Analyzing Transaction Codes in Manufacturing for Compliance Monitoring

Completed Research

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Abstract

Companies, especially manufacturers, are operating in increasing demands of variability and customizability nowadays. They are faced with a multitude of complex rules and regulations that must be complied with, as well as supply chain disruptions that threaten business. Smart manufacturers take advantage of advanced information and manufacturing technologies to enable flexibility in physical processes. However, existing information systems are far from being effective and efficient for compliance monitoring in service-oriented manufacturing. Failure to interface well with different information systems is still a general phenomenon among manufacturers, leading to problems such as delay of goods delivery or missing inventory. This research analyzes transaction codes in information systems using process modelling with simulation, validated by an intensive manufacturing case study. Design principles in IT systems for continuous monitoring and auditing in manufacturing are developed. The results contribute to enterprise systems configuration by proposing internal control measures based on IoT fault detection sensors.

Keywords

Auditing, compliance, information systems, manufacturing.

Introduction

Companies usually have complex supply chains in which some parts are purchased in one region but assembled or manufactured in another region, and eventually shipped and sold to other regions. They are compelled to comply with different legal and regulatory requirements while moving goods quickly and cost effectively. Consider for example customs legislation, excise, food and health regulations, safety and security measures, etc. (Tan et al. 2011). Smart Manufacturing Systems attempt to maximize the capabilities of using advanced technologies that promote rapid flow and widespread use of digital information within and between manufacturing systems, and the supply chains that feed them (Lu 2016; Papazoglou et al. 2015). However, specifically for regulatory reporting, there is a lack of information systems tailored to compliance management that integrate seamlessly with a company’s operational processes and Enterprise Resource Planning (ERP) environments. Much of the data from information systems can be presented to people through dashboards that also enable direct control and immediate audit. Similarly, dashboards for monitoring and controlling the smart manufacturing system are needed. Such systems could facilitate continuous monitoring or continuous auditing (Chan and Vasarhelyi 2011; Kogan et al. 2014; Kuhn and Sutton 2010). Even though these systems with governance, risk and compliance (GRC) tools provide features for compliance monitoring and auditing, Failures of systems integration or adoption still exist globally. In the 8th edition of the Deloitte Global Risk Management Survey, 75% of organisations are extremely, very or somewhat concerned about a lack of integration among systems. Meanwhile, international manufacturers are experiencing problems of adopting information systems to be compliant with customs legislation for the process of export clearance, due to the complex nature of the supply chain management across the border (Hesketh 2010).
Therefore, manufacturers are facing risks concerning compliance (Spira and Page 2003), such as altering shipping documentations, inter-company manipulations, and fictitious inventory. The role of inventory management is to coordinate the actions and requirements so that all internal and external movements of goods satisfy the demands of customers or of a production process. The production process within a company is executed using work orders. To be able to rapidly access these orders in information systems each function in information systems is associated with a transaction code. According to standard ERP operations, goods movement as material flow should be recorded in terms of movement types. These codes capture information flow, but not financial flow. A transaction code (e.g. t-code in SAP) consists of letters, numbers or both. Each type of material movement is given a unique movement type, following after the transaction code. The same transaction code can be used for different movement types. For example according to SAP manuals, MIGO-261 stands for ‘Goods issue for a production order’, and MIGO-262 means ‘Reversal of MIGO-261’, i.e. cancellation of the production order.

Essentially these transaction codes comprise a ‘model’ of the main business process. Compliance means adherence to a norm (Lu et al. 2009). In this case the norm is the transaction model behind operational processes. Although this ideal model might differ under different contingency factors, standardization in manufacturing is particularly necessary for quality control. Ideally, operational processes correspond to the model and the model is designed to satisfy the organization’s legal and regulatory requirements. In reality there are always deviations, resulting in inventory mismatches, suspicious goods movement, missing data, etc. This research aims to devise methods for the detection and mitigation of such deviations, by analyzing transaction codes in information systems for manufacturers. A systematic approach with design principles is developed to reduce compliance problems in manufacturing and facilitate continuous monitoring. In order to achieve these objectives, the main research questions are:

What are design principles in information systems for continuous monitoring and auditing in the manufacturing domain?

More specifically, how can root causes of deviations from standard operational processes be discovered and solved by detecting and analyzing transaction codes in manufacturing?

