Total Traceability System: A Novel System by Combination of Horizontal and Vertical Traceability Systems for Food Supply Chains

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Abstract

Traceability systems have become a dominant component within the production and marketing companies as they can efficiently control the supply chain, minimize the risks of the production process, and help to enhance the consumer/customer reliability on products. Moreover, such systems can be used to meet the requirements of government rules and regulations about safety of the products. The potential of traceability systems to reap multifaceted benefits have been identified by many research works for many years but the apparent anomaly that these business industries do not still feel traceability systems as a catalyst for financial gains inhibits the practical deployment of tractability systems. Moreover, most of such systems could be traced the characteristics of one process or one location. But today, to get the cost benefits, final product may be a collection of intermediate sub products, produced and process in different locations. Efficient system of tracing such types of supply chain and processes are still a challenging issue.

This paper we first review the currently available traceability systems and analyze the effectiveness, limitations practical problems of implementation. Most of these systems are less cost effectiveness, lack of accuracy and also lack of technological knowledge of the staff. We focus on a supply chain which has several sub processes and then we focus on the limitations and problems and introduce a traceability system by combination of horizontal and vertical traceability systems. Further, we are going to implement our system with a sales and marketing company business model. Our system mainly addresses the cost effectiveness, accuracy, user friendliness, preciseness and security. Further more, we have planned to implement this system in three phases.

Key Words—*Traceability system, Supply chain management, Horizontal traceability, Vertical Traceability*

1. Introduction

With the development of new technology, most of the production processing systems have become highly complex and such processes have been span across intermediate processes within the same company and/or between several companies achieving some cost benefits. With these benefits, sometimes there may have problems of quality, reliability or durability of the products which may highly influential to the may have many sub-processing steps or several locations in a one production process; there should be an efficient method or system to trace the processes, the items flow and the whole supply chain in order to maintain the quality and to minimize the risks. This may change the type of the products, value of them and risk to the society etc.; for instance, construction of aircraft and nuclear power plant, must have an advanced, efficient and automated monitoring system for the whole production chain, while food products want a continuous traceability system to enhance the reliability and trust on products. Hence, today the traceability systems have become an integral part of the supply chain and services.

But, still most of the small and medium scale manufacturing companies are not using advanced traceability systems because of the high cost of such systems, lack of skilled staff to operate such systems and also they do not have clear idea about the advantages of using such system. Hence most of such companies are using paper-based record system as shows in Figure 1.

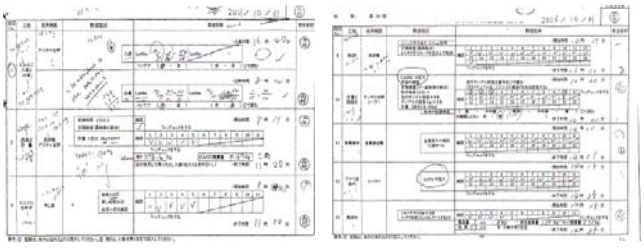

Figure 1: Paper-based Recording System

. As there are several paper records for one process, the inefficiency in back-tracing the data from the papers and securely storing the paper records are still unsolved problems of such companies. Moreover, most of such traceability systems have been seen as a mere legal enforcement which is a burden to the daily work routines in the company.

But today most of the production processes and supply chain have been integrated with several processes and companies, each of such related companies will be focused to use good tracing systems and connect to the main supply chain in future. But most of such companies will reluctant to use such

systems because of some security problems of the company secrets and methods.

1.1. Motivation and features of the designed system

Since most of the industries still don't find a way of how to use traceability systems as an integrated element in the workflow, the operational conditions of traceability systems are kept at bare minimum merely to fulfill legal requirements. But, especially the small and medium scale industries must be clearly understood the need of traceability systems and its global deployment and its non-trivial issues.

The authors believe that, deriving from some past work [1],[2] the industries will not be motivated to use traceability systems aggressively as long as traceability systems have not been perceived as an integral element of the systems which renders financial and other benefits. Thus, lack of a systemic and systematic approach to deploy traceability systems in industries together with recent increased government encouragements through enforcement of the new regulations are the motivations for the authors to revisit the traceability systems and to design a novel system which can evolve from a simple co-exiting model to a fully functional farm-to-fork traceability system.

In view of these facts, this paper is mainly concerned with reviewing the benefits of traceability systems in the context of food industry and presenting the rationale of design and deployment of a Total Traceability System (TTS) with following key features.

