Optimization of Logistics Processes by Mining Business Transactions and Determining the Optimal Inventory Level

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Abstract. This paper presents a practical approach to process mining of logistics processes that we applied for several organizations. We used 'regular' process mining for process discovery, giving us a first impression of the structure of the process (e.g. dependency between individual events/activities, frequency of occurrence of activities, and timing aspects). Using the DEMO methodology (based on Ψ-theory) we manually identified the main business transactions from this discovered process and we annotated the different events/activities as either coordination or products acts belonging to a certain business transaction. After this step we were able to analyze the logistics process at a higher level of abstraction; we could mine data about business transactions instead of low level events and/or activities. The business transaction process visualizations were easier to understand for stakeholders than flowcharts. Next to this, we determined the optimal inventory level for guaranteeing a certain service level (using Lean Six Sigma), making it possible for organizations to make a tradeoff between item price and service level.

Key words: process mining, logistics, enterprise ontology, DEMO, lean six sigma, inventory control

1 Situation

Recently we have come across several organizations that face difficulties getting the *right* material to the *right* place at the *right* moment for carrying out preventive and corrective maintenance. Preventive maintenance deals with inspecting the current state of a machine, detecting potential problems and cleaning/replacing items before defects occur. It is scheduled after a certain fixed period or after a certain amount of usage (e.g. working hours of a factory machine or vehicle mileage). Corrective maintenance deals with fixing the machine after a defect occurred. The demand for items is less predictable for the second type of maintenance (and quick delivery is even more important). Inventory can be stored at different locations having different lead times for transportation of the item to the machine or vice versa, e.g.:

- the project location (for instance a construction area or an offshore location),
- the mechanics workplace (for instance a garage or a hangar),
- a local warehouse,
- a central warehouse,
- warehouse of the supplier.

Organizations must find a balance between costs of inventory and provided service level to the mechanic who requires the items. Too little inventory may lead to unnecessary downtime of machines and mechanics waiting instead of working, too much inventory leads to high storage costs, less money available for other business activities, and higher risk of an item becoming obsolete, damaged or stolen.

2 Task

The task we were faced with at several organizations was to find bottlenecks in logistics processes that lead to unnecessary downtime of machines. This task included determining which items should be kept in inventory to provide an optimal service level to mechanics for preventive and corrective maintenance.

3 Approach

We extracted data from ERP systems (Infor, SAP, and tailor made systems), combined this data with data from other enterprise applications and converted them to a structure suitable for process mining [1]. We mined processes using the inductive mining algorithm [2] to get a first insight into the process. This enabled us to discover:

- the most frequent activities and process paths,
- the dependencies between different activities/events,
- time between activities/events.

This type of process mining, however, does not deal with the semantics of the individual activities/events. We combined process mining with the DEMO methodology (based on the ψ-theory [3]) to get a better understanding of the semantics of the business process. We annotated activities/events as coordination or production acts as defined in the complete transaction pattern. By doing this we could get a better understanding of the mined business process; we could easily see which business transactions where executed as they should and which business transactions failed somehow.

Though process mining can be used to analyze item movement between different locations, it does not deal with optimal inventory levels. To find such an optimal inventory level, we had to make additions to our process mining factory. We introduced ideas from Lean Six Sigma on this topic and used a continuous review model (inventory can be ordered at any moment). We determined for each item type *when* new items should be ordered and *how many* items should be ordered by calculating the inventory reorder point and the optimum order quantity. The inventory reorder point is the level of inventory at which the inventory should be replenished to make sure a certain service level can be guaranteed. It is calculated as follows:

$$n = L\left(\frac{d}{D}\right) + \sigma\left[\Phi(S)\right], \text{ where:}$$

- L is the lead time in days,
- d is the annual demand for the item,
- D is the number of working days in a year,
- σ is the demand standard deviation (per lead time),
- S is the required service level,
- Φ is the inverse of the standard normal distribution.

As we can see a higher variation in demand leads to a higher inventory level. In our cases we assumed we cannot influence the demand or the variation in demand (though this might be possible by analyzing the maintenance process!). The service level is a process requirement which is, in general, dependent on the price of the item. In some situations (very expensive or rarely used items) only one item is ordered each time. In other cases we want to know how many items we should order. This optimum order quantity can be calculated as follows:

$$\text{Q} = \sqrt{\frac{2od}{ui}}, \text{ where:}$$

- o is the order cost,
- d is the annual demand,
- u is the unit cost,
- i is the interest rate or carrying cost.

4 Result

We made custom visualizations (see Fig. 1) in our process mining factory for presenting logistics processes. These comprised more coarse-grained business transactions instead of fine-grained activities/events. This enabled us to show the process to domain experts in a way that reflect their way of thinking (different actors communicating about services they offer to each other).

