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Developing a Framework for Traceability Implementation in the Textile Supply Chain

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Abstract: Traceability has recently gained considerable attention in the textile industry. Traceability stands for information sharing about a product including the product history, specification, or location. With the involvement of globally dispersed actors in the textile supply chain, ensuring appropriate product quality with timely supplies is crucial for surviving in this industry with ever increasing competition. Hence it is of paramount importance for a supply chain actor to track every product and trace its history in the supply chain. In this context, this paper presents a framework to implement traceability in the textile supply chain. A system approach has been followed, where firstly the usage requirement of traceability is defined, and then a framework for implementing intra-actor or internal traceability and inter-actor or external traceability is discussed. This article further presents a sequential diagram to demonstrate the interaction and information exchange between the actors in the supply chain, when the traceability information is requested. An example is also illustrated for data storage using a relational database management system and information exchange using XML for the textile weaver. Finally, the article discusses challenges and future studies required to implement traceability in the textile supply chain.

Keywords: supply chain traceability; traceability framework; textile; RDBMS; XML

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1. Introduction

Globalization has played a major role in the relocation and outsourcing of textile manufacturing to destinations where less stringent laws, cheap labor, and the availability of supplies is possible [1–3]. The modern textile supply chain consists of a dispersed network of manufacturing sectors, each having a series of complex operations [1,4]. The outsourcing of manufacturing activities helps the textile and clothing (T&C) retailers/brand owners to reduce risks by not owning any production facilities, therefore keeping the supply chains flexible and encouraging the constant search for quality-conscious and cost-effective producers [5,6]. Flexibility is particularly important regarding today's short-lived fashion, where fashion trends change quickly [7]. However, due to geographical separation and institutional differences between different partners, effective information sharing has become a key issue and inadequate information sharing hampers the flexibility and synchronous functioning of the textile supply chain [7,8]. Information is a value creating entity in the modern textile industry, which relates to transparency, product safety, and supply chain management. For instance, outsourcing enhances the chances for buyers to get better quality at a lower price, but it also has a risk side. The increased reliance on global suppliers, raw material providers, and transporters intensify the need for visibility and the risk associated with regulatory compliance during the production or sourcing phases. For example, the NYU-Stern report on supply chain and sourcing revealed a series of discrepancies related to wages and working records, where the suppliers have fabricated these records for compliance with regulatory or code standards [9]. Subsequently, it has become imperative to brand owners to have full information about their supply chains.

Another important aspect of information relates to product recall and end-user safety. An increasing trend of product recalls has been observed in the European Union (EU) for non-food categories as reported by RAPEX (also known as the Rapid Alert System for dangerous non-food products). Textile and fashion products are reported among top contributors in these recalls and an increasing trend has been observed over the past decade [10]. In 2014, 530 recalls were observed from the clothing, textile, and fashion product category among a total of 2435 recall notifications [11]. To manage the execution of product recalls efficiently, it is important that recall handling agencies have authentic information about product distribution from the brand owner or distributor, which essentially relies on the ability to trace-back the origin of the identified products for recalling [12]. Moreover, regulation addressing these issues, such as materials procurement from conflict zones, requires due diligence to comply with the regulations, such as the implementation of origin assurance on the products [13]. Moreover, European regulations on chemicals including dyes and other reagents used in textile chemical processing has put the responsibility on the industry to manage the risks associated with their imported chemicals; hence it becomes imperative to trace the supplies they import [14].

In the context of information sharing, traceability has emerged as a viable solution for current manufacturing and distribution sectors. Traceability extends the informational boundaries of the supply chain actors beyond their organizational scope which helps in informationally integrating the whole supply chain. Further, traceability assists in communicating the important information, which contributes to the better management of globally dispersed supply chains [15]. Experts suggest implementing traceability to assure product safety and proper recall execution [12]. From the customer side, there is a growing interest in the history of products [16–18]. End users are even willing to pay higher for traceable items [19] and consider traceability as equivalent to certification [20]. For the current practice in clothing retail, the most of traceability information is limited to the country-of-origin—which is conveyed using printed labels. However, according to Henninger [21], these labels are not enough to convey the customer-expected traceability information. Hence the implementation of information exchange based traceability is expected to inevitably emerge in the future for clothing brands.

The focus of this research is to develop a framework to implement traceability, which would support the internal and external traceability for different actors in the textile supply chain. Presently, organizations tend to use Product Lifecycle Management (PLM) and Product Data Management (PDM) to organize the product and/or process specific information locally [8]. However, the lack of explicit semantics and the content of information are major problems towards integrating and exchanging the locally stored information among different partners in the supply chain. In such a scenario of fragmented information where integration may be tough due to technical complexities and organizational issues, interoperability is considered a promising approach [22]. Furthermore, from the implementation perspective, it is imperative to address traceability from the standpoint of data management strategies and related operational techniques, which essentially relies on some kind of framework [23]. Framework provides guidelines to the involved supply chain actors to streamline their operation processes with each other in order to implement and maintain traceability. Therefore, this paper focuses on the framework from the technical aspect of the implementation of traceability and a framework for implementing traceability is discussed which includes planning, gathering, arranging, and exchanging the traceability information in the textile supply chain. According to Bechini et al. [24], "designing and implementation of traceability systems need preliminary investigations to point out problems and solutions at different abstraction levels. The foundation for any possible discussion about the development of this kind of systems is represented by the adoption of a generic data model for traceability". Therefore, this paper follows a generic data model for traceability implementation in the textile supply chain.

In this paper, we follow the methodological framework proposed by Thakur and Hurburgh [23] and Hu el al. [25]—which is based on a systematic approach to implement traceability by using business integration tools including requirement planning, enterprise modeling, and integration. We first define the usage requirements of the traceability model, followed by the development of data gathering and management at an individual actor level. These steps focus on traceability at the intra-actor level—which not only complies with the requirements posed by other supply chain actors but also by regulatory requirements. The purpose of this paper is to propose a generic framework for traceability. Therefore we define the traceability requirements loosely (i.e., not limiting to a specific case) using a use-case diagram and then utilize the IDEF-0 (Integrated Computer-Aided Manufacturing (ICAM) Definition Part 0) model to show its implementation at an actor level. Furthermore, this paper illustrates the integration of the different supply chain actors to exchange the traceability information and realize full supply chain traceability using a Unified Modeling Language (UML) sequential diagram and the eXtensible Markup Language (XML). The contribution of this paper can be seen as a very first step of real traceability implementation, proposing a framework for traceability based upon the supply chain characteristics of the textile industry.

The subsequent part of the paper is organized as follows: Section 2 describes the related work and Section 3 discusses the usage requirement of traceability in the textile industry. Sections 4 and 5 discuss the framework for internal and external traceability, respectively. Section 6 illustrates an example for the management of traceability data. Finally, Section 7 concludes the paper and states the future scope.

2. Related Work

Traceability has gained more attention recently in a variety of industries [2,15,26,27]. According to GS1 system [28], traceability is defined as "the ability to track forward the movement through specified stage(s) of the extended supply chain and trace backward the history, application or location of that which is under consideration". Furthermore, a detailed definition proposed by Moe [29], which is probably one of the frequently used definitions, is given as, "ability to track a product batch and its history through the whole, or part, of a production chain from harvest through transport, storage, processing, distribution and sales (hereafter called chain traceability) or internally in one of the steps in the chain for example the production step (hereafter called internal traceability)". The history of traceability dates back to the 1930s with regards to the origin of high-quality products such as French champagne [13]. Over the decades, institutions have made guidelines for product safety and security which mandate the implementation of traceability in some sectors. Government regulation is a major factor for traceability implementation in sectors including agrifood and medicines. The EU law for food safety mandates companies to record the one step forwards–one step backwards suppliers' information [23]. Hence all the actors involved in the food supply chain act as links for traceability. The textile industry does not have a long history of promoting traceability, however, recently it has become a large concern for the industry [7,16].

