule.

Standard and Framework orders This orders share similar conformance and compliance issues as the previously described ones. In about 4.5% of all considered cases, the invoice has been cleared before recording any goods. Slightly more frequent (5%) an invoice has been recorded before recording goods. Regarding the first rule, two vendors, namely vendorID_0404 and vendorID_0236, stand out. Out of 423 violated cases, the first vendor participates in 89 cases, the second in 82 cases. Further, the majority of cases are of item type "Standard" (281 cases), followed by "Service" types (124 cases). Finally, about 46% of all cases belong to "Sales".

vendor ID	participated cases
vendorID_0118	385
vendorID_0246	234
vendorID_0136	166
vendorID_0108	156
vendorID_0236	151
vendorID_0110	134
vendorID_0404	126
vendorID_0122	114

Table 3. Most frequent vendors, participating in cases which violate rule 13 in table 4 (all vendors in average = 10 and median = 2).

For the second rule, the same vendors (vendorID_0404: 120 times, vendorID_0236: 88 times out of 533) participate the most in all affected cases. Again around 44% of all cases belong to "Sales", followed by "Packaging" in about 17%.

4.2 3-way Match, Invoice before Goods Receipt

PO of this item category can be handled more flexible. Since it is possible to record an invoice receipt before and after goods have been received. However, if an invoice has been received before the goods received a payment block has to be set.

EC purchase orders As stated in table 4, all cases with the activity "Remove Payment Block" lack of a preceding "Set Payment Block" activity. This activity is not contained in any case at all. While all purchase orders are "Standard" types, almost 50% of the cases belong to the "Enterprise Service" spend area. Since this activity is not recorded once, it is may hint for another data quality issue. In about 2.4% of all cases, invoices have been cleared without receiving goods before. However, there seems no direct root cause to exist.

Standard PO Most cases of the log fall into this item type. Like described before, the "Set Payment Block" does not occur in 99.98% of all cases containing "Remove Payment Block". Around 52% of these cases belong to "Packaging" and another 25% to the "Sales" area. In total 98% are standard orders, while the remaining 2% are split between "Subcontracting" and "Third-party" orders. Again, this might be hint for a general data collection issue.

The 13'th rule, "Record Goods Receipt" before "Clear Invoice", is violated in 2.83% of all cases. Eight vendors participate in these cases way above the average of 10 times, as listed in table 4.2. In the median, each vendor participates only twice. About one-third of these cases belong to the "Sales" area, 22% to "Packaging" and 21% fall into "Trading & End Products". Together, these spend areas make about 30% of the cumulated order value of the affected orders.

4.3 2-way Match and Consignment

Cases of purchase orders belonging to either 2-way match or consignment are the least violated ones. Since there are no invoices recorded for consignment purchase orders, there cannot be any business rules derived from the control flow, for compliance analysis. Also, only one rule could be derived for 2-way match items. According to our analysis, this is never violated in the observed cases (see table 4).

5 Process Performance

The event log of this year's challenge provides timestamps for the completion of each activity, such that throughput time can be further analyzed as performance dimension. For this, we first define the performance measures for the *Purchase-To-Pay* process whereby we consider two types of customers: (1) the internal departments and (2) the vendors. Then, the results are visualized and presented, based on which, question were raised. Finally, these are answered by a root cause analysis.

5.1 Definition of Performance Indicators

A *Purchase-To-Pay* process has actually two customers to-be served: (1) the internal production department or other departments (called here internal customer) requiring certain goods for producing the final products based on which the company generates revenue and (2) the suppliers which deliver the goods. A good supplier relation is important to receive high quality products, good prices, and a fast delivery. Based on these, we define performance measurements for the internal customers and the vendors.

Internal Customer. For internal customers, we assume that fast processing of the purchase requisition is important. Thus, the following aspects are measured:

- *From Requisition/SRM to PO Item* (Time between "Create Purchase Requisition Item" or "SRM:created' and "Create Purchase Order Item")
- *From PO Item to Goods* (Time between "Create Purchase Order Item" and "Record Good receipt")

Whereas the first indicator measures the time until a PO item is created, the latter measures the time between its creation and the good receipt.

Vendor Relationship. For vendors, we assume that they want to get quickly paid for the delivered goods.

- *From invoice to invoice receipt* (Time between "Vendor creates invoice" and "Record Invoice receipt")
- *From invoice receipt to clear invoice* (Time between "Record Invoice receipt" and "Clear Invoice")

– *From goods to clear invoice* (Time between "Record good receipt" and "Clear Invoice")

The first performance indicator computes how long it takes to actually record the invoice of the vendor. The second and third one measure the time between invoice receipt and also good receipt until the invoice is finally cleared which is important for the vendor.

