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TOWARDS SMART MANUFACTURING: COMPLIANCE MONITORING FOR COMPUTATIONAL AUDITING

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Research paper

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Abstract

Manufacturers operating in international markets are faced with complex rules and regulations that must be complied with in order to trade successfully. A general phenomenon among international enterprises is that, when they are conducting business across borders, their internal information systems fail to interface well with systems or platforms built specially for compliance reports. This leads to inventory mismatch and results in other types of problems, such as delay of goods delivery or incorrect duty payment. One of the main difficulties in fully integrating information systems arises from the highly flexible and volatile nature of manufacturing processes, which would need highly customizable and adaptive information systems. Currently, there is a lack of systematic method to monitor compliance within flexible multinational manufacturing processes and supply chains. Moreover, improper operations could hamper compliance even normal business processes. In order to have well integrated systems as well as timely detection and mitigation of compliance faults, data processing tools are needed to identify and diagnose inconsistencies in manufacturing and inventory management. This research aims to innovate accounting information systems by designing a framework with the application of process mining and engineering techniques in computational auditing. An in-depth case study is conducted for research validation.

Keywords: Auditing, Business process, Compliance, Fault detection.

1 Introduction

Companies, especially manufacturers, are operating in increasing demands of variability and customizability nowadays. Meanwhile, international companies usually have complex supply chains in which some materials are purchased in one region but assembled or manufactured in another region, and eventually shipped and sold in other regions. To trace which materials end up in a finished product and to optimize costs allocation, sophisticated software tools are necessary. Smart manufacturers take advantage of advanced information and manufacturing technologies to enable flexibility in physical processes. However, they are faced with supply chain disruptions that threaten business, as well as a multitude of complex rules and regulations that must be complied with, such as Harmonized System classification, Authorized Economic Operator certificate, General Agreement on Tariffs and Trade principle (WCO, 2011). Currently, existing information systems are far from being reliable and efficient for compliance monitoring in the service-oriented manufacturing ecosystem. Areas that need new support include reference architecture, supply chain integration and data transfer, etc. (Lu, 2016)

Computational audit approaches make it possible to provide assurance over the reliability of a data stream at or near real time (Vasarhelyi et al., 2004), e.g. online auditing (Koch, 1981, Vasarhelyi and Halper, 1991), continuous control monitoring (Alles et al., 2006) or continuous auditing (Kogan et al., 1999, Kuhn and Sutton, 2010). Auditors can be external and rely on evidence prepared by the company, hence reliability is ensured by internal controls. According to a survey conducted by Chiu et al. (2014), most research papers on continuous auditing are either conceptual, or focus on the technical aspects. The governance aspects are largely left unexplored. Moreover, most reported literature are positioned in the financial sector, other application domains have not been explored.

One of the main difficulties for computational auditing is integration of information systems, which arises from the highly flexible and volatile nature of supply chains and manufacturing processes. Additionally, human mistakes in manufacturing and inventory management could hamper business processes. Currently, there is a lack of systematic method to integrate information systems as well as humans for compliance within flexible multinational manufacturing processes and supply chains. Failure to interface well with different information systems, e.g. governance, risk and compliance (GRC) systems, is still a general phenomenon among enterprises (Buede and Miller, 2016), resulting in different aspects of errors, i.e. faults. These issues raise the main research question addressed in this work:

How can compliance faults in manufacturing and supply chains be discovered in information systems, and how can root causes be diagnosed automatically?

To address this question, this research aims to devise methods for *(i)* the detection and mitigation of compliance faults in manufacturing and *(ii)* the elicitation of production configuration to facilitate tracking compliance status of materials throughout manufacturing and supply chains. Practically, both companies and government authorities may benefit from our descriptive and prescriptive analytics, for both operational gains and audit purposes, respectively. Theoretically, our control strategies developed at the executional level facilitates mitigation of risks of compliance faults at root causes. Furthermore, the taxonomy of compliance faults that we propose, opens possibilities of applying more advanced data processing techniques to the auditing field.

In this research, a combination of research methodologies is applied. The general framework is design science; the aim is to design a *framework*. The framework is validated by case study results and empirical data. The information systems research is either developing theories or building artefacts. The developments of appropriately evaluated methods or instantiations that extend and improve the existing foundations in the design-science knowledge base are important contributions.

Firstly, desk research is used to study relevant scientific literature, regulations, software user guides and internal control reports from organizations. Secondly, process mining is a useful tool when business processes support and control software systems. The general research of process mining includes process discovery, conformance checking, performance analysis, process prediction and process improvement (van der Aalst et al., 2007). We use conformance checking techniques specifically for analysing empirical data to detect faults/deviations. Thirdly, to investigate distinct phenomena characterized by a lack of detailed preliminary research, one intensive case study is adopted. This is to formulate hypotheses that can be tested, while with a specific research environment that limits the choice of methodology. In the case study, several actors are identified during interviews from May 2015 to May 2017, including different departments inside company ABC (anonymized from a world leading manufacturer in electronic equipment), Customs Administration of the Netherlands, third party logistics (3PL), information system providers, suppliers and customers.

2 Theoretical Foundations and Applications

2.1 Compliance and auditing system in manufacturing and supply chains

Main compliance objectives are ensuring correctness, ensuring continuity of business and administration, even creating reputation (Essig et al., 2013). Compliance management not only includes financial reporting compliance (e.g. Sarbanes-Oxley Act), industry specific regulation (e.g. ISO 9000), but also internal policies with documentations, workflows, controls and associated risks.

IT solutions, such as ERP systems and GRC tools provide features for tracking origins or destination attributes of items in their data file to ensure supply chain compliance. There are many standardized information systems to enhance visibility, digitize documentations and automate declaration processes for supply chain management (Shaul and Tauber, 2013). However, the problem of compatibility for integration between systems is still prominent, which triggers massive manual efforts, redundancy and errors. 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. Standards, such as XBRL (Debreceny et al., 2009) and DLT (Distributed Ledger Technologies) could mitigate the problems of compatibility for information integration. Control algorithms, for example model predictive control for decision making in manufacturing and supply chains, are crucial for the design of adequate human-computer interfaces following usability guidelines (Wang and Rivera, 2008).

IS compliance ensures data quality for information exchange and audit purpose (Bonazzi et al., 2010). 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. This has the disadvantage that, in principle, the company could manipulate the code. 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). Security measures should ensure confidentiality (for corporate sensitive data), integrity (that real data is being monitored; data cannot be manipulated) and availability (24/7) of the data streams. 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, Christiaanse and Hulstijn, 2013).