Achieving these objectives leads to the following steps that an enterprise can take for continuous monitoring. This research is a proof-of-concept: the purpose is to validate the adequacy and relevance of the method by means of a case study. These steps also structure the main research activities reported.

Step 1: discover how manufacturing and inventory management is performed and which components are typically used to assemble a product, especially in the prototyping phase when there is no complete bill of materials. To this end, elicit the main artifact used in the approach, i.e. a transaction code diagram for manufacturing, and process models representing the internal organizational processes of a company.

Step 2: apply conformance checking methods to event logs in information systems to detect deviations from prescribed behavior indicated by the transaction code diagram.

Step 3: propose appropriate data requirements and control methods from conformance results to reduce misuse of transaction codes. Design principles for continuous monitoring and auditing in manufacturing are then developed by these requirements and controls.

The research methods are as follows. Firstly, desk research is used to study relevant scientific literature, customs laws and regulations, business software user guides and audit reports. Secondly, process modelling with simulation is applied to develop the standard operational process represented by transaction code diagram. Thirdly, we use conformance checking techniques specifically for analyzing empirical data to detect deviations. All the process models and transaction models have been validated by domain experts from the case. To investigate operational details and analyse data empirically, one intensive case study is performed. The case concerns compliance reporting based on a customs warehouse license and inward processing license for a company called ABC. The name is anonymized from a world leading enterprise in electronic equipment manufacturing. In the case study, representatives of several actors are interviewed between May 2015 and May 2017, including different departments inside company ABC (e.g. logistics, compliance), Customs Administration of the Netherlands, a third party logistics provider (3PL), information system providers, suppliers and customers.
**Theoretical Foundation**

**Process Models**

The scientific foundation for this research is process modelling combined with data modelling. A process model defines the functional decomposition of the system function and the flow of inputs and outputs for those functions (Buede and Miller 2016). Several notations have been proposed for process modelling: informal (e.g. natural language) for the general public; semi-formal (e.g. BPMN) which requires some training for understanding (White and Miers 2008); formal (e.g. Petri-Nets) which is hard to master but allows advanced analysis. In this paper, we adopt Petri-nets as the representation for the specification of business processes (Cardoso and van der Aalst 2009).

**Definition.** A marked Petri net is a tuple \((P, T, F, m_i, m_f)\) where \(P\) is a set of places, \(T\) is a set of transitions representing transaction codes, \(F \subseteq (P \times T) \cup (T \times P)\) is the flow relation connecting places and transitions, \(m_i\) is the initial marking and \(m_f\) is the final marking. A marking of a Petri net (graph) is a multiset of its places and assigns to each place a number of tokens (Reisig 1991).

Petri nets provide a formal semantics that can be exploited for automated analysis, e.g. simulation. In addition, there are many approaches for data modeling. Entity–relationship (ER) diagrams are the oldest form of data modeling. We use ER diagram to provide data requirements in the case study.

**Continuous Monitoring and Continuous Auditing**

The terminology ‘continuous auditing’ is linked with ‘continuous assurance’ and ‘continuous monitoring’. Continuous assurance is shown to be composed of verification of properties of data at or near real time, by means of continued application of computational auditing techniques, and by continuously monitoring the reliability of the data (Coderre 2005). Specifically for audit and control, there are two kinds of architectures regarding continuous auditing: Embedded Audit Module (EAM) and Monitoring Control layer (MCL) (Kuhn and Sutton 2010). EAM uses the ERP system to run analytic procedures. Rules are programmed in the local ABAP code of an ERP system. This has the disadvantage that the company could manipulate the code, and reliability cannot be easily ensured. Moreover, foreign code in an ERP system leads to large maintenance costs when updates are made. Therefore, most reported implementations use MCL, with a separate server for control monitoring (Kuhn and Sutton 2010; Singh and Best 2015). Security measures should ensure confidentiality for corporate sensitive data, as well as integrity that data cannot be manipulated. This triggers the question which party should host the server: the company, an external auditor or regulator, or a trusted party in the role of intermediary (Chan and Vasarhelyi 2011; Christiananse and Hulstijn 2013). This is particularly interesting, as in the case study we later found that server performance problems leading to downtime, is one of the major root causes of compliance faults.

Recent surveys (Chiu et al. 2014) indicate that currently there is no detailed scientific research into the right way to adopt continuous monitoring and continuous auditing techniques for compliance reporting. In particular, the conditions or indicators that need to be monitored are still unexplored. In this research, we propose to analyze transaction codes for continuous auditing. Our research will fill the gap by developing design principles in IT systems of manufacturing for continuous monitoring and auditing.