5.2 Results

We measured the performance indicators with the help of Lana Labs Tool by using the dashboard functionality to analyze the throughput for a selected eventually follow relation. The tool provides the mean and the median for the throughput time between two selected events. We performed this evaluation individually for each item category and considered thereby only those performance indicators relevant for a certain category. Traces with incorrect timestamps as reported in Section 2.3 were filtered out beforehand. The results are visualized in Fig. 9 and Fig. 11 and presented in the following.

Internal Customer Fig. 9 shows the mean and median throughput times in days to create a PO item based on a requisition (or SRM:created for EC purchase orders) and to actually receive the goods for the different item categories. Thereby, it is distinguished between without and with EC purchase orders for the 3-way match procedure, because EC purchase orders have the extra SRM activities involved. 2-way match is not considered here because no tangible goods are received which can be checked, such as government payments and rents.

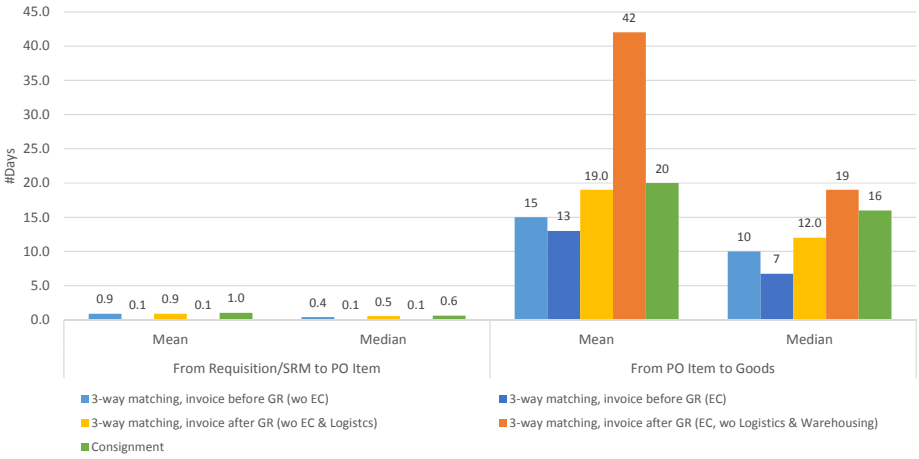

Fig. 9. Resulting performance measures for the internal customer (throughput time for creating a PO item and for receiving the goods)

From the recorded data, it seems that a PO item is usually generated quickly within a day. Especially for EC purchase orders, where a SRM process runs before the actual creation of the PO item, this is conducted in less than 2.5 hours in most cases.

After placing the PO item, goods are delivered in different time. For the items following the **3-way match, invoice before GR** it is in average 15 days (median value 10 days) and for EC purchase orders in average 13 days (median value 7 days). That means that there are some outliers. This item category has the most items processed and most of them are production-relevant (85%). Thus, it is positive that these items are delivered in a relatively short timeframe. Still, we want to place a question, because these PO items seems to be very relevant for the company: *"Why can we observe a difference between the mean and median value for the delivery time of items in the category: 3-way match, invoice before GR?"*.

Regarding **3-way match, invoice after GR**, we filtered out some cases to report meaningful results. In the case of non-EC purchase orders, logistics items (4,498 traces, 32% of these traces), such as road were filtered because they are usually received instantly leading to a median of 4 minutes and an average value of 7 days. Considering not the logistics items, the average receipt time is 19 days with a median value of 12 days. In comparison, EC purchase orders need in average 42 days and have mean of 19 days when not considering items of the spend area *Logistics* and *Workflow Services* (18% of these traces, 93 traces). These encompass Express, HR Services, and Third Party Labor and have quite long times until the good is recognized. Still, they have a comparable long delivery time because this type of purchase orders includes usually the payment of services, e.g., laboratory services, consultancy, design, market research etc. (cf. Fig. 10) We assume that "Record good receipt" is recorded as soon as the service is terminated, such that a longer throughput time is not harmful as long as it takes the time as specified in the contract of the vendor. This is not part of the data.