Smart manufacturing has been used increasingly to reference a general advanced manufacturing theme about next-generation business and operational practices with the wide adoption of advanced sensing, control, modelling, and platform technologies (Lu, 2016). In a smart operation, autonomous and intelligent machine behaviours—including reasoning, planning, and self-correction—are key, but information resulting from these behaviours must flow up and down the pyramid. This integration from machine to plant to enterprise systems is vital and critically depends upon compliance, and with the inter-organizational need it extends to supply chain level as well.

2.2 A generic fault taxonomy for computational auditing

Different aspects of faults are analogous to different error classes in the accounting literature (Lea et al., 1992). In the engineering field, fault detection, isolation and reconfiguration (FDIR) is a mature control methodology that ensures continual safe or acceptable operation of a system (Isermann, 1984). Applying fault taxonomy from FDIR (Hwang et al., 2010), compliance faults for computational auditing can be categorized into three corresponding types. We present the dynamics of compliance faults with manufacturing systems in Figure 1 and some examples in Table 1.

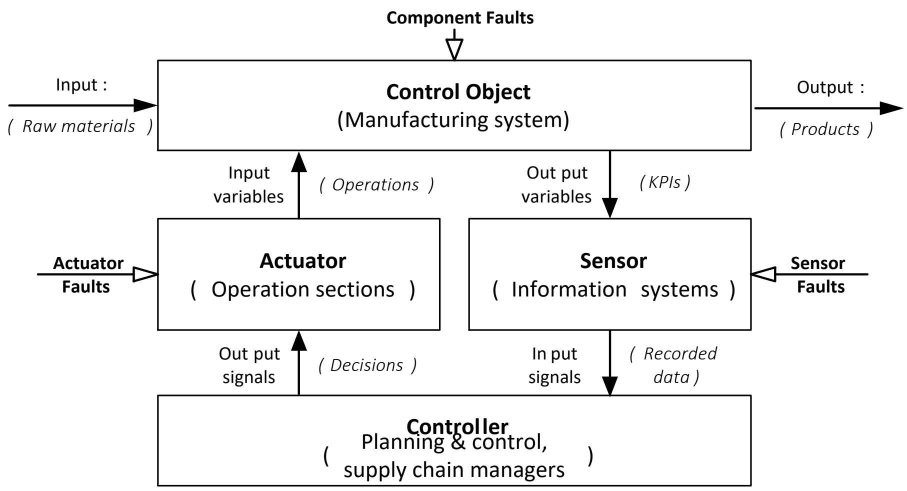

Figure 1. Manufacturing system dynamics with compliance faults from engineering perspective. Managers act as controller and decide how the actuator should operate. The control object is the manufacturing system with output recorded by information systems. Recorded data is transmitted back to managers and fulfils the feedback loop.

Sensor faults are unreliable measurement in monitoring, which may be under-reporting of audit evidence. Evidence is generated under control of the party being audited, which may have legitimate or illegitimate reasons for manipulation. Therefore, the auditor expects that certain internal control measures are built into the organizations, procedures and systems (COSO, 1992). The quality of audit evidence is crucial and it involves both *relevance* and *reliability* (Christiaanse et al., 2015). In IT audit the typical key criteria for reliability are *correctness* and *completeness* of data. Therefore, it needs observability, i.e. research on the minimal number of sources (sensors) to monitor a compliance process.

Once audit evidence is in place to report on the state of a process, the next issue is the ability to affect or actuate the system in order to move the process from the current state to a desired state, i.e. to remove faults and improve processes. Thus, actuation is another intrinsic element in control problems. **Actuator faults** can be seen as human-driven faults in business processes, which in manufacturing and supply chains could be altering shipping documentations, inter-company manipulations, etc.

Thirdly, **component faults** could be faults in logistics and manufacturing or even the whole supply chain system. This requires knowledge of the balance between inputs and outputs in the whole system. Auditing not only deals with financial flow, but also goods flow and underlying information flow.

Fault Taxonomy	Examples of Compliance Faults
Sensor fault	Under-reporting reserves for obsolete inventory, especially in industries where products are constantly being updated or have a short shelf life
	Undetected data transmission errors
	Changing between reporting methods e.g. average costing, last invoice price, LIFO, FIFO
	Inadequate documents and records
Actuator fault	Manipulating unit of measurement to inflate value
	Recording false sales of goods
	False write-offs as damaged or scrap due to lack of adequate supervision
Component fault	System failure due to malware attacks
	Software errors, server failure or equipment malfunctions

Table 1. Compliance fault examples with the taxonomy for computational auditing.

With this taxonomy, fault detection techniques from engineering could be applied in the manufacturing and supply chain systems for compliance. When comparing the role of regulatory authorities with the role of supply chain and manufacturing managers regarding internal controls, we can see that they both use information systems as a *sensor*, and humans as *actuator*. However, there is a fundamental difference. Supply chain managers need to increase efficiency of the production process as well as upstream and downstream supply chain when they receive fault messages, whereas regulatory authorities will interrupt the flow of goods, decreasing efficiency of the supply chain process. Therefore, reducing audit interruptions requires decreasing *sensor faults*, which means to increase accuracy of reporting and internal controls in information systems.

3 Research Design: A Production Configuration-based Framework for Compliance Monitoring

In this research, we propose a framework to assist manufacturing companies and regulatory authorities with computational auditing, based on a fault taxonomy. An overview of the system design is presented in Figure 2, with the innovations colour highlighted. First, unlike current ERP systems (Romney and Steinbart, 2015), we propose a data processing system with conformance checking, based on the main artefacts used for compliance monitoring, namely *process model*, *movement type diagram* and *production configuration*. The *process model* provides an understanding of the internal processes of the organization. The *process model* is used to define a *movement type diagram* encoding all the sequences of movement types that are allowed by the organization's information systems. The *production configuration* provides a representation of the blueprint annotated with information on the compliance status of the materials used to build a designated product. The *movement type diagram* is then used in combination with conformance checking techniques to analyse movement logs to detect possible deviations/faults. Second, database of production configuration is stored instead of Bill of Materials (BOM) only. This artefact is used to understand the criticality of the identified fault scenarios. Third, current ERP systems cannot generate adequate compliance reports. Our system design supports compliance reports automation after appropriate fault mitigation methods as internal controls placing accordingly.

