Data Quality Assurance in International Supply Chains: An Application of the Value Cycle Approach

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Abstract. With increasing international trade and growing emphasis on security and efficiency, enhanced information and data sharing between different stakeholders in global supply chains is required. Currently data quality is not only problematic for traders, but also for various government agencies involved in border control, such as customs authorities and border force. We adapt principles from value cycle modelling in accounting, and show how these principles enabled by ICT can be extended to supply chain management to ensure quality of data reported to customs. We then describe a typical application scenario based on a real but anonymsed case to show that value cycle monitoring can be applied (feasibility), and if applied, what the expected benefits are (usefulness).

Keywords: Data quality, auditing, assurance, information sharing, supply chain

1 Introduction

Currently, data about shipments available in international supply chains does not provide a timely and accurate description of the goods [1]. For customs authorities, the low quality of data in reporting has proved to be a big problem, e.g. the explosion at the sea vessel MSC Flaminia, where authorities discovered that 605 of the data elements about the cargo in the containers were not accurate. Stakeholders involved have different data formats and communication channels. Also, redundancy and post processing are common problems in measures of control. For example, import declarations and bills of lading about goods are often made several days after the vessels have left the port of origin. Suppose companies in transport logistics and supply chains would be able to improve data quality, then customs can rely on business controls of enterprises, and at least for fiscal matters, additional inspecting and correcting customs related data afterwards at the port of destination would be unnecessary. Data quality issues often result from other stakeholders, further upstream in the supply chain. Under these circumstances, the so called 'push-left principle'[2] could be a solution: the consequences of deviations that are found in an audit or inspection, are 'pushed left', i.e. upstream in the supply chain to the party that caused them.

How can we identify and develop new value adding services and accounting information systems design principles for enterprise, legislative and the audit profession

community to solve these data quality problems and achieve sustainable collaboration in international supply chains? This involves enhanced cooperation between different stakeholders. Their bonds and connections are enforced by contracts. However, the principal-agent problem cannot be ignored [3]. Moral hazard and adverse selection[1] problems are sometimes inevitable. Therefore, assurance over data quality is needed, in particular for accounting information systems that are used to record such data [4].

Data Quality Management (DQM) entails the establishment and deployment of roles, responsibilities, policies, and procedures concerning the acquisition, maintenance, dissemination, and disposition of data [5]. We identify some specific challenges concerning DQM in international supply chains and provide some solution guidelines based on a case scenario afterwards in this paper.

Firstly, roles and responsibilities of different stakeholders involved needs to be analyzed, from the manufacturer, exporter and forwarder to the warehouse keeper, customs agent, cargo packers, etc. Secondly, cross-organizational boundaries are difficult to delineate. For example, customs import formalities which are formally the responsibility of the importer, are outsourced to his freight forwarder or customs broker. Thirdly, the contractual relationship is often weak and difficult to manage. For example, the importer depends for his import declaration on data about the goods provided to him by the ocean carrier, but this carrier only has a contractual relationship with the freight forwarder of the exporter of the goods in the country of origin. Business processes and data governance processes need to be well integrated. But contracts are often negotiated on price, not on service level. Other challenges, like the allocation of financial and human resources, require more cost and benefit analysis.

How can we ensure quality of data reported to customs with these challenges? Business reality can generally be modelled as a value cycle: an interrelated system of flows of money and goods [6]. The flow of money should mirror the flow of goods, but in reverse. The point of an accounting information system is to accurately and completely capture these two reverse flows using accounts information. Value-cycle models are well established in the owner-ordered audit tradition in the Netherlands that concentrates on financial reporting completeness, in addition to correctness[7]. When applied to data quality management, value-cycle models can prove to be beneficial and this will be illustrated in this paper.

Our goal here is to propose guidelines for designing and developing an information infrastructure and technology-based mechanism in international supply chains, for data quality monitoring. In this paper, data quality needs are assessed and evaluated within the context of organizational strategies, supply chain structure and existing business processes. First, we provide a brief overview of data quality and relevant definitions, as well as the general steps of data quality assurance. We then apply the value cycle approach to DQM in international supply chains. The next section is an application scenario of a real case in the Netherlands. The paper concludes with recommendations and implications on design principles for implementing value cycle (customs) controls in supply chains.

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[1] It refers to a market process in which undesired results occur when buyers and sellers have asymmetric information; the "bad" customers are more likely to apply for the service.