Traceability acts as a vital link for sharing information within and between the partners, such as design details, component description, procedures, bill of materials, etc. Therefore, it helps to integrate the supply chain. Traceability brings more transparency in the supply chain by systematically managing the product related information. Moreover, information sharing is an integral part of supply chain management. According to Lam and Postle [7], the supply chain can be defined as, "All the activities involved in delivering a product from raw material through to the customer including [...] and the information systems necessary to monitor all of these activities." Information management and sharing, product tracking, and tracing have been reported in the other definitions of the supply chain as well [30–32]. Information sharing has been seen as a primary requirement for sustainable and effective green supply chain strategy [33–36]. Studies in the past have attempted to determine the effect of information sharing in inventory management [37,38], organizational efficiency [39], and supply chain performance [40,41]. Lam and Poste [7] identified "no information sharing" as a major barrier in the supply chain in the textile and apparel sector in Hong Kong and argued that lack of standardized semantics or a common framework to share information is one of the reasons behind this. A recent study [42] reveals that the poor state of traceability in the textile sector—which enlisted 59 clothing brands or retailers in Australia in the report for their traceability. From the enlisted companies in abovementioned report, it can be concluded that only 61% retailers fully identified their immediate suppliers while only 8% of the retailers knew fully about the fiber suppliers for their products [42]. In fact, traceability is a mutual effort of involved supply chain stakeholders, and regulatory enforcements play an important role by engaging the stakeholders. For example, the food companies in the European Union have regulatory requirements for minimum traceability levels for product safety [43]. As a result, traceability in the food sector is considered one of the most effective implementations [44]. However, the textile industry does not have any formal regulations for traceability, which act as a deterring factor in traceability implementation. Nevertheless, voluntary traceability initiatives are gaining momentum, for example, the Union of the Italian Chambers of Commerce has promoted the adoption of a voluntary traceability system for the entire supply chain which can be applied to a range of manufacturing sectors [2]. Furthermore, the textile supply chain actors have started to realize the potential of traceability [45]. For example, with the involvement of globally spread actors, the quality of the final product largely depends on the supplies. Appropriate product quality with timely availability is necessary for surviving in the ever increasing competition. The textile supply chain consists of multiple actors and the total production lead-time can be as high as 12–24 months, whereas the fashion trend changes almost every season [46]. Any delay in production or quality issues can hamper the brands severely. Hence it is of the utmost importance to have a synchronous production, and the tracking of products and their quality throughout the supply chain [14]. Furthermore, traceability is considered an essential tool for attaining sustainability goals by tracing the raw material through complex supply chains and ensuring good practices throughout the processes [4,13]. A stream of researchers in the past has investigated the use of traceability information in the context of textile industry. Guercini and Runfola [47] studied traceability as a tool for inter-organizational control and as a marketing tool including "made-in" to be used by clothing brands. Traceability as a tool for inter-organizational monitoring and customer safety is further confirmed by Gobbi and Massa [2]. Cheng et al. [48] investigated traceability to control quality and maximize the profit of the textile supply chain. According to Guercini and Runfola [47] addressing traceability involves at least three facets—the information content to be shared, coding of the information and the way it is transferred, and the extent of information access with the other actors in the supply chain. However, studies technically addressing the above mentioned or related facets have gained limited attention. For instance, Alves et al. [14] presented a generic solution to implement traceability with the help of semantic web technology and demonstrated the application in the textile sector. From the implementation perspective, it is imperative to address traceability from the standpoint of data management strategies and related operational techniques, which essentially relies on the standardized framework [24]. However, limited attention is paid to comprehend the abovementioned aspects from the textile supply chain perspectives.

3. Usage Requirement of the Traceability Information in the Textile Supply Chain

Traceability is fundamentally data management about a product. Furthermore, traceability should be helpful in understanding the relationships that exist within and across product lifecycle information, including requirements, design details, component description, product and production specification, process information, and actor information [49]. Traceability information should be reusable at any point when it is necessary. The textile supply chain consists of multiple players, therefore it is important for all of them to understand and exchange the traceability information and use the uniform/standard semantics for information exchange [8,26].

To design a traceability framework, we firstly briefly describe the textile supply chain and then define the usage requirement of traceability.

The textile supply chain is a relatively long and complex network; it involves a number of actors located worldwide and deals with diverse raw materials and processes such as fibre industries, spinning mills, weaving mills, chemical processing industries, apparel manufacturers, and retailers, beside various logistical actors involved in transportation and distribution [50]. Most of the textile supply chains are driven by the retailers or brand owners, who monitor the market demands and place the order for upstream suppliers [46]. A retailer generally does not own any production facilities and acts as a reseller who procures the products from the upstream suppliers and sells them to the customers [46]. Therefore, all the actors excluding the retailer are considered as B2B (business-to-business), whereas the retailer is considered as B2C (business-to-customer) as shown in Figure 1.

Despite not owning any production facility, retailers act as the most dominating actors in the textile supply chain who forecast the market demand and place orders to the upstream suppliers [7]. Therefore, demand flows upwards in the supply chain and the demand fulfillment flows downwards, which can be termed as pull dynamics in the supply chain. It should be noted that logistics partners interconnect various actors, but legally they do not own or alter the products. Therefore, we do not take them into consideration. Moreover, the actors—excluding the retailer—are B2B and act as a linkage in the supply chain. At the macro-scale, each link takes the raw material as an input from the previous supplier(s), applies operations, and produces the final product. This process repeats over and over again until it reaches the retailer.

To define the usage requirement, we follow a system-level approach as also followed in defining traceability in the food and vegetable sectors, which involves the use case diagram technique commonly used in the UML [23,25]. A use case captures the behavior of the actors of a system and the use case diagram graphically demonstrates the relationship between the actors and helps in understanding the most important parts of the system and user requirements [51]. Moreover, the use case-based analysis contributes to understanding a complex system by the explicit representation of the important parts of the system. Figure 2 shows the use case diagram to capture traceability information in the textile supply chain network. As mentioned before, B2B actors work similar to each other, i.e., transform the inbound raw material physically or chemically into the outbound product. Accordingly the B2B actors are shown as similar components capturing/contributing to the similar sorts of information as shown in Figure 2. The retailer acts as a B2C and the customers are an independent component. Consequently, the use case diagram contains three components as shown in Figure 2.

As B2B actors are the product transforming actors by the application of various processes, they act as the main contributors to the traceability information. Whereas, the retailer controls the information flow between the B2B actors and the consumers.

There are a large number of processes performed by each actor. As a result, there is a significant amount of information created by each actor. Information is a critical component of a supply chain, therefore it is important that each supply chain actor controls the flow and protects confidential information [52]. The use case diagram shows two layers of information, namely primary information and secondary information. Primary information consists of all the information available with a B2B actor, whereas the secondary information is the processed information generated from the primary information, a part of which (i.e., shareable information in Figure 2) can be shared with other supply chain actors. The following shows the information components of the use case diagram.