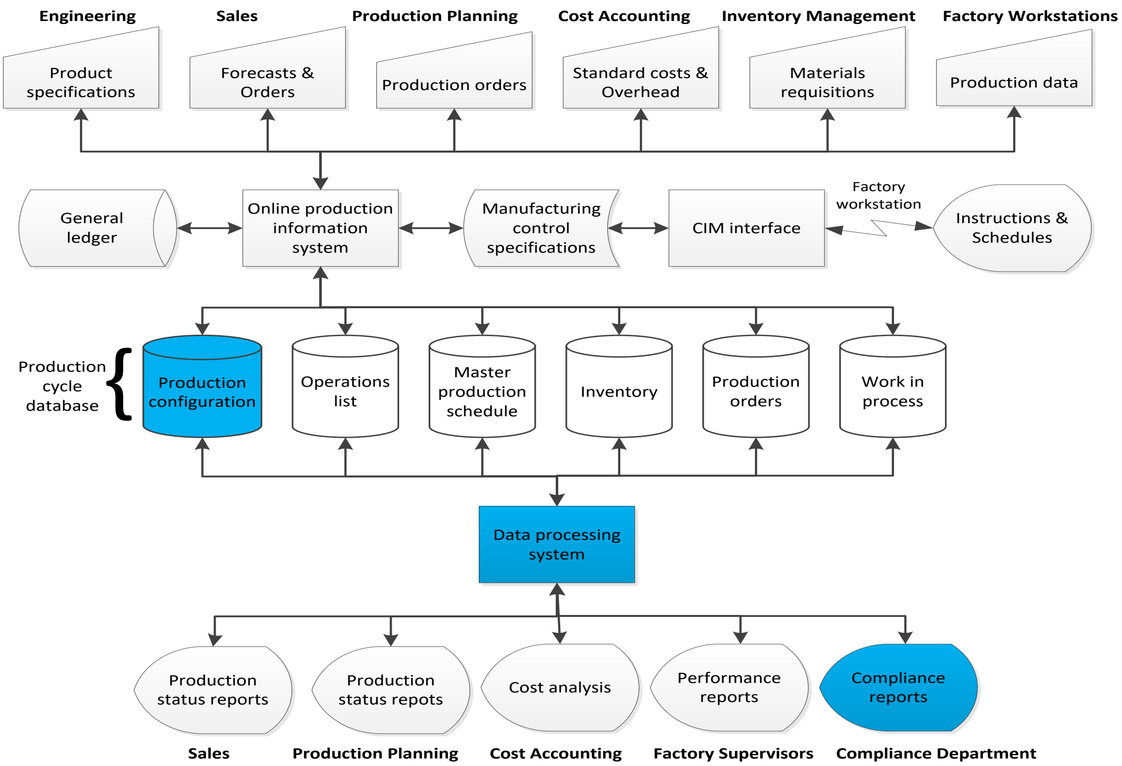

Figure 2. Overview of system design, adapted from Figure 14 in Romney and Steinbart (2015).

3.1 Process model

Business process models are typically used by companies to represent the activities and procedures needed to achieve their business goals. In this research, process models are used to capture various organization's internal processes encompassing the manufacturing process and compliance recording process (e.g., movements in/out warehouse, changes in compliance status of materials).

A *process model* represents the business functions (so called *activities*) and processes of an organization. To ensure the understanding by stakeholders with different skill levels, several notations have been proposed for process modelling: informal (e.g. natural language) for general public; semi-formal (e.g. BPMN) which requires some training; formal (e.g. Petri-Nets) which is hard to master but allows advanced analysis. In this work, we adopt Business Process Modelling Notation (BPMN) as the graphical representation for the specification of business processes. Being widely used in industry, BPMN provides a common language to meet user requirements for improving processes and the IT specification for system connections, business rules and data architecture (White and Miers, 2008).

Figure 3 shows the production process typically performed and compliant to SAP requirements using BPMN. The process starts with a work order defining which materials are to be processed, at which location, at what time and how much work is required. As soon as the work order and other requests are generated, the order is passed on to the employees for goods issue. The order-relevant data is also added to ensure complete order processing. After receiving materials needed for production, manufacturing processing starts. Meanwhile, goods issued can be cancelled due to different reasons during production. Unused materials or tools that are not needed will be reversed back in stock. Malfunctioning materials are returned to the supplier or a request for repair is created. Here we assume that the work order is for a product D, which may consist of separate sub-work orders. Each order requires several materials for production and employees need to pick them from stock.

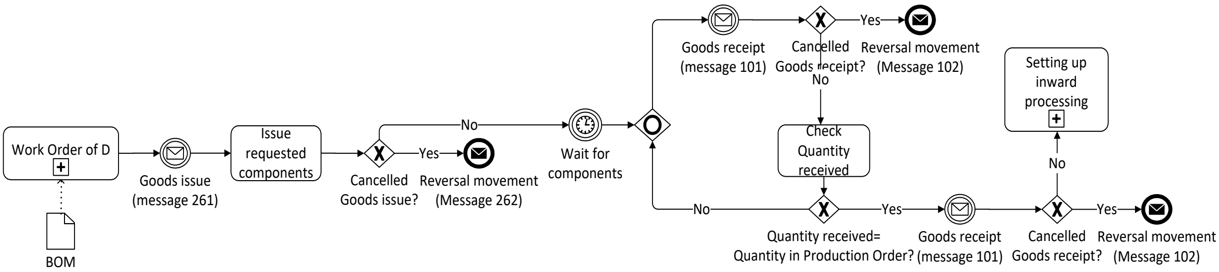

Figure 3. Process model representing the production of product D using BPMN.

3.2 Movement type diagram

Business processes within an enterprise are executed on the basis of orders, e.g. purchase orders, work orders. In SAP, work orders constitute a fundamental part of Production Planning and Control (PP). PP is fully integrated in the Logistics module (LO) and has interfaces to Sales and Distribution (SD), Materials Management (MM) and Controlling (CO). Goods movements are recorded in MM and are typically associated with movement types in the information systems to associate with orders.

Production typically requires several components that have to be retrieved from various warehouses. Moreover, components might be transformed and aggregated to other components before they can be used to build the final product. Thus, large amount of goods movements may be necessary to complete a work order. To complete a production process, predefined sequences of movement types are expected to be executed. To capture such sequences, we introduce the notion of *movement type diagram*. This diagram is used in conformance checking to identify possible faults for computational auditing.