2 Data Quality Assurance and Data Quality Management

2.1 Defining Data Quality

Data quality is conformance to valid requirements. We should first [5] determine who set the requirements, then determine how the requirements are set. After that, determine the degree of conformance that is needed. In international supply chain domain, both the business and customs need to set data quality requirements. IT organizations/departments need to ensure that the business and customs can have accurate reporting data. They are aware of the existing data quality deficiencies, also the possibility and cost of overcoming them. Sometimes, changes in business processes are needed to address data quality problems. These factors must enter decision process.

Operationally, we can first define data quality in terms of data quality parameters and data quality indicators [8]: A **data quality indicator** is a data dimension that provides objective information about the data. Source, creation time, and collection method are examples. A **data quality parameter** is a qualitative or subjective dimension by which a user evaluates data quality. Source credibility and timeliness are examples. The value is directly or indirectly based on underlying quality indicator values. User-defined functions may be used to map quality indicator values to quality parameter values. For example, if the source is a RFID database, an auditor may conclude that data credibility is high. A **data quality requirement** specifies the indicators required to be documented for the data, so that at query time users can retrieve data within some acceptable range of quality indicator values.

2.2 Dimensions of Data Quality Management (DQM) Objectives

Under general accounting settings, data quality should improve from these dimensions[9]: (a) accuracy/correctness (b) completeness (c) timeliness (d) consistency, etc. For information system and IT infrastructure settings, there are more goals of DQM: (a) integrity (b) independency (c) relevance (d) confidentiality, etc.

2.3 General Processes of Data Quality Assurance (DQA)

Data quality assurance is the process of verifying the reliability of data. Protocols and methods must be employed to ensure that data are properly collected, handled, processed, used, and maintained at all stages of the scientific data lifecycle. This is commonly referred to as 'QA/QC' (Quality Assurance/Quality Control). QA focuses on building-in quality to prevent defects while QC focuses on testing for quality (e.g., detecting defects) [10]. To improve data quality, it is necessary to improve the linkage among the various uses of data throughout the system and across all business process:

1. **Data acquisition and identification**: The first step is to identify critical data areas. Normally this is manifest in two areas: (a) the basic business processes and (b) support for decision making about management of these business processes [11].

2. **Data discovery and profiling**: Data profiling is the systematic analysis of data to gather actionable and measurable information about its quality. Data discovery is achieved by executing data profiling and data monitoring tasks, analyzing data and determining the business rules used to populate the data.
3. **Data cleansing and enrichment**: Detect and correct erroneous data and data inconsistencies both within and across systems. Data enrichment involves enhancing existing data, by adding meta-data or changing data from industry standards and business insights to make it more useful downstream.

3 Data Quality Assurance with the Value Cycle Approach

3.1 Data Quality Assurance (DQA) in Supply Chain Management (SCM)

The relation between DQA and SCM is crucial, stakeholders in supply chains depend on each other, therefore information about agreements and situations must be reliable. Supply chains are generally present in enterprises across logistics, retail and other sectors. In these sectors, supply chains are crucial for business operations and SCM has a significant effect on business performance. "Supply Chain Management describes the discipline of optimizing the delivery of goods, services and related information from supplier to customer" [12]. *Enterprise Resource Planning* (ERP) systems are seen as the digital backbone for information in supply chains, especially when the supply chains are integrated over several companies or departments [13]. There are other information systems as well. Therefore, data monitoring and quality control in SCM can be continuous and automated throughout the whole DQA processes.

In SCM, data quality can have strong effects on operations. Consider for instance the bullwhip effect, which is the phenomenon of amplifying demand variability when moving up the supply chain, leading to growing inefficiencies and diminishing revenues [14]. This means that if a certain piece of data in a supply chain is erroneous or uncertain, fluctuations are increasing rapidly along the supply chain. This effect is affected by data quality, as business processes rely on data provided by others. When data cannot be relied on, it is prudential to keep extra stock. The next link in the chain will think likewise, amplifying the effect. When no specific requirements are set for a certain data element in the supply chain, this will not only cause an overall low data quality, but also amplified variances in stock levels along the supply chain.