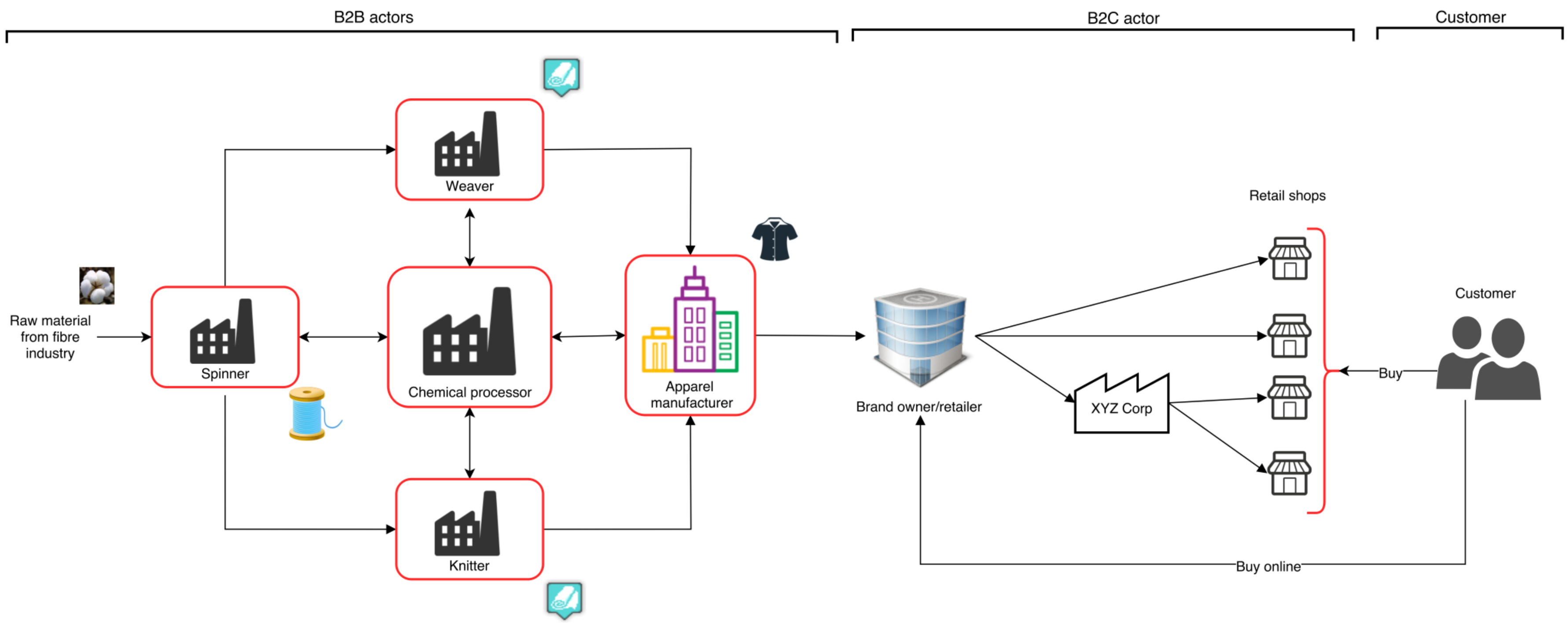


Figure 1. Textile supply chain network.

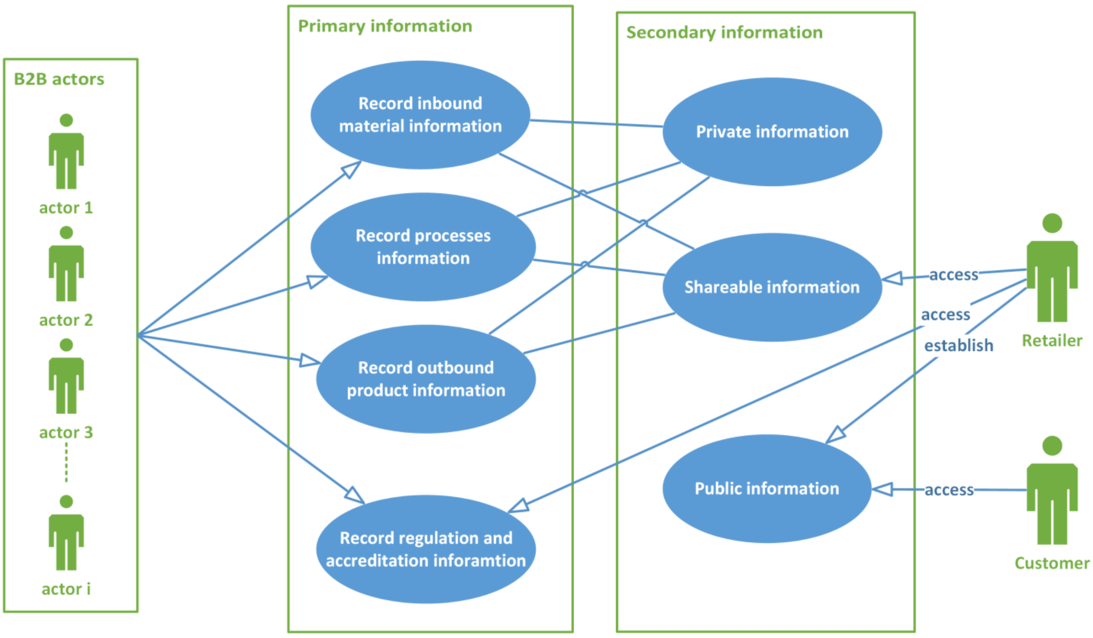


Figure 2. The use-case diagram for the traceability information.

3.1. Record Inbound Material Information

The inbound material is the material procured by an actor from an upstream supplier/actor in the supply chain. Therefore the actor should record the input material information such as material quality characteristics and specifications, supplier information, lot number, etc., so that a material transformed after various processes can be recalled for its history.

3.2. Record Process Information

Process information includes the information related to the processes carried out by an actor to transform the inbound material into the outbound material. As mentioned before, only B2B actors carry out processes to transform inbound material. Therefore, this information is recorded by respective B2B actors.

3.3. Record Outbound Product Information

The outbound material characteristics are different from the inbound material characteristics. As a result, an actor should record the outbound material characteristics such as specifications, buyer information, the difference between the requested specifications and actual specifications, etc.

3.4. Record Regulation and Accreditation Information

Every actor should record the certification, accreditation and other information required for regulatory requirement about the materials/processes/production practices, etc., so that this information can be used by other actors for their claims or practices. For example, The European Confederation of Linen and Hemp (CELC) requires every actor to follow standard prescribed materials and processes to use their stamp on a retail product [19]. Consequently, every actor should follow and record material/process related information which show how does it conform to certain claims (e.g., certification)

3.5. Private Information and Shareable Information

The information mentioned in above sections is the primary information. As aforementioned, it is important to protect confidential information from sharing in the supply chain. Hence the actors should segregate the primary information into private and shareable information. Private information remains with the actor, while the shareable information is shared with the buyer (or the next actor in the supply chain). Private information is used in case of crisis, such as in product recalls.

3.6. Public Information

Public information is the information established by the retailer, accessible to the consumer based on secondary information and certification/accreditation information which are made available to the retailer. The extent of the public information depends on the willingness of the retailer and agreement of actors in the supply chain. For instance, actors may agree to share the information between each other; however, disclosing the complete information in public may invite unforeseen consequences from competitors. Moreover, all the recorded information may not be relevant to the customers. As a result, the retailer establishes the information which can be accessed by the public.

4. Intra-Actor or Internal Traceability

4.1. Traceability Information Identification and Planning

The textile supply chain consists of multiple independent actors, working synchronously with each other. As mentioned earlier, each actor acts as a link, therefore, for implementing traceability, firstly each actor should effectively capture the traceability information and secondly communicate it in the supply chain. For the former, it is important that each actor identifies the essential traceability information which is not only required for the next actor but also to verify the claim. Moreover, the system development process involves the various phases from the practical context, including planning, design, analysis, and so forth, and these processes involve the coordination and communication within and between industries. Following the references [23,25], we use IDEF-0 modeling to define a plan to capture the required internal traceability information. IDEF-0 was initially developed by the Air Force Wright Aeronautical Laboratories and extensively used the developing function models [53]. It uses basic structured analysis (SA) boxes linked hierarchically to define a network of data and control relationships [53]. Figure 3a shows the structure of a basic SA box for the internal traceability of a B2B actor. Here, horizontally inwards and outwards arrows represent the input and output, respectively. Similarly, vertically downwards and upwards arrows represent the control and mechanism, respectively, for setting up internal traceability [53]. While designing a framework for traceability for an actor, guidelines from accreditation and regulatory authorities act as inputs and control along with traceability requirements from internal needs and the information available from the last actor. Furthermore, the captured information should also comply with the obligation from the next supply chain actor, hence requested traceability acts as another input while designing traceability, as shown in Figure 3a. The output of this framework would be traceability information segregated as private and shareable information which comply with the accreditation and regulations from the local government and/or third parties.