In particular, classes of goods movements are distinguished using a three-digit key which is called movement type. Each type of material movement is given a unique movement type, i.e., only one movement type is allowed per transaction. Movement types are used to control adjustment of inventory and for financial purposes as well. Intuitively, a *movement type diagram* represents the sequences of movement types (associated to goods movements) allowed by the system for the manufacturing of a designated product. We model movement type diagrams as Petri nets, which provides a formal semantics that can be exploited for automated analysis. A 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.

Figure 4 presents the movement type diagram in the form of Petri net regarding the process model in Figure 3. The normal sequence of movement types should follow certain patterns denoted by black arrows in Figure 4. These patterns start with a work order and with movement type 261 in SAP (meaning "Goods issue for a work order") followed by parallel movements and loops. When some goods issued are cancelled, the production process regarding these related materials should always be reversed back in stock by a reversal movement, i.e. issue movement type+1. The production of a certain product can require various subcomponents. Assume that product D consists of three subcomponents, namely E, F and G. To differentiate movement types involving different components, we label transitions in the movement type diagram with both the *movement type* and the *material type*. Accordingly, label "261E" denotes a movement type 261 for material E.

A *movement type diagram* can be derived from the activities and control-flow of the business process i.e. the ideal execution of business process, not based on factual data about it. In particular, the transitions in the movement type diagram correspond to movement types in the business process, whereas the control-flow of the process model governs the control-flow of movement type diagram.

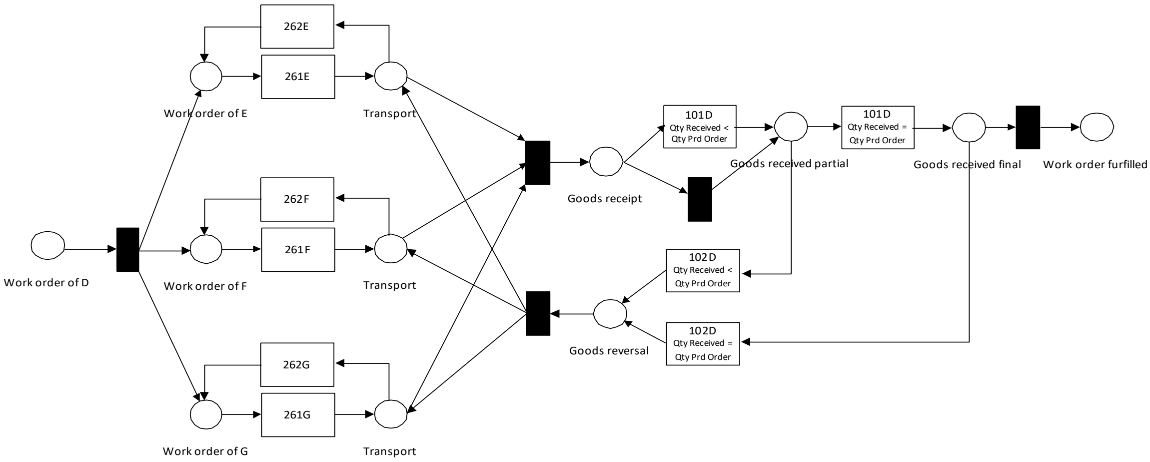

Figure 4. An example of movement type diagram regarding the production process of D.

3.3 Production configuration

A work order specifies the materials needed to be transferred in order to build a product based on the *production configuration* developed either at runtime or predefined. Based on the work order, reservations should be generated for the materials held in stock. The goal of the *production configuration* is to provide a more comprehensive view of the production process compared to the BOM. In particular, the production configuration augment the BOM with information on the compliance status of materials. This allows discovering and reasoning on the value of the final product in financial terms. Compliance status is critical both for inventory management of the company and regulatory supervision. For example, the amount of duties and taxes a company needs to pay differs significantly based on customs status of goods crossing the border. Errors in inventory management can result in excessive duties to be paid or in fines when the due duties are not paid.

To keep track of all materials used in the production and understand the related financial value, the *production configuration* should include: 1) details regarding every picking and reversal of goods movement including subassemblies that reflect the manufacturing process; 2) contain all materials and tools (mechanical, electrical, software etc.) required to build the product, and related compliance status of individual item-level material; 3) not only represent the physical product, but including packaging and related documentations; 4) disclose the related financial information of every materials used or produced including human labour hours involved.

Production configuration is an artefact that relates to both the ERP system and compliance management system, i.e. given the blueprint from ERP systems and the amount of materials stored in each compartment from compliance management system, it represents all possible combinations of materials considering their compliance status to build the product. We present the example in Section 4.5.

3.4 Conformance checking

Ideally, the material flow underling the production process complies with the behaviour as prescribed in the movement type diagram. However, reality can diverge from the prescribed behaviour. This may be the case when an execution order is not explicitly enforced by the information system. It is also possible that people deliberately work around the system. Deviations from the prescribed behaviour can have significant consequences with respect to compliance. Thus, it is desirable for organizations to identify such deviations as early as possible to be able to take necessary measures.

In this research, conformance checking techniques are applied for the detection of faults in goods movements. Conformance checking provides a promising means to systematically analyse event logs recorded by information systems (Jans et al., 2013). The literature distinguishes two event data types:

historic data refers to complete event logs from the past, while current data represents ongoing processes typically used to perform operational support. An *event log* can be seen as a collection of *cases*. A *case* can be seen as a *trace*/sequence of *events*. Specifically, conformance checking provides auditors a more extensive way for understanding the state of the control environment than the procedures on which organization rely nowadays by detecting inconsistencies (Rozinat and van der Aalst, 2008).

To check the conformance of a recorded sequence of movement types with the movement type diagram, we use *alignments* (Aalst et al., 2012). Alignments provide a robust approach to conformance checking by allowing the detection and analysis of nonconformity between the observed and prescribed behaviour. In particular, alignments are able to pinpoint deviations that have caused nonconformity. For example, the instance of work order D can be represented by trace $\sigma_L =< 261E, 262E, 261E, 262E, 101E, 101D >$. We present two possible alignments between this trace and the movement type diagram in Figure 4:

$$\gamma_1 = \frac{|261E|262E|261E|262E| \gg |101E|101D|}{|261E|262E|261E|262E|261E|101E|101D|} \qquad \gamma_2 = \frac{|261E|262E|261E|\ 262E|101E|101D|}{|261E|262E|261E| \gg |101E|101D|}$$

The top row of the alignments shows the sequence of movement types in the log and the bottom row shows the sequence in the petri net model. Deviations are shown by columns that contain symbol ≫. For example, the second column in γ_2 shows that a movement type occurs in the trace although it is not allowed according to petri net, i.e. a move in log. The third column in γ_1 shows that a movement type should have occurred in the trace according to the petri net model, but it is absent in the trace, i.e. a move in model. Note that γ_1 and $\gamma_2$provide possible explanation of what could have happened.