**Process Mining and Conformance Checking**

Process mining is a promising means to systematically analyze data recorded by information systems like ERP, for compliance and auditing purposes (Jans et al. 2013). It provides auditors a more comprehensive way to understand the control environment than the manual procedures that they rely on today. Process mining can be used for several tasks: process discovery, conformance checking, performance analysis, process prediction and process improvement. Conformance checking is specifically useful when business processes support and control software systems. It aims at the detection of inconsistencies between a process model and its corresponding execution log (Rozinat and van der Aalst 2008). Logs represent observed execution sequences of activities from the normative process model. In the desirable case, logs completely comply with the behavior defined by the process model and are called valid execution sequences. In practice, observed execution sequences often deviate from the predefined behavior.
Process mining in general aims to generate knowledge from event logs. Event logs can be extracted from information systems (van der Aalst et al. 2007). Information systems capture activities happening in the “real world”. To perform conformance checking on data, the digital traces captured in the information systems must be extracted and transformed into event logs. We assume the existence of an event log where each event refers to a case, an activity, and a point in time, i.e. timestamp. In case there are two timestamps (beginning and end) also duration can be measured. An event log can be seen as a collection of cases, for instance customer orders, or transaction codes. A case can be seen as a trace or sequence of event that all related to the same case, identified by a case ID. When also involvement of resources or persons in the process events is recorded, an analysis can be performed on the distribution of resources, or on segregation of duties (Rozinat and van der Aalst 2008).

**Transaction Code Diagram**

**Process Modelling**

Manufacturing typically requires materials that have to be retrieved from various locations of the warehouse. Moreover, materials might be transformed and aggregated to intermediate components before they can be used to build the final products. Thus, a large amount of goods movements may be necessary to complete a production work order. To complete a production process, predefined sequences of transaction codes are expected to be executed. To analyze transactions codes, we derive a transaction code diagram representing the possible sequences of transaction codes that should be executed, i.e. the ideal execution of a business process. A transaction code diagram is essentially a Petri net, where transitions are labelled with transaction codes. This type of diagram can be used in conformance checking to identify possible faults, relative to the compliance requirements. According to SAP manuals several different movement types are allowed per transaction code, and for each movement posted, a material document will be created and stored in the database. The movement type is important because it is used to control adjustment of inventories and the General Ledger account for financial purposes etc.

![Transaction Code Diagram](image)

**Figure 1. An Example of Transaction Code Diagram Regarding a Production Process**

Figure 1 presents an example of the transaction code diagram in the form of Petri net regarding the production process. The normal sequence of movement types should follow a certain pattern as the process model, as the black arrows shown in Figure 1. For example, movement type 261 initiates a “Goods issue for a production order”. When some components are cancelled, the components should always be reversed by 262 even though there would be sophisticated manufacturing processes after 261. By the end of the production phase any remaining unused components are returned to the inventory and a 262 against this order should be posted. Below is the detailed description with the transactions codes used:

1. Create production order - CO01
2. Issue goods for production order - MIGO-261
**Simulation**

WoPeD (Workflow Petri Net Designer) is an open-source software tool developed for modelling, simulating and analyzing processes described by Petri nets (Freytag and Sänger 2014). A built-in resource editor in WoPeD allows for each process the definition of a resource model, i.e. roles, groups, and objects. Here, we model sensors in the transitions which can have resource class assignments. Based on the capacity requirement per transition, we can calculate the capacity of each resource class (Figure 2).

Given an expected supply of materials and a number of assumptions about their processing, we can use simulation and/or the queueing theory to determine the capacity requirement during a particular period. Two different algorithms are implemented, both based on stochastic distributions of arrival rate, task service times and XOR branching probabilities (van der Aalst et al. 2003): Firstly, a quantitative simulator engine for the random construction of execution traces, allowing to derive quantitative properties like average waiting or completion time. Secondly, a capacity planner in order to calculate the optimal number of resource objects for each resource class.

Suppose four resource classes are modelled: Bonded, Free, Production and Finance (Figure 2). A resource belongs to either Production (left) or Finance (right), but not to both. The materials are either Bonded or Free. Bonded materials refer to goods under supervision by the customs authority, as import duties are due but payment has been postponed. Free materials refer to goods ready for free circulation, after paying import duties, or because no duties are due (UCC 2013).