- Cost effective initial deployment: At the initial phase of the deployment, TTS can fully accommodate the printed document based or electronic document based record keeping systems in most of food supply chains. Hence, with slight modifications to an existing system, traceability system can be introduced with a minimum capital expenditure at the same time keeping running costs low.
- Easy integration to existing system: The success of a traceability system is determined by its ability to be a part and parcel of the business value chain. The optimal design of TTS supports two folds integration: use of existing input modalities (hard prints, manual input tables) for traceability recording and more importantly, integrating traceability system modalities to the value chain (transformation from paper based to document based).
- Interface for cascaded deployment: While the TTS begins in its initial phase as an isolated sub process segment of a large production change; as it evolves, the XML based metadata handling mechanism allows easy integration with different isolated segments to realize a total traceability.
- User friendly and easy to learn: By providing menu driven functionalities, interface support for most of scanning devices, and other features that are required for efficient data input, editing and viewing etc. makes the system more and more user friendly.
- High security: By using state of the art secure transmission and authentication technologies, TTS provides a highly secured traceability system with some special tools to protect the company secrets. In TTS design, VPN connections, secure protocols and digital signatures are used for this purpose.

1.2. Related Works

With the introduction and enforcement of new laws and regulations for food industry by the European Commission (Article 18 of Regulation (EC) 178 2002) and the government instructions, most of the production industries especially food industries want to implement these laws through traceability.

However, this legal and regularity scenario does not assist companies in managing product traceability unless they have proper system to trace the process. Pugh et al. [3] in 1973 have done the first significant contribution by establishing the fundamental principles of product traceability. In Recent years Borst et al., in [4] and then Gordijn et al., in [5], studied the global impact and the ontological requirements of a traceability system.

The advancement of Information Technology was one of a main milestone in reshaping the research concepts and in shifting the focus towards computer-based traceability systems. Most of the researches in that time had introduced RFID, and bar-code systems [6], [7], [8] [9] and computer vision [11] for quality control and traceability to store, retrieve and to analyze the information in a production process and/or in a supply chain.

Radio frequency identification system (RFID) is one of a more advanced system that can be used in traceability systems [9]. This RFID system uses wireless microchips to create tags which do not require the physical contact or particular alignment with reader. Important characteristics of this system are increased speed in reading, significant reduction of the size of the tag (to few millimeters), no compatibility problems with foods, easier linkage between products and tags. Furthermore, in using this system, there are several other benefits, such as significant reduction of labor cost, acceleration of physical flows, increased cost savings and more efficient control of supply chain operations in terms of improvements in inventory management and production flow monitoring. Moreover, this system provides an efficient management information system by tracking and tracing of quality problems of food processing. These systems offer significant advantages; namely ease of automation, increased speed, practically increased accuracy, and more economical relative to other systems because one tag can be used for the whole supply chain. But these systems have varying levels of limitations and they are significantly depending on the nature of the business model of the company. For instance, the traceability

systems for high critical applications require characteristics like high accuracy, high reliability, and also have automated back trace and detection systems. For instance, air line manufacturers and maintenance companies use Back-to-Birth traceability systems to identify the un-airworthy (not fit to fly) components and for tracking the time/cycle of life-limited parts.
However, customized traceability systems with highly advanced tools have become costly that most of the small and medium scale industries with low profit margin of their products cannot be afforded such a huge cost. The cost of the system is directly influencing the final price of the products. Section 2 provides a brief review of existing traceability systems and their various types. Section 3 presents the design rationale of our proposed system "total traceability system (TTS)". Also this section briefly describes the target business model, system architecture and the implementation of the total traceability system. Sections 4 discuss deployment of TTS and some practical issues and final section presents the conclusion and future works of the TTS.

2. Traceability Systems

The 'traceability' is now a common term that are widely used in various industries and contexts particular in food industries. The traceability can be considered as the combination of engineering metrology standards, and calibration in the context of requiring the nationally accepted tools and methods. In other words traceability is characterized by a set of parameters. They are space (traceable location), time (trace time) ,volume (quantity) of the traced items. Considering these parameters and the applications in various fields such as production process, creation construction and development, traceability systems can be cauterized to the following several dimensions.

A. Agrichain Traceability

Agrichain traceability systems are the most common and essential index for food and agri product industries. The agrichain traceability systems have facility to identify the product history, location time and also to help to recall of defective products. Moreover, in agriculture and food business, an integrated supply chain traceability mainly encompass several elements [10]. They are *product traceability* that refers to identification of physical location and stages of the supply chain, *Input Traceability* that refers the information about the types and origin (source, suppliers) of the input materials and raw materials and information about product quality control, *Disease Traceability* that refers the outbrake and monitor the epidemiology of biotichazards such as bactria, virus and other emerging pathogens which are potential risks to the humans, *Genetic Traceability* that refers the genetic constitution of product, including variety,type,origin and alterations in the basic DNA structure and *Measurement Traceability* that refers the accurate calibration of the raw materials and how to eveluate the individual measurement such as product quality and safety.

B. Measurement Traceability

The main purposes measurement treaceability are to avoid the mesurement uncertainties and complxcities and to introduce adaquate accuracy of measurement using the standards, the compatibility of different measurement systems, and the interchangability of parts. In relation to engineering measurements, traceability can therefore be viewed as a system of transforming the International Systems of Units (SI) from the point of definition of user. When there exists the measurement and calibration standrads and this may become part of broader contractual responsibility of the suppliers and manufactruers in which the porduct quality is preeminnent.