3.2 Data Quality in Flows of Money and Goods

Supply chains have a big impact on organizations and are represented by the following flows [12]: goods flow as primary processes, information flow as CRUD (Create, Read, Update, Delete) processes, as well as financial flow. How is information flow linked with goods flow and financial flow? By CRUD operations in a database, whenever the status of the goods or money in the actual flow changes, information changes as well. CRUD processes are the four basic processes that can be performed with data in databases and describe the state of the data at a certain point in the pro-

cess [15, 16], e.g. import status changes have to do with the flow of money, as well as the flow of goods through the supply chain. These flows can often be used for cross verification. For establishing proper DQM in supply chains, it is thus required to take into account the goods flow and financial flow. The process of payments depends greatly on data quality, as errors in data can damage the relations with customers.
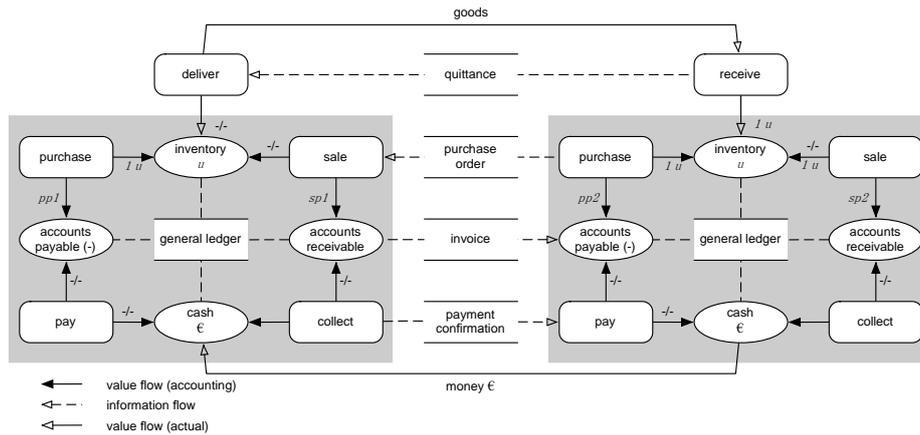
Fig. 1. Value cycle models of two trading companies linked by trade documents [18]

We look at data quality issues from an accounting perspective. Accounting has practices to deal with cross verification, using independent sources of data. One of these practices is to model businesses as a value cycle. Fig.1 shows an example of the value cycle for two trading companies, connected by trade documents (e.g. quittance, invoice, purchase order). We use the following notation. Activities are shown as a rectangle, such as a sales event. Ovals are the recordings of a state of a certain value to the company, such as inventory or accounts payable. States, i.e. accounts, are related through reconciliation relationships, indicated by dashed lines, which come together in the general ledger. The direction of the arrow indicates the influence of events. Arrows generally indicate an increment, while the sign '–/–' indicates a decrement of the corresponding account. Thus, a purchase leads to an increment of the accounts payable, while the purchased goods are added to the inventory. A sale leads to an increment of the accounts receivable and a decrement of the inventory, and so on.

The general idea of value cycle modelling is to use *Reconciliation Relations* to define a mathematically precise model of how the flow of money and goods should be (SOLL), depending on the specific manufacturing inputs and outputs for each type of business, and use it to verify actual audit business samples against (IST) [7]. The mathematical models could be instantiations of the following kinds of equations.

In Fig.1, for all accounts S, T that are affected by an event e: $(S) \leftarrow [e] \rightarrow (T)$, e.g. $(inventory) \leftarrow [sale] \rightarrow (accounts\ receivable)$, we have the following transformation equations, where f is a constant (here *sales price*) that depends on the business model:
$$input(T, e) = f \cdot output(S, e),$$

As we record accounts in specific units of measurement (kg, 22 ft container, \$, mph), we also need conversion equations:

$$T \text{ in unit } u = f \cdot T \text{ in unit } v \text{ [9].}$$

In addition, for all accounts S, we have the following preservation equation:

$$S(t_1) = S(t_0) + input(S, [t_0, t_1]) - output(S, [t_0, t_1]),$$

where for time interval $[t_0, t_1]$, $input(S, [t_0, t_1]) =_{def} Sum(input(S, e), \text{ for } e \text{ in } [t_0, t_1])$

3.3   Applying the Value Cycle Model to Customs Reporting

We need to adjust the value cycle model in three respects for international supply chains. First, add costs components related to goods transport and handling. Second, verify across inter-organizational links. Third, the key approach is finding the right reconciliation relationships that govern the international supply chain domain, in particular, capturing equations related to the flow of physical goods [18].
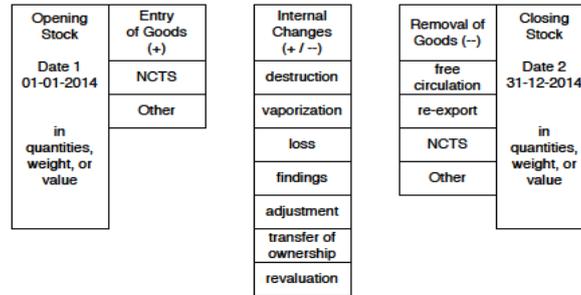