Furthermore, Figure 3b shows the detailed steps for implementing traceability and is discussed as follows:

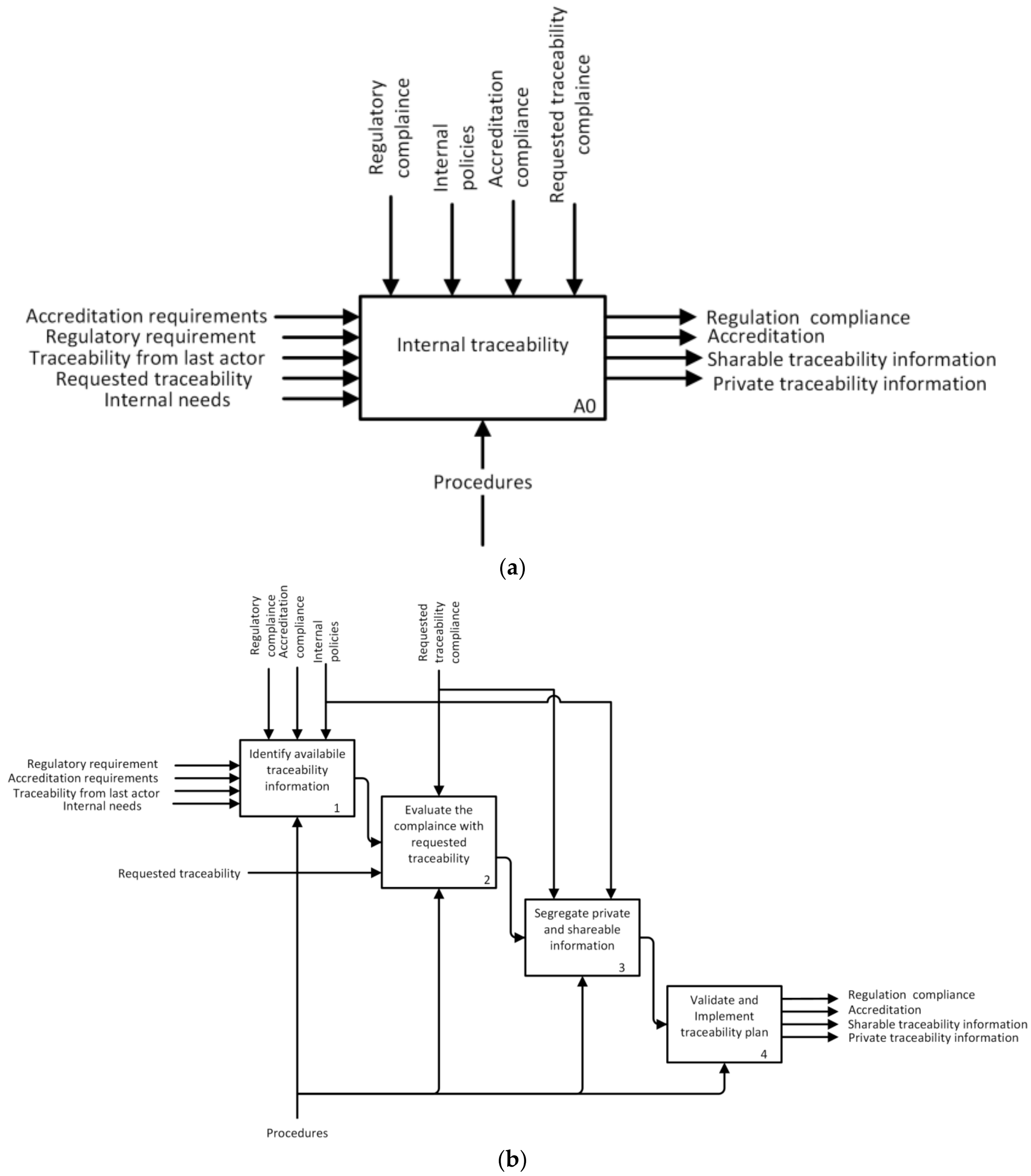


Figure 3. Integrated computer-aided manufacturing definition Part 0 (IDEF0) model for the internal traceability framework. (**a**) shows the basic structured analysis (SA) box and (**b**) shows the step-wise process for implementing internal traceability.

4.1.1. Identify Available Traceability Information

This step includes the identification of all available traceability information in an organization. Traceability information serves different purposes for an actor and supply chain; therefore, it is important to identify all available traceability information for satisfying internal policies, regulations and accreditation requirements, and take into account the previously available traceability information. Government generally has certain regulations related to traceability; therefore, it is important to take these into account for performing business activities. Similarly, accreditations (such as those provided by International Organization for Standardization or ISO) have their requirements for traceability which should be accounted for while planning the framework for traceability implementation.

4.1.2. Evaluate Compliance with Requested Traceability

Traceability has supply chain wide importance and every actor in the supply chain acts as a link for traceability. Accordingly, after the identification of all available traceability information inside an organization, it is important to verify that the collected traceability information in Process 1 contains the traceability data requested by the next actor. The requested traceability information may be due to the buyer's internal requirements including supply chain management, transparency, or local government regulation.

4.1.3. Segregate Private and Shareable Information

Information sharing is an important and crucial step in the supply chain. Any unwanted information shared with the buyer can give an undue advantage. Therefore, this step segregates the traceability information into private and shareable parts. The sharable part includes the information requested by and accessible to the buyer while the private part includes all the information which is available with the supplier only. Furthermore, there is some common components of information, such as the item number or lot number that is available in both parts of the information, to link these parts together.

4.1.4. Validate and Implement Traceability Plan

In this step, the designed traceability plan is validated for all the requirements using real information. The information is stored in database management systems, and reports are generated to validate if the designed system fulfills all the requirements posed by various controls including regulations, accreditation, internal policies, and the buyer. The actor should also use a unified data storage strategy and semantics for an unhindered communication with other actors in the supply chain.

Currently, the industry uses PDM/PLM, which stores the information and has a scope limited to one department or intra-organization. Consequently, the actors freely choose the technology or semantics. However, the limited interoperability due to different semantics, technology, or data storing strategy limits the use in traceability, and it has been identified as a major issue [7]. Companies find it tough to use different semantics for various suppliers/buyers not only due to increased financial investment but also due to maintenance of the system. Financial investment acts as a significant deterring reason for small organizations to implement traceability [7].

4.2. The Traceability Data Sorting and Storing Model

The traceability system has some core requirements for implementation including gathering and sorting product and process related data, lot forming information, upstream and downstream actor details, etc. [54]. These requirements are managed by the proper identification and classification of information, and the classification helps with easier identification of entities and relationships of various ingredients to form the traceable entity [25,54]. The traceable entity can be a batch of products, lot, or a single product. In other words, on requesting the information about a traceable unit, the supply chain actor should be able to recall the relevant traceability information regarding the traceable unit such as ingredients or constituting materials, applied processes, and supplier as well as buyer details. Many approaches have been adopted in the past to visualize the data modeling plan, including entity relation modeling (ERM) and the unified modeling language (UML) which formalize the relationship among various data entries. The ERM approach uses static entities of data and a clear relation between different entities, which allow users to design databases more naturally. However, the discrete relationship makes it less flexible and more appropriate for a clear purpose/use. On the other hand, the UML diagram is a generic modelling tool, which provides better support during comprehension of the data models as compared to ERM [55]. In the present paper, we intend to propose a generic framework which should allow the readers or subsequent studies to modify it according to their specific needs, technology of implementation, and other unforeseen concerns, which would inevitably require a better comprehension of the proposed framework; subsequently we use the UML approach. Figure 4 shows the static UML diagram model developed for implementing mutual relations among various pieces of information related to a traceable entity.