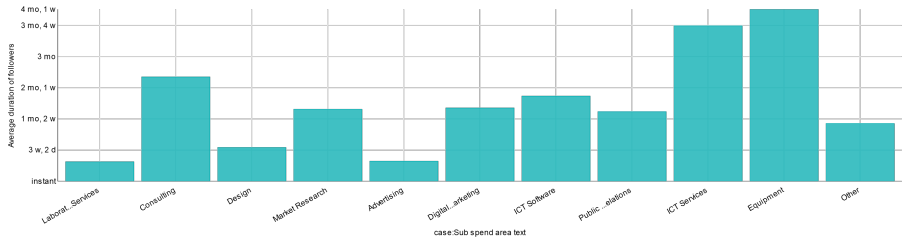

Fig. 10. Average throughput times from PO item creation until good receipt for EC POs in different sub-spend areas in 3-way match after GR

Consignment PO items are received in average in 20 days with a median value of 16 days. We assume that this timeframe is not harmful for the internal customers as it delivered in a warehouse where usually enough capacity should be available. Here it would be interesting to compare the delivery times with the warehouse data. It could be observed that Titanium Dioxides (ordered in 2,453 PO items) needs longer time until goods are receipt, up to 2 months (56 days) in average.

Vendor Relationship Fig. 11 shows the throughput time in days as mean and median from the creation of an invoice until recording it, from invoice receipt until clearing, and from goods receipt until clearing. Thereby, it is again distinguished between the different item categories. Consignment items are not considered because the invoice handling for them is not included in the event log.

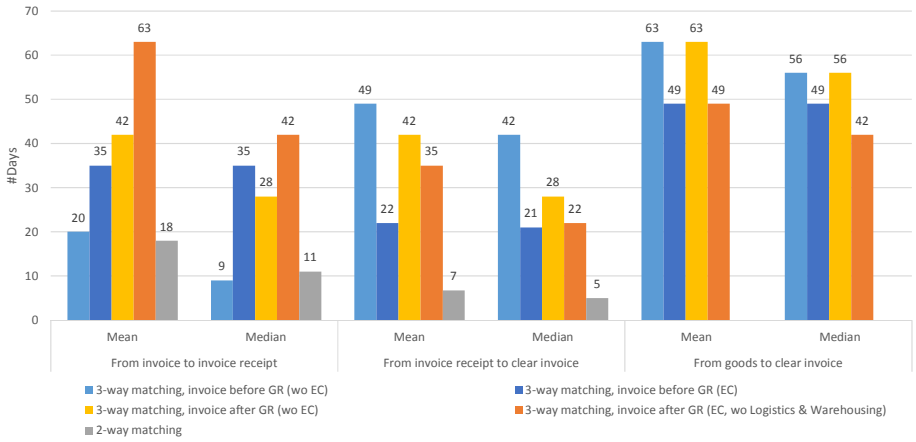

Fig. 11. Resulting performance measures for the vendor relationship (throughput times between goods, invoices, and payment)

For items of the category **3-way match, invoice before GR**, the invoice could be received before receiving the goods.

Invoice receipt usually happens in average 20 days (median: 9 days) after the invoice was placed. For EC purchase order items, it is done mostly after 35 days. After invoice receipt, it needs in average 49 days with a median of 42 days to clear the invoice. For EC purchase order, the clearing after invoice receipt is quite stably conducted after mostly 21 days, and also the clearing after goods receipt is executed mostly after 49 days. For all other purchase order items, the time between goods receipt and clearing the invoice is in average 63 days with a median of 56 days.

For items of the category **3-way match, invoice after GR**, first the goods have to be receipt until the invoice can be receipt and cleared. That means the vendor can create its invoice at any time but it is only receipt after goods receipt. Therefore it is not surprisingly that EC purchase order items in this category take more time to receive them because also the delivery takes longer, in average 63 days with a median of 42 days. The Standard and Framework PO items need in average 42 days with a median of 28 days what is in comparison to receipt of goods quite high.

The clearing of the invoice needs in average another 42 days (for EC: 35 days) with a median of 28 days (for EC: 28 days).

This leads to a total time between goods receipt and clearing the invoice of in average 63 days with a median of 56 days. For EC purchase orders is less, in average 49 days with a median of 42 days. This leads to the assumption that vendors are creating their invoices quite early. Between the two categories of 3-way match not so much differences can be observed, although the invoice in the first category could be received earlier and then payed as soon as the goods were received. Thus, our question is: *"Why is the time between goods receipt and clear invoice is comparatively long for items where the invoice can be already received before the goods receipt?"*

2-way matching only requests to check the invoice, such that we can observe a quick clearing of an invoice as soon as the invoice receipt was recorded, in average in 7 days with a median of 5 days. However, it takes usually in average 18 days (median of 11 days) to record the invoice receipt after the vendor has created the invoice. That might be due to that usually first the vendor sends the invoice and then the purchase order (item) is created. We observed some outliers in that category: the purchase order items for *Vendor_1914* in the sub-spend area *Business park* (12 cases) which were created more than 10 months later after the vendor has created the invoice.