Fig. 2. Conceptual model of the inflow and outflow of a customs warehouse

Here is a specific example of the goods flow in a bonded warehouse. Fig.2 illustrates that the data about goods entering a bonded warehouse[2] should correspond, according to many reconciliation checks, with the data about goods leaving the warehouse, either in transit or for import into free circulation in the EU. Customs have delegated controls over the warehouse to the company. To make sure the warehouse management system is reliable and no goods or documents are missing, they verify this afterwards every month, on the basis of electronic data. This is called 'electronic declaration' or 'audit file'. The so-called 'stock movement declaration' is part of the electronic declaration. The basic principle is that the total in the movement of goods must be balanced, using the following preservation equation, for any period of time:

opening balance(BV)+entries(BI)–debit entries(AF)–closing balance(EV)=0.

From this formula, we can derive more equations for the case of boned warehouse:

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[2]   The bonded warehouse is under responsibility of a company, and used to store their goods under customs supervision, requiring a formal license from customs to operate. Until a customs destination is known, e.g. re-export (transit) or import (free circulation) no import duties are due. (See also https://en.wikipedia.org/wiki/Bonded_warehouse).

opening stock at the beginning of a calendar year+ entry of goods +internal changes=closing stock at the end of same calendar year+ removal of goods; opening stock at the beginning of a calendar year+ entry of goods– destruction– vaporization–loss +findings +adjustment +other=closing stock at the end of same calendar year + goods released for free circulation + re-export + other.

What makes the above equations complicated is the case when several information lines together make up one mutation. For example, three different articles (A, B, C) are packed together into one article (D) (three-in-1 box) according to the rules governing usual forms of handling. In the stock records, the individual articles are registered separately from the articles packed together (different article codes). When the three articles are packed together, this has an effect on the individual stock levels. The stock of the different articles (A, B, C) reduces and the stock of the article packed together (D) increases. This therefore involves 4 transactions: 3 minus-transactions and 1 plus-transaction. These information lines are linked to each other by including the same mutation number of each information line in the declaration system.

4 Application Scenario

4.1 Data collection

Data for this application scenario description was collected from relatively open interviews with experts in trade, customs legislation, customs audit and companies. The materials from these interviews are supplemented with public sources about customs legislation and inspection policies.

4.2 Scenario Description

ABC is a Dutch company manufacturing machines for international market. Many components in manufacturing are produced abroad. Some of these parts are built into appliances and re-exported within or outside the EU. Other parts are re-exported directly. In the last case, no customs import duties are required. For these reasons, some warehouses at ABC operate as a Bonded Warehouse. Under this license it is allowed to store components from foreign origin, of which payment of import or export duties has been suspended, for an indefinite period until a customs destination is known: entering into the EU (free circulation), or re-exporting outside the EU (transit). In order to obtain and keep the license, ABC must allow regular audits and inspections from the Dutch customs. These involve IT audits of the administrative systems of the warehouse, physical security measures and occasionally inspections to find out if the inventory in the bonded warehouse corresponds to the reported goods.

We are interested in the requirements on ABC's inventory management and information systems. The most important requirement is that customs authorities should be able to rely on ABC's administration. It should be impossible to lose track of the stored goods (accurate and complete recording), to lose goods from the warehouse

(physical security), or to assign the wrong customs destination (procedures). Errors that have a negative impact on accuracy or completeness of reporting data directly affect these key objectives. Data quality is crucial in two capacities:

1. Data quality is part of the requirements that follow from the Customs Warehouse license. It is therefore a key characteristic that must be audited regularly. Both the company and the auditors of the customs office therefore develop policies and procedures for assessing reliability of the company's record keeping.
2. In the audit itself, audit evidence is used and produced by the party being audited, so its reliability is not immediately guaranteed. Therefore, also to improve data quality for its own purposes, the company must build in certain additional precautions into the business processes, procedures and information systems to ensure reliability: so-called internal controls, e.g. segregation of duties; master data management; limited reading and writing access rights; access control measures; logging and monitoring; baseline security. Many controls are implemented using IT systems, hence, IT audit is necessary. These controls also need to be audited.