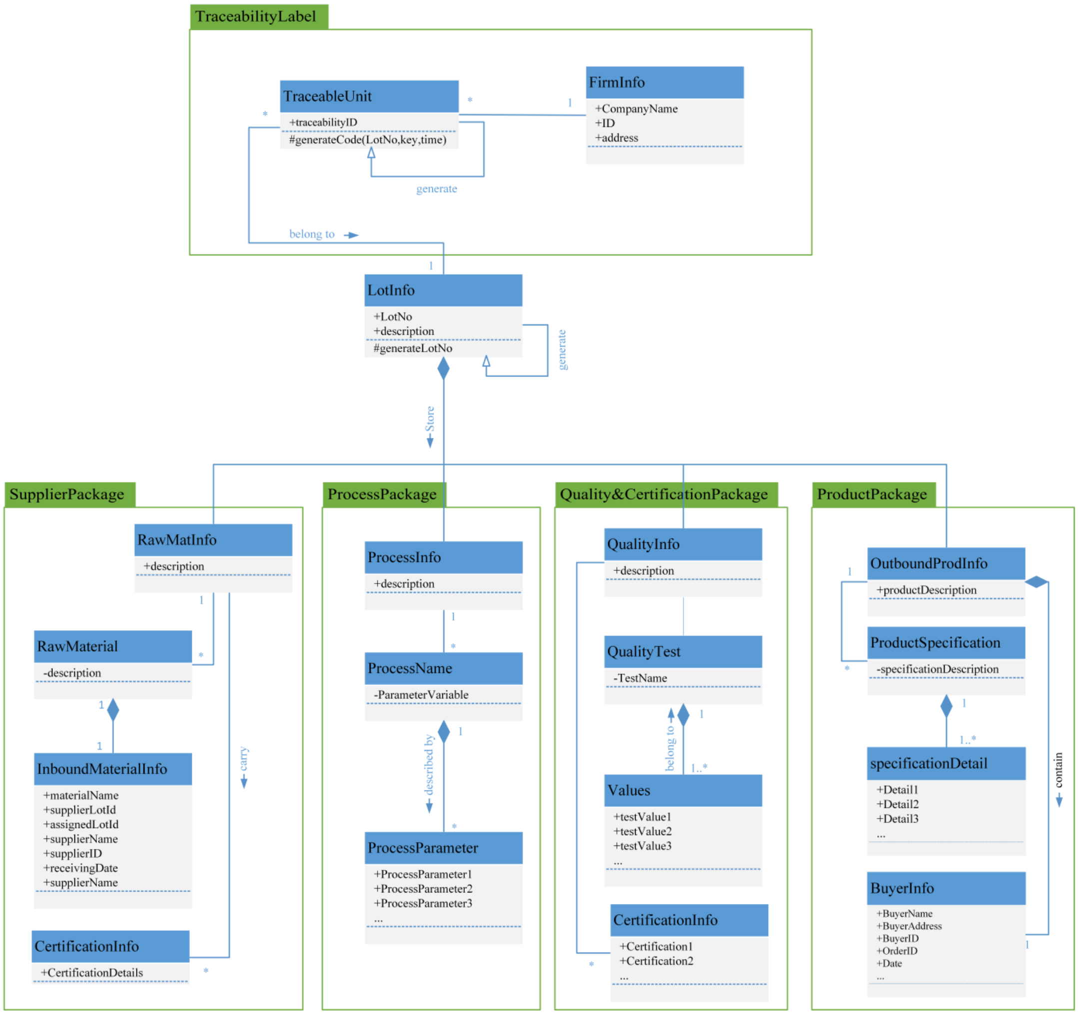


Figure 4. Unified modeling language (UML) static diagram for traceability information sorting and storing.

As mentioned before, the B2B actor imports the supplies from upstream actors and then transforms them physically or chemically by applying various processes. Therefore, it is important to preserve the link to inbound to outbound material information and applied processes during the implementation of traceability. Figure 4 shows the mutual traceability relation among various pieces of information. It primarily contains five packages, i.e., TraceabilityLabel, SupplierPackage, ProcessPackage, Quality&CertificationPackage, and ProductPackage which are targeted to store all relevant traceability information. Furthermore, these packages are linked to the product lot, i.e., LotNo, as a lot generally has products with the same attributes and process parameters. Therefore, the database contains the lot information along with the links to each traceable unit (as discussed in the later part of the paper). It should be noted that here we focus on a lot which represents a discrete entity, where each lot has items with identical attributes. Although in some special processes, a lot may not be represented as a discrete event. For example, a continuous dyeing process requires the continuous addition of dyes and chemicals to maintain the required concentration throughout the process; hence defining the batch or lot is difficult. In such case, alternate routes including the use of some special markers (acting as imaginary start and end) on the material can be used to define a batch or lot, which can be tracked throughout the processing [56]. Therefore the produced entities can be represented by the same traceability data. To identify or trace each item or batch of items uniquely in the supply chain, they are tagged as a traceable resource unit (TRU). The number of items in a TRU depends upon the resolution of required traceability, which signifies the preciseness of the identification. For example, if a TRU is assigned to a batch of 100 products, then each group of 100 articles can be identified uniquely but the articles within the batch are indistinguishable. The UML model in Figure 4 shows the data stored with reference to the individual lot; subsequently, each TRU carries a unique traceability ID which should be capable of recalling the lot number (LotNo) so that respective lot information can be retrieved from the database. The tracking number in the present case can be generated using a function as traceabilityID = generateCode (LotNo, time, key) which takes "LotNo", "time", and "key" as inputs. The "time" variable keeps updating at every instance so that the traceabilityID is always unique. The "key" variable is a private key which ensures that no unauthorized person can generate a duplicate traceabilityID. Therefore it needs to be protected by the producer. As the data is sorted in the database with respect to the LotID, the traceabilityID of the respective TRU needs to be turned back into the LotNo to recall the traceability information. It can be done by applying the inverse function on the traceabilityID with the help of the "public_key", i.e., (LotNo, time) = inverseGenerateCode (traceabilityID, public_key) which deciphers the LotNo from the traceabilityID. The "public_key" variable is dependent on the "key" variable. As traceability requires the forward track and backward trace of the product in the supply chain [57], the lot information consists of upstream suppliers' information to trace the lot backward and buyer information for tracing the product. Furthermore, the process and quality information are stored in the relevant fields by respective departments of a firm as shown in Figure 4. One purpose of keeping the information in packages is that each of the packages can be controlled and maintained by the respective department.

5. Inter-Actor or Full Supply Chain Traceability

Inter-actor or full supply chain traceability refers to the ability to track and trace the responsible actors, activities, and location of entities throughout the supply chain. It occurs when one actor hands over a TRU to another actor. Hu et al. [25] describe traceability as a risk management security system which also allows auxiliary functions including the flow of information documentation from raw materials to finished products in the supply chain. Furthermore, the TRU source and Traceable Item Recipient must communicate and record identification for maintaining the information flow [28]. The following sub-sections explain the strategies to be followed for implementing inter-actor traceability.