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Figure 2. An Example of Sensor Deployment in Petri Net Model for Fault Mitigation

The average processing time in minutes is shown in green. Suppose the sensor in goods issue (MIGO-261) for an ‘easy’ case of free materials takes an average of 10 minutes, whereas for a ‘difficult’ case of bonded components (extra information needs to be registered) it takes an average of 15 minutes. The sensor in variance calculation (KKS1) for an easy case of bonded goods (no need to pay duties) takes an average of 5 minutes, whereas for a difficult case of free components it takes an average of 20 minutes. It is assumed that the time taken to perform those activities which require no resources is negligible. On average, 70% of goods received are classified as bonded goods, 30% as free goods. Suppose 85% of the bonded goods have moved to production (shown as WIP for work in process) and 15% are reversed (percentages shown...
in red). If we know the number $\lambda$ of new components arriving each day, we can calculate the capacity requirement for each activity. Because there are always fluctuations in the supply of components and the processing times, it is not always possible to make full use of the capacity available. It is therefore not sensible to assume that the resources will be utilized to their full capacity. To illustrate this, examine a process with 80% capacity. When $\lambda=50$, WoPed predicts that the minimum number of sensors for Finance is 1.11, Production 3.74, Bonded 2.71, Free 2.15. In this way the deployment of activities is calculated with process modelling and simulation. One can make similar calculations by means of value-nets (special kind of Petri nets), using another simulation software called Pacioli (Griffioen et al. 2018; Griffioen et al. 2016).

**Case Study of Manufacturer ABC**

**Problem Investigation**

ABC relies on international supply chains for the manufacturing of electronic equipment. The materials that are necessary for the production of the machinery are purchased both inside and outside the European Union (EU). Products are eventually re-exported outside the EU. Therefore companies with a customs warehouse license, may suspend payment of import duties, until a customs destination is known (UCC 2013). Those goods are called ‘bonded’ goods. Goods purchased within the EU or goods for which duties are already paid are considered ‘free’ goods. Note that all materials are stored in the same physical warehouse, but only the customs status differs. ABC has adopted several information systems to support manufacturing and inventory management (Figure 3): an ERP system SAP/R3, an interfacing system called TibCo and a compliance reporting system called SaF. The logistical and financial records are registered in SAP/R3. The required monthly declarations for Customs cannot directly be created from SAP/R3, due to the fact it does not maintain the customs status of the goods. Therefore, customs relevant data are processed from SAP/R3 to SaF. Based on SAP transaction codes, SaF is able to recognize the customs relevant transaction codes using a correlation table. Upon receiving goods from suppliers, SaF recognizes whether the goods are free or bonded and process them differently.

![Figure 3. Overview of Information Systems and Data Flow in ABC for Customs Declaration](http://www.processmining.org/ and http://www.promtools.org/doku.php)

In practice, some records are entered manually into information systems at working sites, specifically when the production orders are being implemented. In this circumstance, manual mistakes could be made. ABC regularly implements stock reconciliation procedures between information systems. However, large inventory differences underlying SAP/R3 and SaF are repeatedly discovered from 2013 until 2017.

**Conformance Checking**

ProM is an extensible software that supports a wide variety of process mining techniques in the form of plug-ins$. Using ProM 6.7 we analyzed ABC’s 88538 records of monthly declarations to customs in 2012, and 41706 signals from the compliance reporting system. To discover root causes of the reconciliation mismatch, we analysed two production work orders 9910 and 9900 (number anonymized) in 2016, obtained from the Department of Production Planning at ABC. The resulting product of 9910 is issued to production in 9900. To compare the transaction code diagram of the production process in Figure 1 with

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the logs recording the instances of the work order, pre-processing is needed on the logs of 9910 and 9900 to differentiate movement types involving different materials.

We found that 305 material types were issued to the production in work order 9910. Three of them were reversed back to inventory, however, the storage locations were different from what were recorded in the corresponding 261 movements. The storage locations are related to the bonded or free goods status in the customs warehouse. If an error happens here, then a mistake can happen for customs reporting. For example, the material AM ISOLATOR with item value €1,474,53 was issued to production twice and reversed only once. Suppose the two materials are from different origins for classification of bonded or free, it is possible that the wrong material was reversed with movement 262. This shows how misplacement faults regarding the compliance status of goods can happen, as bonded and free goods are mixed in the warehouse.