4.3 Issue

As part of the regular audits, both customs and the internal control department of ABC have now identified a number of weaknesses in the internal controls. Initial analysis has revealed that many errors can be attributed to the crucial process of 'reception', when goods are entered into the warehouse. At this point, ABC can still ensure that records of the goods match with the actual contents, on aspects like order numbers, container numbers, price, origin, goods description and bar-codes. Once goods have entered into the warehouse, it is much harder to trace errors and mistakes. For this reason, ABC has temporarily implemented a number of manual checks regarding the reception of goods. These controls are meant to detect and immediately correct deviations between shipping documents, such as the purchase order, invoice, customs declaration, the actual goods being received at the warehouse, etc.

What complicates the issue is that the bonded warehouse, usually consists of many physical warehouses also contains goods that are not under customs supervision.

Another complication is that at some of these premises, the reception process is not carried out by ABC itself, but has been outsourced to logistics service providers. So, ABC is dependent on logistics providers to carry out these checks adequately.

4.4 Solution Analysis

ABC has identified risks of overall processes, from general IT control, setting up purchase order and production order to sales. Also using controls in their ERP system and prescribing the right sequence of procedures in ERP, ABC sets up controls based on risks. The risk matrix ABC identified is updated on a regular basis. Experts from ABC jointly with the customs made the following steps to produce the risk matrix:

1. Identify for each individual movement type in ABC's ERP whether it is customs relevant or not. Not customs related means end of data flow, so if the goods are mistakenly categorized, it should trigger a control response in the system.
2. ABC implements for each identified customs relevant movement type a specific internal control to mitigate that risk.
3. These internal controls are built in ABC's ERP system. Financial flows rely on logistics flows and are fully automated in ERP.
4. ABC arranges regular IT audits to ensure these controls are working well in ERP.

The monthly declarations of ABC for customs are made using *Automated Periodic Reporting* (GPA), which is generated by a special information system. The EU has a special system *New Customs Transit System* (NCTS) for the reporting of so-called transit goods; i.e. goods that have entered the EU via a specific country, but have not yet been formally imported, and hence, for which no import duties have been paid yet. NCTS requires a manual step to enter the transit status of goods, and then returns a specific *Movement Reference Number* (MRN), which can be used as proof that these goods have the transit status. MRN is essential for ABC to generate an accurate GPA about goods. This manual reporting is done by the freight forwarder FF that has arranged the transport of their goods into the Netherlands.

We propose a systematic approach to improve internal controls, based on general risk management approaches (e.g. COSO ERM). First, identify remaining deficiencies in data quality; these may indicate risks related to customs compliance. Second, find the underlying root cause of these deficiencies. In many cases, the cause will be with another party, on whose data the organization depends. Try to fix deficiencies by improving information systems, processes or even conditions in the contract with other parties. Third, evaluate the remaining compliance risks. If they are unacceptable then repeat the procedure. This approach is called 'push-left' principle [2], because it aims to push any remaining control deficiencies left in the supply chain.

How can we measure the residual risks in a manageable level and indeed 'push left'? Process control in data processing is the underlying basis for data quality. If there is a gap in that process, this could mean goods are disappearing in this case. Only after being fully in control of the data processing can we go to the next level to see if the data is correct. If data at the next level is wrong, it might have financial impact but this can be fixed afterwards. Process control is on top of data quality problem, and is more about optimizing the physical goods' movement. From GPA to the risk matrix, assume which fields are mapped and covered by standard procedures, and then scope into a customs related risk matrix. After that we can delve into data quality. The suggested process controls for data quality assurance (DQA) are as follows:

1. ***Acquire and record data from various sources with segregation of duties***.

Get data from different sources with adequate controls. Segregation of duties before data collection is a precondition for DQA at the source company. Despite internal controls, third parties who manage the information should also be unbiased.

Value cycle monitoring, as represented in Fig.1, can play a crucial role in the analysis of the segregation of duties. The key auditing question from a customs point of view is how ABC can assure the accuracy of reporting data. This is an issue, because

of the chain dependency of ABC on FF in providing relevant data. Also due to the manual processing of the transit status of goods transported by FF to the bonded warehouse of ABC, mistakes can happen. We will now explain how the model in Fig.1 can be applied to analyze this auditing problem.

First, these transit status reports of FF can be viewed as an information service provided by FF to ABC. Actually this information service is just one activity in a broader portfolio of information services called customs brokerage, which are typically provided by FF and customs brokers.