3.5 Internal controls on inventory and goods movement

Inventory and goods are assets of an enterprise. Overstated assets comprised 51% the cases of financial fraud statements (COSO, 2004). Misstatements of inventory comprised the majority of asset valuation frauds. For example, an overvaluation of ending inventory will understate cost of goods sold and therefore overstate net income. The higher the value of the inventory, the more the company will be able to finance with higher net income. Inflating inventory value achieves the same impact as manipulating the physical count of goods movement. Improper goods movement include certain types of actuator faults: physical removal of the goods from the location with manipulation of the records in information systems, e.g. creating false journal entries, false write offs or other credits to inventory, delay the write-down of obsolete inventory.

To mitigate these actuator faults and ensure adequate security, controls are necessary to include independent reconciliation of records and separation of incompatible functions such as purchasing and writing off. All write offs and disposals in information systems should be monitored. All entries should be referenced to a purchase, sale or other record, and periodic checks should be performed.

4 Case Study: Reconciliation Mismatch in Manufacturing

4.1 Research methodology and data collection

ABC (anonymized from a world leading manufacturer in electronic equipment) employs several information systems to support manufacturing and supply chain management and ultimately the generation of audit files. Firstly, desk research is used to study customs regulations, software user guides and internal control reports from ABC. Secondly, we analysed ABC's 88538 records of the 2012 customs declarations and 41706 signals from ABC's compliance management system. In addition, stock data of 7496 material types in the last two quarters of 2013 is used for problem investigation. And data of two production work orders is used for conformance checking. Lastly, several interviews and onsite visits are performed from May 2015 to May 2017, therefore this research is validated by ABC, Customs Administration of the Netherlands, third party logistics (3PL) and information system providers.

4.2 Problem investigation – Sensor fault

Figure 5 illustrates an ERP system provided by SAP, a compliance management system called SaF and TibCo as the interfacing system. Logistical and financial records are registered in SAP/R3. Due to the high flexibility of the manufacturing process as well as lack of customs compliance requirements in SAP, it does not contain information about the manufacturing's production configuration related to compliance status of goods movement. The output messages from SAP are in a so called 'idoc' format. This format is not at valid format for SaF and not accepted by SaF. To solve this TibCo converts these 'idoc' messages into 'xml' messages, which are valid for SaF.

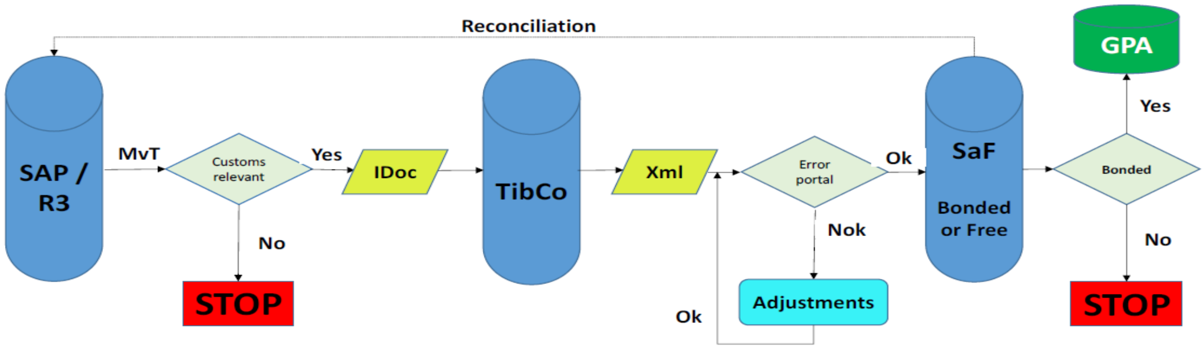

Figure 5. Overview of information systems and data flow in ABC for customs declaration (Customs Administration of the Netherlands, 2017).

Overall only the customs relevant data are processed from SAP to SaF. Based on a SAP movement type, SaF is able to recognize customs transaction codes using a correlation table. With this table SaF is able to recognize inbound, production, outbound, surplus of goods, etc. Goods that are in the country, but have not been formally imported and hence exempted from payment of import duties are stored in the bonded warehouse. These goods are called *bonded goods*. Goods for which import duties have been paid (called *free goods*) are stored in the free warehouse.

Every quarter ABC reconciles inventory between SAP and SaF. During this action the stock of all the products and materials in SAP and in SaF are compared at begin and end of quarter, as well as the documents sent from SAP and the received documents in SaF. The internal control of reconciliation checks in ABC has shown that there are large stock differences between the SaF stock and the SAP stock. This has prompted the manager of Department Trade and Customs to initiate further analysis of the causes. Their analysis has revealed that stock differences are most likely relate to the partially finished goods waiting for completion and eventual sale or the value of these items, i.e. Work in Process.

The inventory differences are not only large in value but also in the percentage as of material types. As they are reporting discrepancies in information systems, these mismatches are sensor faults according to Section 2.2. Follow-up investigations conclude that these sensor faults are still prominent until now.

4.3 Conformance checking with empirical data – Actuator fault

To discover root causes of reconciliation mismatch, we analysed two production work orders 9910 and 9900 (number anonymized) in 2016 from Department Production Planning. The resulting product of 9910 is issued to production in 9900. Consider the movement type diagram regarding the production of product D in Figure 4 and the log recording the instance of work order. Pre-processing the logs of 9910 and 9900 is needed to differentiate movement types involving different materials.

To this end, we characterize a goods movement using both *movement type* and *material type* (represented by E, F, G in Figure 4). Another issue is dealing with the quantities of materials required to assemble a product. To this end, when instantiating a movement type diagram for a specific work order, we duplicate the (sub)processes for each material with respect to its quantity as defined in the work order. Similarly, the movement types in the log are duplicated based on the quantity of the material. Specifically, the log entry is replaced with a number of copies of the entry equal to the amount of materials. This transformation has the advantage that we can use a simpler representation of Petri net for which several tools are available for conformance checking, e.g. Disco, ProM.