As Figure 1 shows, MIGO-262 is used when a production order needs partial quantity reversal. However, sometimes the fault of using MIGO-101 happens. Some employees confuse the use of code 262 and 101, or they cannot distinguish whether these materials are received for cancellation reversal or production order. Typing 262 as a reversal movement into the system will close the production order, but they use 101 to receive goods instead. This may cause unnecessary duties repeatedly levied on the same goods, because 101 acts as an intermediate message, and another duty levy process may start again automatically.

In addition, there are lots of reversal movements 262 without the corresponding goods issue to production 261 in 9900. These deviations are not allowed in the Petri net model of Figure 1. The effects of these deviations on inventory management and customs compliance can be significant. Since duties are automatically calculated based on quantities of taxable goods in declarations generated by SaF, the inventory differences in status will lead to errors in the computation of customs duties to be paid.

The simple case is to reverse a movement once, however, the reversal movement can also be reversed. Suppose that is called the second reversal. Even the reversed reversal movement can be reversed as the third reversal, which lead to the propagation of faults. A single misused movement will not only affect the status of this single material, but will propagate into the chain through the work order.

![Figure 1](image1.png)

**Figure 4. An Illustrative Example of Machine Manufacturing**

As for assigning customs status, there could be faults when taking bonded goods as priority to save duties, or vice versa taking free goods as priority to save extra customs procedures. We illustrate the 'greedy' policy of assigning bonded goods as priority to save duties in Figure 4. Suppose materials A, B and C are free goods while C’ are bonded materials of type C. The final product of one machine needs components F and G. The intermediate product F needs components D and E, while component D needs materials A, B, C, and component E needs B, C. Suppose producing E only requires 4 pieces of C, but 8 pieces are issued. The remaining 4 pieces are returned to stock. The 'greedy' policy is to assign bonded goods as long as they can't be distinguished from each other. Then the 4 returned bonded pieces will appear in information systems to be reissued to production of D. However, when 2 pieces of D are produced, one must continue in inward processing ('bonded'), the other could go into free circulation if the customer is within EU. In this case the bonded stock is subtracted by 8 pieces of C', but that should be 4 instead.

The need for flexible manufacturing processes makes interfacing different information systems difficult to accomplish. Therefore monitoring the customs status of every single piece of material is currently not achievable. In addition, there could be changes in customs status during production. Customs status is assigned only after the product is ready for the customers, for instance not made to order but as an
intermediate product for sales. As we can see in Figure 4, if the customer of the intermediate product D is outside of EU, then it is accepted that D consists of bonded goods. When the customer is within EU, D will first have to be imported and duties paid, so it can be labelled as free goods.

**Data Requirements and Controls**

Further analysis of the root causes of inventory differences can be categorized as four main reasons: (1) Current ERP systems do not have strict controls on the issue of reversals. (2) Time lag and low frequency of reconciliation checks. (3) For composed goods, customs status is only assigned to the finished product after production, and not to semi-finished products during production. (4) Server performance problems of the interfacing system and long queues of messages occur, leading to inventory status differences. Our solutions can be categorized under three design principles, that govern the design of information systems for compliance monitoring in the manufacturing domain.

Firstly, the feasible control method is to enrich the data requirements for recording transactions in ERP. Every goods movement types with corresponding customs status should be recorded in log files. A production order should not only define which material is to be processed, at which location, at what time and how much work is required. It should also define which resources are to be used and how the order costs are to be settled, especially regarding compliance status. In the ABC case the compliance status refers to the customs status of each material items, but this can be generalized to other legal conditions (e.g. approved or not). As soon as a planned order or other request is generated from material requirements planning, the information is passed onto shop floor control. The order-relevant data including compliance status is also added to ensure complete order processing.

Secondly, the assignment of customs status to components should be done on individual item level and monitored continuously during processing. A control measure is that master data is recorded and can be extracted whenever possible to determine customs status. Therefore, keeping track of customs status at item level is more achievable if one information system is used, without interfacing systems for compliance reports. The master data of goods origin, destination and related tax information (e.g. duty rate) are key attributes to determine customs status. Even though they are irrelevant for production process directly, they should be included in the database design as additional data requirements.