5.3 Deep-dive Analysis

In the following we want to discuss the questions placed earlier in more depth:

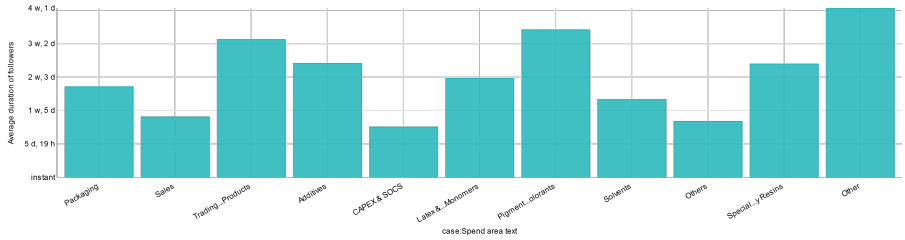

Fig. 12. Average throughput times from PO item creation until good receipt for the different spend areas in 3-way match before GR, without EC.

1. "Why can we observe a difference between the mean and median value for the delivery time of items in the category: 3-way match, invoice before GR?" Fig. 9 shows the throughput times for the different spend areas for this item category without EC purchase orders. *Trading&End Products* and *Pigments&Colorants* of the most common items have higher average delivery time than the others. When looking on the changes which can occur after the PO item was created, the "Change quantity" is the most relevant ones. This happens in 13140 cases (6.9% of these cases) and leads to an increase in the throughput time up to in average 28 days (median of 23 days), which is twice as much than in the most cases. Thus, this activity has a negative influence for a fast delivery of products.

2. "Why is the time between goods receipt and clear invoice is comparatively long for items in which the invoice can be already received before the goods receipt?" Interestingly, the invoice is received before the good receipt in only 8% (16,168 cases). Those have also a minor improved throughput between goods received to invoice clearing of two weeks less than the reported average of all those PO items. The Fig. 13 shows that items from different sub-spend areas are also treated differently. For example, the *Lables* have a comparable long payment time of in average three month whereas, *MRO (components)* only takes in average 3 month.

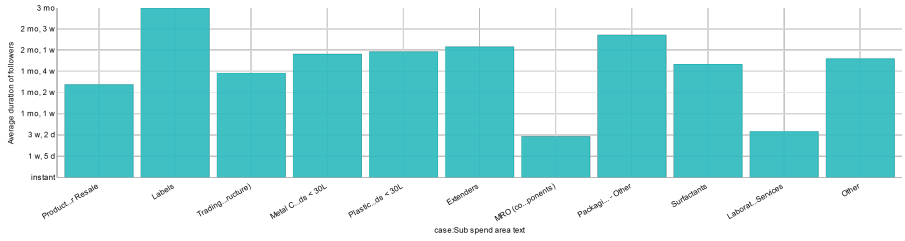

Fig. 13. Average throughput times from good receipt until clear invoice for the different sub-spend areas in 3-way match before GR, without EC.

In general, we assume that regularly a batch for the invoice is run. How this batch behavior influence the performance for invoice clearing needs to be further evaluated.

6 Conclusion

After presenting some statistics, insights, and data quality issues on the event log for a *Purchase-to-Pay* Process, we discovered in this report the most common flows of the different item categories and presented them as understandable BPMN process diagrams. In this step, the high variance and flexibility of the process were challenging.

Next, we performed conformance checking and discovered compliance issues based on control-flow rules. To this end, we developed a Python tool, made publicly available. Among other things, we found that 54,534 times, a payment block was not recorded before removing it. For 3-way match items, in 6,135 observations invoices have been cleared without recording goods before. Last but not least, 1,767 times invoices have been cleared without recording an invoice before.

Finally, we defined performance indicators for the two customers of this process: the internal departments of the company and the vendors. This revealed that the receipt of goods takes place within less than two weeks for the standard purchase orders which are relevant for production. However, clearing the invoice takes several weeks. The same holds for the *3-way match, invoice before goods receipt* items. Here we recommend checking whether these type of invoice could be already receipt earlier to decrease the time of payment.

We think that a fast payment of invoice can lead to a better vendor relationship. Therefore, in the future, we would like to investigate the root causes of the payment duration further. We assume that this is regularly done in a batch-like fashion for which we would like to identify the rules and pattern.

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