We found that 305 material types were issued to production in 9910. Three of them were reversed back to inventory, however, the storage locations were different from their corresponding 261 movements. The storage locations are related to the bonded/free zone in the customs warehouse. If a fault happens here, then a mistake can happen for GPA. For example, the material AM ISOLATOR with item value 14742,53€ was issued to production twice and reversed back 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 262. Therefore, instead of producing correct declarations, misplacement faults regarding compliance status of goods happen with bonded and free goods mixed in the warehouse.

In addition, there are lots of reversal movements 262 without corresponding goods issue to production 261 in 9900. These deviations are not allowed in the petri net model of Figure 4. The effects of these deviations on inventory management and customs compliance can be significant. Since duties payable are automatically calculated based on quantities of taxable goods in declarations generated by SaF, the inventory differences of taxable goods will lead to errors in the computation of customs duties to be paid by ABC. Suppose an employee has omitted recording movement type 261 for goods issue of E in SAP. The inventory of E would stay the same in SAP, however, it should be subtracted by one item according to the movement type diagram. Depending on the customs status of the goods received after production, this discrepancy in the inventory can affect the duties due by a company for the product.

The simple case is to reverse 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 fault. The consequence of a single misused movement will not only affect this single material, but into the chain through the work order.

Therefore, after conformance checking with empirical data, we conclude that actuator faults on misplacement of goods are hidden in the sensor faults of inventory mismatches. What lies behind these faults are component faults regarding information system design. Below we list the root causes of ICT.

4.4 Root causes of ICT – Component fault

As we discussed in the previous section, no record is kept if the reversed material is bonded or free as of customs status in SAP. With more reversals in production the probability of faults increases. To reduce potential fault propagation, reversals must be exactly the same on quantity and value as previous movement. However, current ERP systems do not have strict controls on this issue as reversals in information systems can have different reasons such as correction plus in inventory, transport material of a module into the cleanroom and some internal orders.

In addition, this reconciliation mismatch can be caused by problems in the selection of customs relevant movements in the interface between SAP and TibCo. In particular, goods movements that are not selected, whereas they should have been selected, and hence they are not forwarded via TibCo to SaF. The main causes for this selection problem are *(i)* software design errors in the interface *(ii)* programmed incapable to detect human errors. For example, an employee used movement type 262 which is different from the designed use of reversal, and this code is not identified by SAP as customs relevant. Therefore this goods movement is not forwarded via TibCo to SaF.

Thirdly, this mismatch can be caused by the recording time lag. Sometimes a goods movement is entered by SaF in the electronic customs declaration for period month n and the consumption of the goods in production is recorded by SaF in the next period month $n+1$. In SAP the movements of goods are recorded real time, i.e. continuously during the production (which can take several months, hence over different reporting periods). In SaF all the customs relevant movements are recorded only after production of a finished product has ended.

Fourthly, there could be software problems in SaF, which is programmed and maintained by an external party. And they could make wrong changes in the software or changes that are not compatible with SAP, so that the whole flow does not work correctly.

Last but not least, regularly there are server problems with TibCo and long queues of messages occur. When the server is then re-started it often happens that part of the queue is lost, and then those messages disappear, and hence are missed in SaF.

4.5 Fault mitigation with internal controls

The ideal solution is to use IT for item-level tracking of all goods at individual material level. ABC is already using at limited scale bar code scanning RFID, and in future it could be extended to Internet of Things. If this IT solution follows every movement of every material from warehouse to manufacturing to final product that is shipped out, then one can check reconciliation between SAP and SaF at individual item level, including the bonded or free customs status of this item.

Figure 6 shows an example of item-level tracking production configuration of product D in ERP systems. Goods storage can be divided into two compartments virtually from the perspective of customs status: a Free Warehouse and a Bonded Warehouse. Product D requires assembling different types of materials, e.g. A, B and C. To differentiate the origins/sources and storing locations/warehouses of the materials required, these materials are further divided into six classes as illustrated in the left part of Figure 5. More specifically, A and C are labelled unique materials from EU and non-EU suppliers respectively. The fundamental difference between $C_{non\text{-}EU,Bonded}$ and $C_{non\text{-}EU,Free}$ lies in their target customers. Materials $C_{non\text{-}EU,Bonded}$ are labelled to non-EU customers, while materials $C_{nonEU,Free}$ will be delivered to EU customers after levying all the necessary duties. Therefore, their data is labelled with different compartments and related picking activities can result in a transformation of their customs status. While for replaceable materials B, there are three classes: $B_{EU,Free}$, $B_{non\text{-}EU,Bonded}$ and $B_{non\text{-}EU,Free}$. Materials B are usually standard materials from either EU or non-EU suppliers. However, their storage locations are different. The customs status of bounded material ($B_{non\text{-}EU,Bonded}$) can be changed into free, thus resulting in material $B_{non\text{-}EU,Free,}$ and delivered to EU customers after levying all the duties.

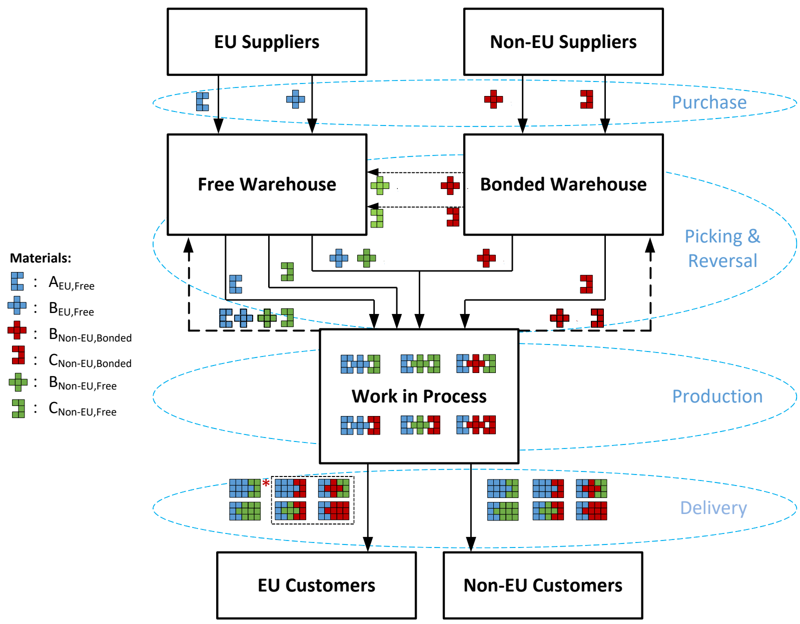

Figure 6. An illustrative example of item-level tracking production configuration.