5.1. Traceability Information Management and Sharing

Information sharing is the fundamental requirement for implementing traceability in the supply chain. Traceability has different objectives for different stakeholders in the supply chain. Therefore, the information sharing should fulfill their respective objectives. Data storage and sharing among the actors can be carried out using mainly four types of database structures, including central, cumulative, one-up one-down, and network [12]. In the central database structure, all actors store the data on one centralized server; subsequently, whole traceability data remains in one place. On the other hand, in the cumulative configuration, all the data is collected and transferred to a downstream supply partner. Consequently, the data keeps growing cumulatively as the product physically advances in the supply chain, which offers challenges in terms of cost, data security, and implementation. The major barrier with the above-mentioned database structures is the confidentiality of the data and intellectual property (IP), as the confidential information cannot be shared in a free manner in the supply chain. European regulations mandate the one-up one-down model in the food sector [23]. This system ensures that each actor is responsible for linking the traceability information with one upstream actor and one downstream actor. Hence, the traceability works as a chain where every actor acts as a link. This system distributes the responsibility and each actor needs to keep the traceability information for immediate upstream and downstream actors. Nonetheless, a chain is only as strong as its weakest link. In the one-up one-down arrangement, if any of the actors goes inoperative, the traceability breaks—which is a major drawback of this system. On the other hand, the central system works irrespective of the existence of an individual actor in the supply chain since the data remains at one place. Conversely, the central database is favourable when one single actor is acting as the captain—which controls all the links in a supply chain. Hence the supply chain captain can force all the actors to use uniform semantics and store data on a central database. The fourth type of database structure, i.e., the network database, relies on sharing the traceability number instead of sharing the data. The traceability number acts as a reference for information retrieval from the respective actor. Bechini et al. [24] proposes the use of a third party to store and maintain the traceability numbers and the respective information about the supplier/manufacturer. In case someone requires the traceability information regarding a product, he/she needs to send the respective traceability number to the third party which decodes the supplier information and points the request to respective supplier's database. Furthermore, the supplier replies with the appropriate information to the third party, and the third party forwards the received information to the request generator. Following this mechanism, supply chain actors are responsible for their traceability data. According to [12], the network model is simple and the most efficient, which supports anti-counterfeiting policies with the ability to completely retrace product information. Nonetheless, the actors should follow the specified data format for assigning the traceability key so that the other supply chain actors can identify the respective traceability data owner to retrieve the relevant traceability data.

The textile supply chain consists of many small actors, which often face financial constraints; therefore, one-up one-down traceability could be a viable option as each of the actors would need to invest only on traceability required to link to the immediate upstream and downstream actors. However, all supply chain actors should be operative to provide full supply chain traceability. On the other hand, network traceability needs a third party to maintain the traceability network. Therefore, to design a robust data storage and sharing system, it is important to consider the interaction of the supply chain stakeholders.

The textile supply chain, similar to other supply chains, consists of multiple actors arranged in a hierarchical manner such as first tier supplier, second tier supplier, and so on, and as aforementioned, the retailer or brand owner acts as the main actor in most of the cases. Additionally, there are brokers, agents, and logistic partners which act as middlemen. These middlemen serve as mediators, who only handle the products and do not add any traceability information from the process or product perspective. Hence the first tier suppliers mean the suppliers (not the mediator) that directly interact with the retailers, whereas second tier suppliers are those suppliers that interact with the first tier suppliers. According to Lambert and Cooper [58], the supply chain network consists of multiple actors and integrating them is not only a complex issue but also counter-productive, since all the members are not equally important. Some links are more critical in terms of innovation and value creation (such as actors dealing with specialized materials) than other actors (such as actors which deal with regular materials). As a result, a firm tends to pay more attention to the former suppliers rather than the latter. Based upon this argument, for a company, the suppliers can be divided into mainly four categories—managed process links, monitored process links, non-managed process, and non-monitored process links [58]. Managed process links are the most important links for a buyer, which he/she would like to manage and make direct contact with them, whereas the remaining links are not that important, hence the buyer does not directly control them. For example, the retailer acts as supply chain captain in the textile sector which monitors the market demands and places orders to the upstream supplier. At the same time, the fashion industry is an innovative product-based industry where a firm needs to provide a steady stream of innovation [7]. The absence of design protecting regulations gives an easy edge to the imitator, which erodes the competition advantage available on innovative products [59]. Therefore, the retailer would like to manage all the actors who directly affect any innovation. The managed-links essentially consist of the 1st tier supplier. However, these can go beyond 1st tier suppliers [60].

The monitored process links involve the resources which are not critical to the brand owner, who acts as the supply chain captain. Therefore they are not directly managed by the supply chain captain; rather, they are occasionally audited. Similarly, not-managed process and non-monitored process links are neither actively monitored nor critical enough to use resources. Consequently, they are not integrated by the supply chain captain.

Based upon the above discussion, the managed links are directly in contact with the retailer, whereas the remaining links are not directly monitored. For appropriately managing and exchanging the traceability information, a hybrid inter-actor traceability configuration is shown in Figure 5. It involves the use of central traceability for managed-links and one-up-one-down traceability for the remaining links. Here central traceability does not necessarily imply that all actors will use only database. It implies that the supply chain actors have their own databases and they exchange the sharable information via a central data server which is maintained by the retailer. Therefore the retailer acts as a mediator which stores the information being exchanged between the managed links and controls the information flow. The region shown by direct links is the 1st tier suppliers only, whereas the managed links region shows the suppliers operated by the retailer using the managed links. Hypothetically, if one-up one-down traceability covers the whole supply chain, the retailer's direct reach for traceability is limited to direct links only. Whereas for traceability information related to retailer-owned managed links, the retailer has to go through a 1st tier supplier. This will inevitably lead to an increased response time. On the other hand, if the central traceability system is implemented to all the managed links, the retailer can directly reach all of them, bypassing the intermediaries (as shown in Figure 5). This can provide an advantage to the retailer regarding better control and more transparency. Moreover, from the application point of view, it is important for the retailer to hold the valuable information that could affect the business. Providing traceability to the consumers directly gives a financial advantage to the retailer, which can offset the investment in the central traceability system implemented. Moreover, the retailer, as the most influential actor in the supply chain, can force the managed-actors to follow the central traceability.

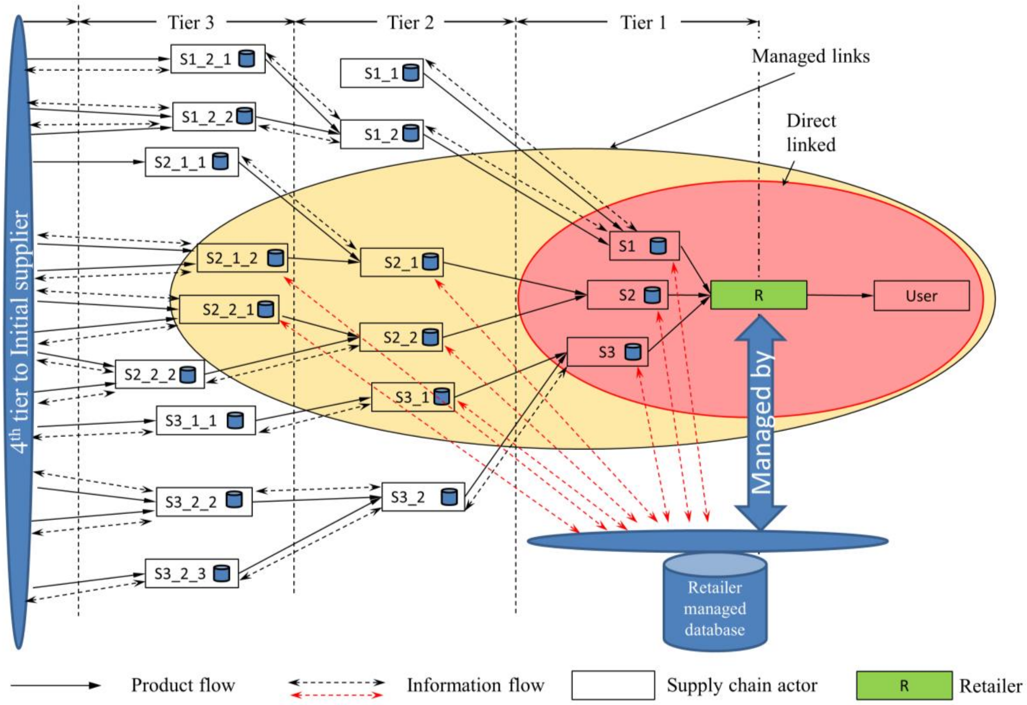


Figure 5. Supply-chain wide traceability (adapted from Lambert and Cooper [58]).