The second observation is the chain perspective. The key assumption of the model is that data accuracy can be improved by using the countervailing interests between the different parties in a value network. In this case the value network consists of a simple chain of two parties: FF and ABC. FF has a different interest than ABC, because, although FF offers the transit status report as a commercial service to ABC, it does not directly affect FF's own business interest if they made a mistake. But the accuracy of these data is of direct interest for ABC, because they need to be compliant to customs, and if the report of ABC were not correct, there would be risks of being fined by customs. Therefore ABC added extra controls in ERP to double check whether the transit status reports that they receive from FF are accurate, accuracy of these data improve the accuracy of ABC's reporting to customs.

Thirdly, from a customs auditing point of view this chain can be viewed as a typical example of segregation of duties, as is depicted in Fig.1, which enhances data accuracy. Another party, namely ABC is double-checking FF who is producing the transit status reports; the whole chain receives a positive audit assessment, because of the built-in segregation of duties between FF and ABC for this data validation.

2. *Validate data at the source against predefined data quality requirements.*

Evaluate those manual checks, set more explicit data requirements in the contract with the vendor. The 'Push left principle' requires more responsibility from the vendor.

Develop automated services for validating data records at the source. A strategic implementation enables the rules and validation mechanisms to be shared across applications and deployed at various organizations' information flow for continuous data inspection. These processes usually result in a variety of reporting schemes, e.g. flagging, documenting and subsequent checking of suspect records. Validation checks may also involve checking for compliance against applicable standards, rules, and conventions. A key stage in data validation and cleaning is to identify the root causes of the errors detected and to focus on preventing those errors from re-occurring [18].

3. *Set up unified standards, data formats and communication channels.*

All data providers need to agree on a communications protocol and the data format, to standardize data. For example, automated checks are performed during the sending of the GPA to customs. The format of data required for filing is a unified standard, and should be the same tracing back to the source manufacturers. The consequence of lack of IT and data interoperability across all stakeholders in a supply chain is that the process halts and the declarant is not informed.

*4. **Build an information infrastructure to share data between stakeholders. Create a data pipeline with built-in controls, allowing more real-time collaborations.***

After negotiating with different parties involved, dedicate IT resources to build the information infrastructure and share data between all parties in the international supply chain. Transport conventions, systems, procedures and data in the Logistics Layer dominate the management of the supply chain. But the data relating to the goods to be bought, sold and moved needs to be known in the Transaction Layer to ensure the order is properly met and paid for. If that information was clarified and verified at the point of consignment completion and captured in a data system running parallel to the Logistics Layer then many of the risks associated with poor data would be reduced [11]. This means for reports about goods entry into the bonded warehouse, collect data via the data pipeline from the actual packing list of the consolidator that actually 'packed the box' with goods in the country of origin.

For automated monitoring and sufficient build-in controls, an application platform should include much more than a traditional server operating system does, e.g. a modern cloud platform could provide capabilities such as data synchronization, identity and entitlement management, and process orchestration[3]. The platform should also provide access to new technologies and ideas of enterprise computing.

*5. **Check reconciliation relationships and build feedback systems to better monitor.***

With the help of normative or prescriptive equations in Section 3.2, deviations in the actual flows of money and goods can be identified based on actual measurements of the variables during operations. The checks could be on the net weight, number of units and money value using the equations we illustrated in section 3.3. Re-valuation and transfer of ownership also need to be carefully checked with details.

Meanwhile, create automated feedback loop with human capital investment. If one data user (either internal or external) detects a data defect, he can create a flag in the system and the defect will be automated sent to the source for reviewing.

5   Conclusions

How can we get quality data with multiple standards, formats and communication channels in international supply chains? How can the value cycle approach contribute to data quality management for customs reporting? To what extent can we reduce the redundant manual checks and costs of control in data quality management?

In this paper we tried to answer these questions by introducing an approach that builds on value chain modelling from a chain perspective to application in international supply chains. This approach, specifically for data quality assurance in customs reporting, is based on segregation of duties and developing verification equations that can be used to verify data quality across the whole supply chain.

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[3]   See more on www.thesupplychaincloud.com and www.opengroup.org: Cloud Computing Open Standards, *the Supply Chain Cloud Report.*

We illustrate the approach by a case scenario of a manufacturing company. It shows that the steps of data quality assurance we proposed can be implemented and if successfully would be beneficial for different stakeholders. If the goods information generated by the vendor, at the starting point of the supply chain, is accurate and complete, those manual checks by parties at the other end of the supply chain would be unnecessary. This is only part of the research, and we leave the development of analytical detection models from reconciliation relationships for further research. Nevertheless, we believe that if information sharing could be improved this way, data quality in international supply chains could also be improved and regulatory compliance risks would be reduced, resulting in operational benefit as well.

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