The arrows in Figure 6 indicate data flows on the change of customs status with corresponding material flows. The whole data flow regarding production of a product D can be associated to four sub-processes: Purchase, Picking & Reversal, Production, and Delivery. More specifically, the Purchase process includes data from suppliers and event logs of inbound process such as unloading cargo from trucks to warehouse entrance and storing them at preassigned locations. The Picking & Reversal process involves data flow between virtual warehouses and Work in Process. When a work order is carried out, labelled materials are issued 261 in SAP, deducted from corresponding inventory and added to Work in Process. Figure 6 shows six possible combinations of assembling product D during production. Leftovers or cancelled goods are returned back to corresponding inventory. Finally, the assembled or processed materials are delivered to customers, either in the EU or in other countries. This has an impact on the duties that have to be paid. In particular, the configurations marked with red asterisk indicate the ones for which duties should be paid because of non-EU materials used.

Alternatively, add functionality of SAP as Figure 2 shows such that it simulates item level tracking in ERP by keeping a unique record of each individual material with a unique ID number (and add customs status *bonded* or *free* as attribute to this ID) throughout the whole process of warehousing, manufacturing and outbound logistics. Ideally integrate the full customs reporting process completely in SAP. In this way TibCo and SaF are no longer needed, and all the potential problems that can occur with these two extra systems can be avoided.

To reduce actuator faults that employees use wrong movement types, restrict the use of movement types that employees can use, for example by authorizing them only to use a limited number of movement types that are relevant for their own activities.

To reduce sensor faults in information systems, the following should be specifically monitored: 1) unusual or suspicious shipping, receiving documents or purchase orders; 2) inventory that does not appear to have been used for some time or stored in unusual locations; 3) unclear (or ineffective) cut-off procedures or inclusions in inventory already sold; 4) material reversing entries to the inventory account without goods issued; 5) improper sales that are reversed and included in inventory but not received yet (for example a company delivers a specifics product to a customer but tells the customer it was a mistake and requests the customer to send the product back); 6) excessive inter-company movement with little or no related documentation.

To prevent component faults, two types of internal controls are necessary for computational audit: 1) the items comprising inventory and their life cycles should be clearly justified; 2) reduce server problems with additional tools and send alerts to the systems manager.

In general, to reduce the errors due to server problems and detect any deviations from movement types diagram, add data processing system with conformance checking as Figure 2 shows. To graphically illustrate fault mitigation with internal controls, we present Figure 7 based on change management procedures from ABC. If there are missed messages due to server problems or deviation detected, the information is noticed and then sends an alert about incident management to the systems manager.

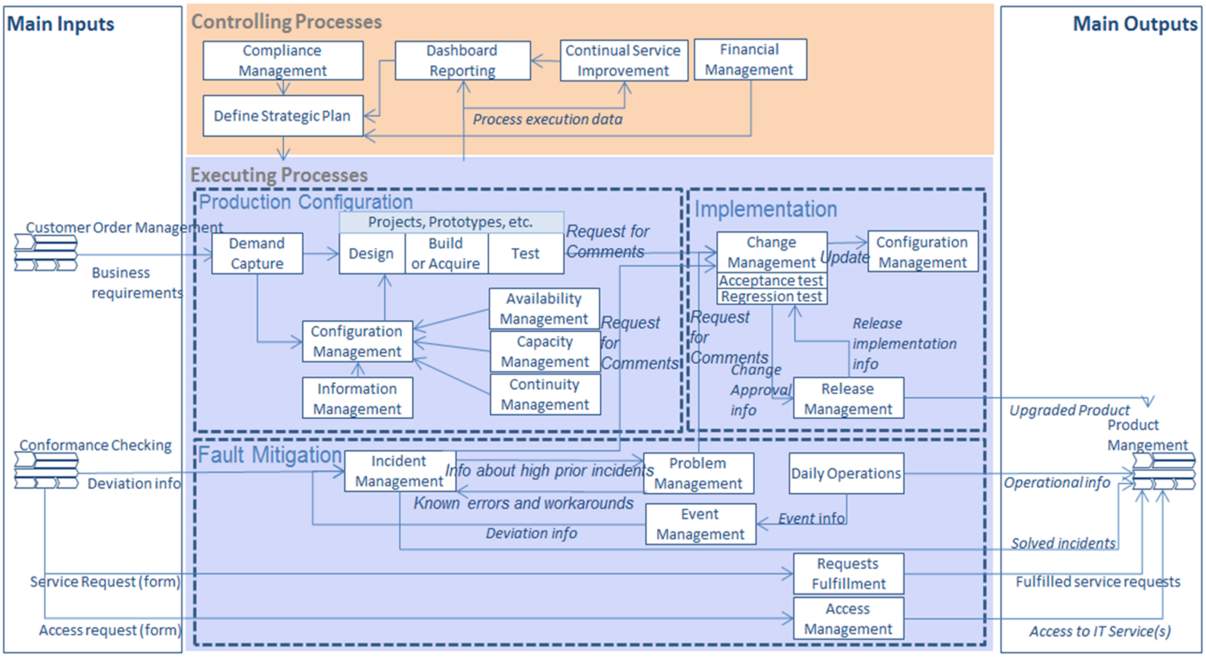

Figure 7. Overview of inputs/outputs for fault mitigation with internal controlling and executing

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 clearing of reconciliation errors. The ideal scenario of implementing our proposal is to timely detect and reduce reconciliation mismatches in such way that is financially beneficial for companies. Furthermore, labor-saving can be achieved with automated fault detection replacing manual controls.

5 Conclusions

The framework developed in this research contributes to computational auditing and enterprise systems design by innovating deployment of IS controls with fault detection and diagnosis. Information in business processes is produced and transformed at the executional activity level. Activities are the potential sources of both the introduction and propagation of fault (Bai et al., 2012). Control strategies developed at the executional level should be able to mitigate the risks of fault at the root causes by eliminating the sources of the introduction and propagation of fault. Companies will be able to detect and hence limit their compliance faults in order to substantiate their claims for reduced inspections from regulatory authorities. Meanwhile, this research supports reduction of trade related costs and extra human labour involved on inspections.