The other links, excluding managed links, are not directly controlled by the retailer; therefore, they interact indirectly with the retailer. In such scenario, one-up-one-down traceability is the most favourable approach, in which an actor maintains data for immediate upstream and downstream suppliers. Since the inter-actor traceability works by the participation of individual actors, the internal traceability should be maintained by individual actors as discussed in Section 4.

Figure 6 demonstrates an example of traceability in the textile supply chain and the corresponding information exchange between the actors for a hybrid traceability server using the UML sequence diagram. Figure 6a shows the retailer managed links from the fabric industry (weaver) to consumers; accordingly, the retailer places order directly to the fabric industry, dyeing industry, and apparel producer. The sequence of actions which needs to be followed for retrieving the traceability information is given in the form of the UML diagram as indicated in Figure 6b. It shows that the traceability information is initiated by the user, which can be a regulatory agent such as RAPEX or the customer. Based upon the extent of information, the traceability events take place combining different actors. For example, if some critical parameters of the fiber are requested, the traceability request takes place from the retailer to the fiber industry through intermediary actors and then the requested information is provided to the user via these intermediaries. Similarly, if the requested traceability information belongs to dyeing process which is directly managed by the retailer, then the retailer directly contacts the dyer and gets the appropriate information for the user.

5.2. Traceability Information Exchange and Mapping

Electronic data interchange (EDI) and XML are the means for information exchange in the industry. EDI uses a sequence of messages transmitted from the sender to the receiver. The transmission uses structured data which is agreed upon for both ends. Consequently, the sender and receiver should use a common framework to understand the transmitted data. XML, on the other hand, also uses structured data for transmission. The tag attributes in XML are used to separate the data fields, which help in understanding the data. Unlike EDI, XML uses a nested tree structure to transmit the information. A supplier's database would contain a large amount of data and when the traceability data is exchanged between two parties, that would involve the data belonging to a specific TRU. Therefore it is important that each TRU is marked with a traceabilityID (as discussed earlier) which points to the specific entry (i.e., lotNo) in the database. Therefore, when someone requests the traceability information about a specific TRU, he sends the traceability ID (marked on the TRU) to the respective supplier and the supplier replies with the information belonging to the particular TRU having the provided traceability ID. These unique codes can be implemented on products using radio frequency identification RFID tags and printed barcodes which are attached to the physical products. Recently, a yarn based-traceability tag has been devised for textiles which can be directly woven or knitted into the product [15]. This includes the use of special yarns which can be integrated into the fabrics; then the coding is directly implemented on the textiles. An example of traceability information exchange using XML is shown in the next section.

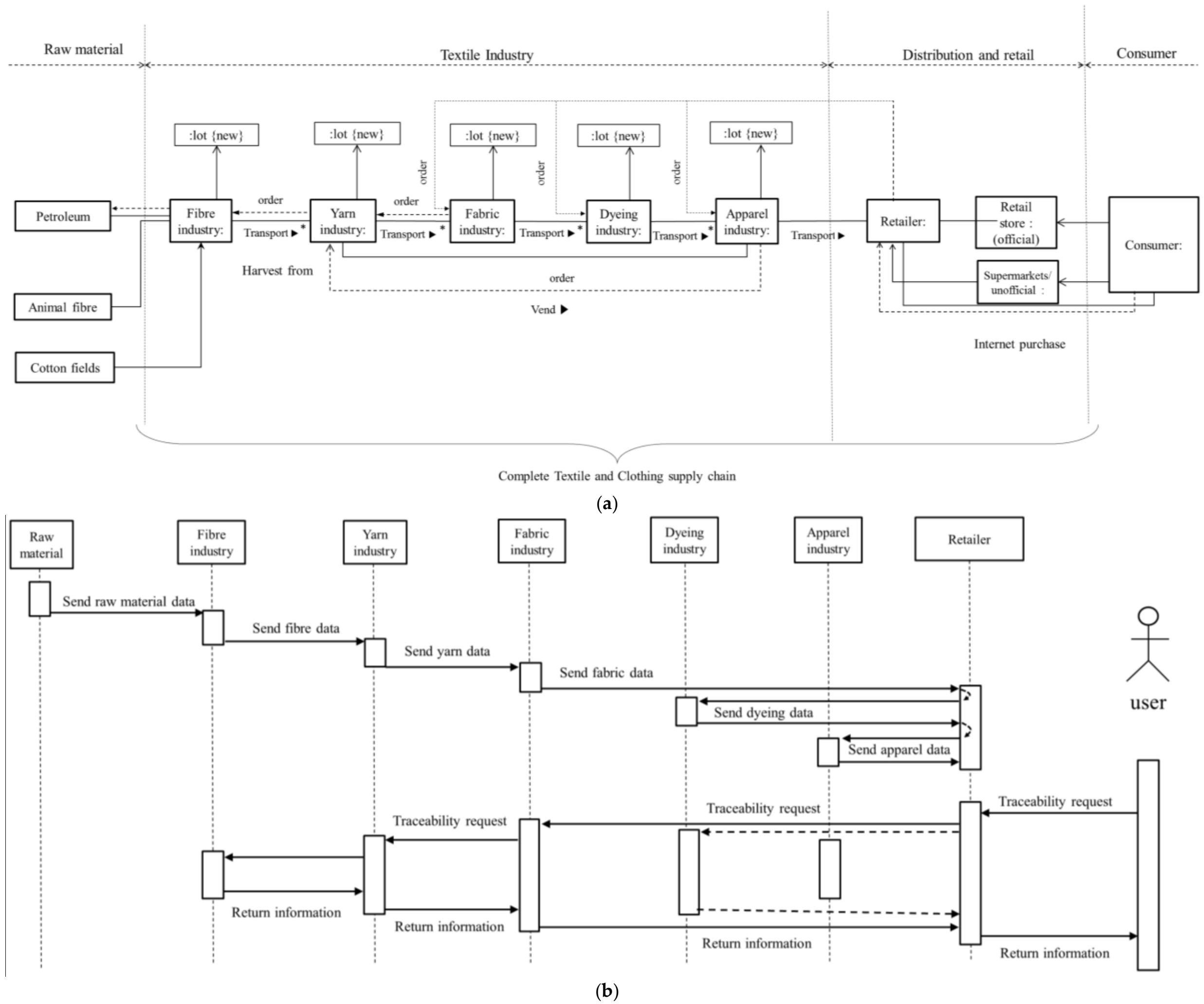
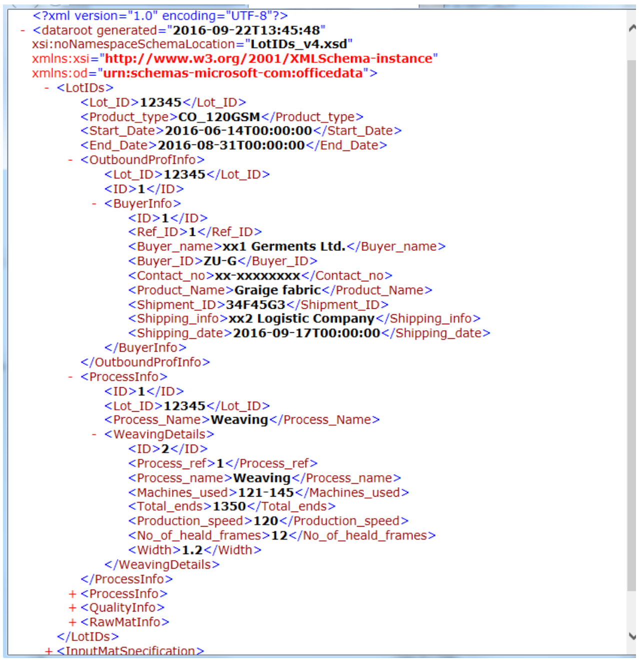


Figure 6. Supply chain illustration (**a**) shows the order and material movement in the supply chain and (**b**) shows the UML sequence diagram for traceability retrieval.