Thirdly, an alternative solution is to place Internet of Things (IoT) or RFID sensors (Xu et al. 2014) at each physical transition, in the Petri net model for fault mitigation (Figure 2). This will avoid physical relocation problems in the warehouse. Regarding the issue of reversal movement types, strict controls should be placed in information systems. For example, the data attributes on location, quantity and value of reversals should be the same with original goods issued. Furthermore, the deployment results in a situation in which we can differentiate between 'easy' and 'difficult' cases. It also shows relations between organization functions with customs compliance management capabilities as we calculated the minimum number of sensors for Finance is 1.11, Production 3.74. We can calculate the results under other conditions with the actual probabilities and operational data in ABC. In particular regarding manufacturing, customs status should be tracked throughout production process. The assignment of customs status to components should be done on item level and customs status should be monitored during processing.

**Conclusion**

This research aims to support manufacturing businesses like ABC for continuous monitoring of compliance. Through tracing abnormal movement sequence patterns, deviations can be distinguished. Ideally the results of this research could be applied in ERP and compliance reporting systems, as an active fault detection and mitigation module. Once the system detects abnormal transaction codes, it can generate alerts, and suggest a recommendation of possible ways to prevent or correct the faults immediately to the relevant managers. This corresponds to one of the main advantages of continuous monitoring and continuous auditing (Singh and Best 2015), namely, that faults can be detected and possibly corrected in real time. If deviations can be found early on, it is more likely and easier to correct them in order to eliminate or minimize their negative impacts.
To this end, we analyze transaction codes based on process modelling with simulation, and propose a systematic approach with design principles in information systems that allow:

1. identifying different deviation scenarios related to trade and compliance;
2. checking whether processes are in place and functioning as intended;
3. assessing the impact of transaction codes misusage in compliance monitoring;
4. providing recommendations about internal controls and risk mitigation mechanisms.

The case study defines a compliance problem in manufacturing, specifically for customs warehouse licenses, and provides some insights to improve regulatory compliance management. The results correspond to our theoretical modelling and simulation to control compliance risks for continuous auditing. The case also shows relationships between different organization departments in a company on resource allocations that have customs compliance management capabilities and responsibilities.

The geographic boundary of the case study is currently limited, using EU regulations as illustration. However, the item-level tracking production model can be generalized based on specific regulations and data availability for other cases. The customs case focuses on the compliance status of goods in inventory. Tracing customs status (bonded or free) can be generalized to tracing any kind of Boolean condition of goods, that is related to legal conditions in a manufacturing process. For example, for safety regulations we could trace whether products are from a ‘certified’ source or from an ‘untested’ source. Similar issues arise for provenance of goods in the supply chain. For instance, under US law (Dodd-Frank Act, art. 1502) manufacturers have to demonstrate that they do not use products that contain minerals from war zones (i.e. conflict minerals).

In the data collection for the case study, there is a possibility of bias when it comes to subjective judgement, both from the perspective of the interviewee as well as the interviewer. To reduce this risk, we combined data from various sources: company representatives, customs administration, information system providers, freight forwarders. Compared to our simplified models, the real cases are always more complicated and several issues may overlap. In terms of different companies, different contract agreements, and different products, the sequence of some process steps might have to change. But we expect that in the majority of cases, the method is applicable. Therefore, further research could consider these differences and generalize processes for a more specific industry or product.

This research also lacks alternative companies as cases in the sample. We chose one representative company to illustrate the application of analyzing transaction codes for compliance monitoring in manufacturing. Although major production activities and faults regarding compliance are included and discussed, whether the approach could be scalable needs further research.

Scientifically, this research will contribute to 1) enterprise systems configuration by proposing internal control measures based on IoT fault detection sensors; 2) continuous monitoring and auditing framework for compliance. This research develops design principles for continuous monitoring and auditing compliance by analyzing transaction codes. Using Petri nets as an analytic tool, we analyzed the transaction codes of a non-trivial manufacturing case. The analysis suggests, that in case of compliance problems and reconciliation mismatches, there are three design principles that can be applied: (1) enrich the data requirements for ERP systems, (2) if possible, introduce item-level tracking and tracing of compliance status, and (3) introduce IoT or RFID sensors at physical transitions. The design principles for compliance monitoring mitigate the risks of faults at the root by eliminating the sources of the introduction and the propagation of faults. The three principles focus on more detailed data requirements about products or goods in inventory, as manufacturing is operated using inventory.

Another practical contribution of this work is to support reduction of compliance checking costs and extra human labor involved. In ABC’s 2014 internal controls report, it is calculated that the annual amount of import duties which would have to be saved is 11.3 million with no reconciliation mismatch. Therefore, implementing our approach is financially beneficial for companies.

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