In addition, the proposed taxonomy and dynamics of compliance faults contribute to smart manufacturing and its international supply chain control framework. Using fault detection and diagnosis techniques from engineering, stakeholders and policy makers will be guided with scientific approaches that provide optimal compliance requirements to achieve an acceptable level of security in smart manufacturing and its international supply chains. More technical details are left for future research.

Compliance is a very localized issue that falls under the direct jurisdiction of regulation at the national, principality, and even locality level. Therefore, the geographic boundary of the case study is currently limited using EU regulations as illustrations. However, the item-level tracking production configuration can be generalized based on specific regulations and data availability of different cases.

Overall, compliance fault has not received enough attention from academia and organizations globally. For instance, companies outsource their declaration issues to customs brokers. As long as their customs brokers are reliable, they are facing less problems of compliance fault for now. However, the scope of compliance is very broad. It requires concepts from several domains and rigorous theoretical foundations to accomplish fault detection and diagnosis in manufacturing and related supply chains. Our framework combining methods from engineering is theoretically innovative in IS compliance and control. Practically, our control strategies also facilitate risk management approaches in smart manufacturing and provides insights both for businesses and governmental authorities.

References

Aalst, W. v. d., Adriansyah, A. and Dongen, B. v. (2012). "Replaying history on process models for conformance checking and performance analysis." *Wiley Int. Rev. Data Min. and Knowl. Disc.,* 2**,** 182-192.

Alles, M., Brennan, G., Kogan, A. and Vasarhelyi, M. A. (2006). "Continuous monitoring of business process controls: A pilot implementation of a continuous auditing system at Siemens." *International Journal of Accounting Information Systems,* 7**,** 137-161.

Bai, X., Nunez, M. and Kalagnanam, J. R. (2012). "Managing Data Quality Risk in Accounting Information Systems. ." *Information Systems Research,* 23**,** 453-473.

Bonazzi, R., Hussami, L. and Pigneur, Y. (Year) Published. "Compliance Management is Becoming a Major Issue in IS Design." Information Systems: People, Organizations, Institutions, and Technologies, 2010 Berlin. Springer, 391-398.

Buede, D. M. and Miller, W. D. (2016). *The Engineering Design of Systems: Models and Methods*, Wiley.

Chan, D. Y. and Vasarhelyi, M. A. (2011). "Innovation and practice of continuous auditing." *International Journal of Accounting Information Systems,* 12**,** 152–160.

Chiu, V., Liu, Q. and Vasarhelyi, M. A. (2014). "The development and intellectual structure of continuous auditing research." *Journal of Accounting Literature,* 33**,** 37–57.

Christiaanse, R., Griffioen, P. and Hulstijn, J. (2015). "Reliability of Electronic Evidence: an application for model-based auditing." *Proceedings of the 15th International Conference on Artificial Intelligence and Law -- San Diego, June 8-12, 2015.*

Christiaanse, R. and Hulstijn, J. (2013). "Control Automation to reduce Costs of Control." *International Journal of Information System Modeling and Design,* 4**,** 27 - 47.

COSO (1992). "Internal Control - Integrated Framework." Committee of Sponsoring Organizations of the Treadway Commission.

COSO (2004). "Enterprise Risk Management -- Integrated Framework." Committee of Sponsoring Organizations of the Treadway Commission.

Debreceny, R., Felden, C., Ochocki, B. and Piechocki, M. (2009). *XBRL for Interactive Data: Engineering the Information Value Chain,* Berlin, Springer.

Essig, M., Hülsmann, M., Kern, E.-M. and Klein-Schmeink, S. (2013). *Supply Chain Safety Management*, Springer.

Hwang, I., Kim, S., Kim, Y. and Seah, C. E. (2010). "A Survey of Fault Detection, Isolation, and Reconfiguration Methods." *IEEE Transactions on Control Systems Technology,* 18.

Isermann, R. (1984). "Process fault detection based on modeling and estima- tion methods: A survey." *Automatica*.

Jans, M., Alles, M. and Vasarhelyi, M. (2013). "The case for process mining in auditing: Sources of value added and areas of application." *International Journal of Accounting Information Systems*.

Koch, H. S. (1981). "Online Computer Auditing through Continuous and Intermittent Simulation." *MIS Quarterly,* 5**,** 29 - 41.

Kogan, A., Sudit, E. F. and Vasarhelyi, M. (1999). "Continuous online auditing: a program of research." *Journal of Information Systems,* 13**,** 87-103.

Kuhn, J. R. and Sutton, S. G. (2010). "Continuous Auditing in ERP System Environments: The Current State and Future Directions " *Journal of Information Systems* 24**,** 91–111.

Lea, R. B., Adams, S. J., Boykin, R. F. and Smieliauskas, W. (1992). "Modeling of the audit risk assessment process at the assertion level within an account balance." *Auditing: J. Practice Theory,* 11(Supplement)**,** 152–179.

Lu, Y. (2016). "Current Standards Landscape for Smart Manufacturing Systems." *In:* National Institute of Standards and Technology, U. S. D. o. C. (ed.).

Romney, M. B. and Steinbart, P. J. (2015). *Accounting Information Systems, 13e*, Prentice Hall, NJ.

Rozinat, A. and van der Aalst, W. M. P. (2008). "Conformance checking of processes based on monitoring real behavior." *Information Systems,* 33**,** 64-95.

Shaul, L. and Tauber, D. (2013). "Critical Success Factors in Enterprise Resource Planning Systems: Review of the Last Decade." *ACM Computing Surveys* 45.
van der Aalst, W. M., Reijers, H. A., Weijters, A. J., van Dongen, B. F., De Medeiros, A. A. and Song, M. (2007). "Business process mining: An industrial application." *Information Systems* 32**,** 713-732.
Vasarhelyi, M. A., Alles, M. and Kogan, A. (2004). "Principles of analytic monitoring for continuous assurance." *Journal of Emerging Technologies in Accounting,* 1**,** 1-21.
Vasarhelyi, M. A. and Halper, F. B. (1991). "The Continuous Audit of Online Systems." *Auditing: A Journal of Practice and Theory,* 10**,** 110-125.
Wang, W. and Rivera, D. E. (2008). "A model predic- tive control algorithm for tactical decision-making in semiconductor manufacturing supply chain management." *IEEE Transactions on Control Systems Technology*.
WCO. 2011. *SAFE Framework of Standards to Secure and Facilitate Global Trade* [Online].
White, S. A. and Miers, D. (2008). *BPMN Modeling and Reference Guide: Understanding and Using BPMN*, Future Strategies Inc., Lighthouse Pt, FL.