6. Illustration of Traceability Data Management Using RDBMS and Exchange Using XML

In this section, we shall describe an illustrative example of traceability information management using a relational database management system (RDBMS) for a textile weaver, following the framework mentioned in the earlier sections. Textile weaver primarily takes yarns as an input raw material and transforms them into the greige fabric using a weaving process. Besides weaving, there are many operations carried out by the weaver, which includes sizing, desizing, inspection, etc. For the purpose of the illustration, we take weaving and sizing as operations to store the information. Figure S1 (in the Supplementary File) shows the RDBMS formed according to the traceability information sorting the UML diagram as illustrated in Figure 4. It demonstrates the interaction of various small databases that can be designed for storing the critical traceability information. Furthermore, we consider a lot containing a finite number of traceability units, each having a unique traceability code; whereas the traceability information for the lot remains the same. Accordingly, the relation between Lot ID and Traceability ID is related using one-to-many cardinality.

In this example, we show that the traceability ID package contains the Lot ID. However, the traceability ID can be a generated value by the function which takes the input as the Lot ID, as discussed in an earlier section of this paper. Consequently, the Lot ID can be generated by the decryption of the traceability ID (i.e., by applying the inverseGenerate function as shown earlier) and the Lot No. related information can be requested or retrieved from the database. Figure 7 shows the partial view of the XML sheets generated for a record entry, i.e., the Lot ID, from the data stored in the databases. Here the data entries are separated using opening and closing tags such as <*Lot_ID*> xxxx </*Lot_ID*>. Furthermore, the lot data is nested in the lot tags . The XML sheet in Figure 7 contains all the available information related to a lot including the critical information that the weaver may not like to disclose to the downstream buyer. As a result, the weaver trims the information and provides only the component information which is required according to the agreement with the downstream buyer. Furthermore, both parties can agree on common unified semantics such as that defined by the XML Schema Definition (XSD) to follow for exchanging traceability data. XSD defines the rules that specify the elements and structure of an XML document. Therefore, having a standardized XSD would not only help in the smoother exchange of information, but also with cross-border partner organizations that have different working languages and with a standardized format; each one needs to translate the XML tags in their known language before communicating the traceability data to the next counterpart. Figure S2 (Supplementary File) shows the XML sheet for sharing information between the weaver and the downstream buyer. As previously mentioned, a lot contains a finite number of traceability units, each having a unique traceability code. Therefore the XML sheet in Figure S2 indicates the traceability ID instead of the Lot ID, and the information is referenced with the traceability ID. However, when the downstream player needs or requests extra information about the traceability unit, the downstream actor extracts the traceability ID available on the item in the form of a barcode or RFID and sent it to the weaver. The weaver then need to decipher the Lot ID for the corresponding traceability ID and obtains the Lot ID related full information from the database to provide to the downstream actor.




```
<?xml version="1.0" encoding="UTF-8"?>
- <dataroot generated="2016-09-22T13:45:48"
  xsi:noNamespaceSchemaLocation="LotIDs_v4.xsd"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xmlns:od="urn:schemas-microsoft-com:officedata">
  - <LotIDs>
      <Lot_ID>12345</Lot_ID>
      <Product_type>CO_120GSM</Product_type>
      <Start_Date>2016-06-14T00:00:00</Start_Date>
      <End_Date>2016-08-31T00:00:00</End_Date>
    - <OutboundProfInfo>
        <Lot_ID>12345</Lot_ID>
        <ID>1</ID>
      - <BuyerInfo>
          <ID>1</ID>
          <Ref_ID>1</Ref_ID>
          <Buyer_name>xx1 Germents Ltd.</Buyer_name>
          <Buyer_ID>ZU-G</Buyer_ID>
          <Contact_no>xx-xxxxxxxx</Contact_no>
          <Product_Name>Graige fabric</Product_Name>
          <Shipment_ID>34F45G3</Shipment_ID>
          <Shipping_info>xx2 Logistic Company</Shipping_info>
          <Shipping_date>2016-09-17T00:00:00</Shipping_date>
        </BuyerInfo>
      </OutboundProfInfo>
    - <ProcessInfo>
        <ID>1</ID>
        <Lot_ID>12345</Lot_ID>
        <Process_Name>Weaving</Process_Name>
      - <WeavingDetails>
          <ID>2</ID>
          <Process_ref>1</Process_ref>
          <Process_name>Weaving</Process_name>
          <Machines_used>121-145</Machines_used>
          <Total_ends>1350</Total_ends>
          <Production_speed>120</Production_speed>
          <No_of_heald_frames>12</No_of_heald_frames>
          <Width>1.2</Width>
        </WeavingDetails>
      </ProcessInfo>
    + <ProcessInfo>
    + <QualityInfo>
    + <RawMatInfo>
    </LotIDs>
  + <InputMatSpecification>
```


Figure 7. XML data sheet representing the traceability data for a lot.

7. Conclusions

Traceability has been a great concern in today's complex and opaque supply chains. A typical textile supply chain consists of multiple stakeholders—who are located in different parts of the world, specialized in distinct operations and following different regulations set by local bodies. Many supply chain actors combine raw materials from various suppliers and apply operations to create an outbound product with changed physical or chemical characteristics than that of the input materials. Subsequently, it becomes difficult to identify the providers of the input raw materials based on the outbound material if the proper information is not managed during the mixing, combining, or processing of the raw materials. Furthermore, the textile supply chain consists of multiple actors arranged in a sequential configuration; as a result, the identification of initial suppliers is far more complex because it involves the merging of diverse material lots at multiple levels of the supply chain by different actors. In this context, this article presents a traceability framework to capture, manage, and communicate the traceability information in the textile supply chain. The main task of implementing traceability is to identify the critical information to record or preserve, which is not only essential for an organization for better functioning or management and record-keeping purposes (such as to comply with regulations), but is also usable or required for the other supply chain stakeholders in the supply chain. Furthermore, the identified traceability information should be stored, managed, and linked properly in the databases so that it is accessible when some authorized body or organization in the supply chain requests it. Furthermore, information exchange semantics need to be standardized to reduce language barriers. Therefore, regulations from the governments can play an important role by formulating the guidelines for various actors and for the minimum required traceability.

From the risk perspective, as previously mentioned, the supply chain risk increases with the involvement of the global supply chains and more reliance on suppliers, which intensifies the need for visibility and supply chain information. In this context, the described traceability framework illustrates the process so that brand owners can have better information about their supply chains. In the case of quality issues or a recall, this information can be efficiently utilized to trace-back the involved suppliers to rectify the issue. However, traceability is a technology-driven concept, which relies on the adoption of appropriate technologies and maintenance of the system at each level of the supply chain [44]. According to Probst et al. [44], one of the major issues that companies confront is a lack of a skilled workforce to implement and maintain the traceability system. Moreover, the textile supply chain consists of actors dealing with specialized processes or activities and the critical information about them is kept confidential or is disclosed with only specific actors to avoid copying by competitors. In this context, any inadequacy in the protection of the traceability information can potentially increase the risk of disclosing critical data which can jeopardize the relation with other actors and benefit competitors. Nonetheless, the present article provides a generic framework to handle the situation related to traceability implementation in the textile supply chain. The next step would be to implement the proposed framework in an actual textile supply chain with real requirements; which would provide a better comprehension of the limitations and further modifications required for the refinement of this framework. Traceability is an information and communication technology (ICT)-based model, which also acts as a basis for other concepts including "smart cities" and the "Internet of Things" (IoT). Subsequently, future studies can be focused to align these concepts with traceability information and the amendments required in the proposed framework.

Supplementary Materials: The following are available online at www.mdpi.com/2079-8954/5/2/33/s1, Figure S1: RDBMS for data management at the weaver, Figure S2: Traceability data exchange between the weaver and downstream buyer.

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