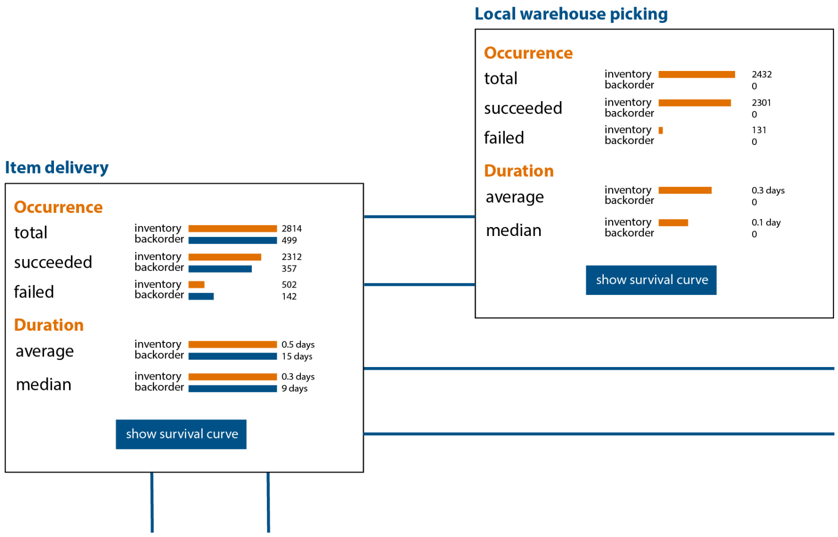

Fig. 1. This figure depicts the root business transaction and a business transaction for local warehouse picking.

These visualizations show the following metrics per business transaction type:

- total number successfully executed (only coordination steps from basic transaction pattern),
- total number failed (includes decline, reject or cancellation acts),
- average duration of the transaction (when item is delivered from inventory or backorder),
- median duration of the transaction (when item is delivered from inventory or backorder),
- the survival curve (how many cases are still 'in the transaction' after a certain period).

Because DEMO processes have a tree structure we can compare the metrics of an individual business transaction to those of the complete process (which is the root transaction!). The bars of the metrics in the different business transactions are therefore made relative to the values of the metrics of the root transaction. We can now easily see which business transactions take up most time and which business transactions fail frequently. We can show this visualization for all types of material, but of course we can also slice it for a specific type of material. When we do this we can view an additional visualization that shows inventory related information as depicted in Fig. 2.

5 Reflection

In this paper we presented a way to combine fully automated process discovery with making manual annotations about the semantics of individual activi-

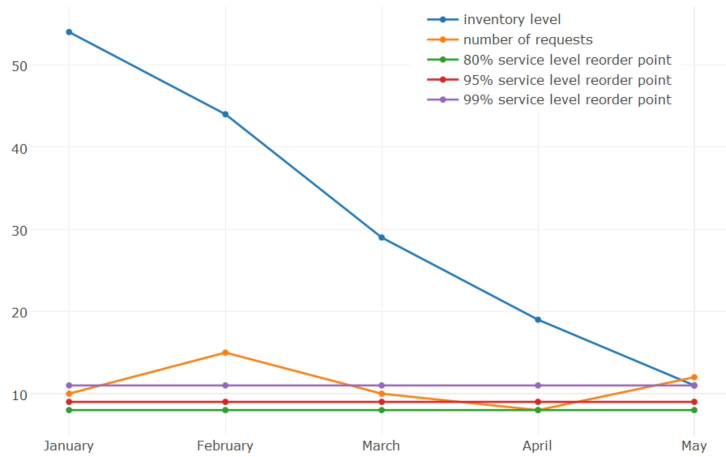

Fig. 2. In this figure we see the monthly number of item requests from mechanics for a certain material. Using the formula presented earlier the inventory reorder point for service levels of 80%, 95%, and 99% are calculated automatically. The results can be compared with the inventory level.

ties/events using the DEMO methodology. We did not only focus on analyzing the logistics process itself, but also on determining the optimal inventory level to guarantee a certain service level. We see some ways of further improving our approach. First, we would like to make a distinction between the different reasons why a business transaction may 'fail' (currently we only distinguish between succeeded and failed). Is it because of a decline, reject, or cancellation? This can give the organization a better understanding on *why* things go wrong and what to do about it. A second improvement is to find a way of dealing with declined, rejected and canceled orders in determining the inventory reorder point. At the moment we exclude them from this calculation, but this is not in all cases the best way to deal with them. A third improvement is to automatically mine *relations* between business transactions and to see where the order does not go as planned.

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