C. Requirements Traceability

Requirement traceability has become a sub-discipline and an essential feature of quality management of software development and software engineering. It help design team to efficiently navigate through document structure of a project eveluate several tasks and progress, software documentation, test and maintainance, life-cycle analysis, access control and monitoring. Also requirements traceability helps to trace the security transactions of high-risk business activities such as E-commerce. Therefore the requirement traceability can be stated as the ability to describe and follow the life of a requirement in both forwards and backwards direction (i.e. from its origins, through its development and specification, to its subsequent development and use, and through all periods of on-going refinement and iteration in any of these phase).

D. Back-to-Birth Traceability

Back-to-Birth traceability is highly used in high critical areas such as building a new neuclear power plant, aircraft manufacturers and high advanced chemical reaction experiments. The term back-to-Birth traceability clearly demonstrates the every installation of a part all the way back to the time that it was manufactured (birth of the part). Hence in aircraft maintainance companies and manufacturers use this system to identify the airwothiness and unairworthiness of life-limited parts.

2.1. Two types of traceability systems

The above mentioned dimensions are mainly used in the following two types.

A. Vertical Traceability

In this traceability one process is deeply analyzed using the traceability dimensions. Row materials of the process are analyzed with the quality validity and the accuracy of the

measurements. And also the process is analyzed using the factory conditions and the production control methods. This type of traceability systems are mostly used in production companies.

B. Horizontal Traceability

Today, with the complexity of the supply chain it may consist of several sub-processes belongs to one or several companies that are geologically distributed each other. The horizontal traceability refers that to trace each of the sub-processes and the locations as an integrated system. Most of the logistic companies are used to trace the current location of the goods in the transportation process.

2.2. Traceability Requirements

Above we explained the different types of traceability systems that are being used in the various companies and manufacturing industries. Each of these systems has a set of specific requirements that are characterized by the system and a set of general requirements that can be applied for all traceability types. In general, traceability systems need to record any intermediate element in the production system at least in terms of 3 basic parameters, namely, *space, time and volume (s, t, and v).* Space could be the geographical location as well as a sub-process of a complete process. Time parameter identifies the time of the instant the element is subject to the given process. The volume identifies the measurable quantity of the element in which has been subject to the given process. The above basic parameters may appear in different forms based on the nature of the production/service line (e.g. conditions of a sub-process, person in charge of handling, Lot number or bar-code of the element etc.).

To conduct a successful traceability analysis, representative parameters of the above *s, t,* and *v* must be measurable and the measurements should be recorded. Successful deployment of traceability systems, a production system should comply with certain requirements namely:

- Accuracy: This is the correctness of the measured parameter. Provisions of the system to have accessibility to correct information and recording and back-tracing of those information in the traceability system is a non trivial issue in a food supply chain where the number of stakeholders are large.
- Precision**:** This is the granularity at which the above accurate measurements are recorded. Finer the granularity higher the precision and better the traceability output. In other words, coarse grain measurements result in a poor traceability output. However, precision is design trade off between the quality of the traceability output and cost of deployment. This also matters with the required quality of traceability a system needs. (E.g. Japanese Railway system needs a traceability system at the granularity of per ticket, per head, per location with a high precision of time stamps whereas a food supply chain requires a traceability of knowing which lot in the market is defective and what raw material lot is responsible for the defect etc.)
- Flexibility: With out some sort of flexibility of the production system, it is impractical to introduce traceability systems. Production/service management should have some flexibility to spare labor for recording traceability parameters as well as flexible enough to integrate some of traceability input modalities to the existing system.

3. Design Rationale of a Total Traceability System

Total Traceability System (TTS) is a combination of vertical traceability and horizontal traceability that can be shown in the following Figure 2.

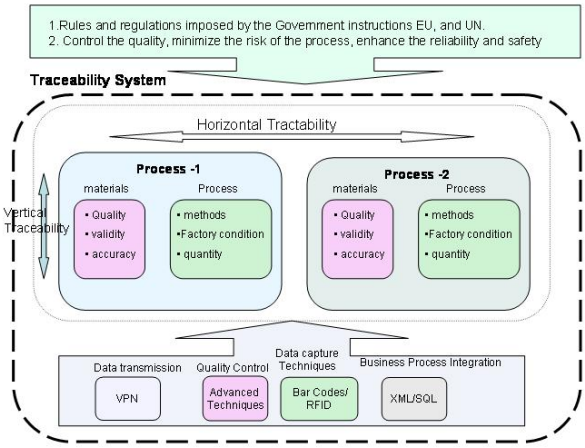

Figure 2. Architecture of Total Traceability System

The main characteristics of this system are that each process is all related processes (horizontally) are analyzed in deep (vertically). Moreover this system uses advanced technologies to transmit data (highly secured VPN network connection), SQL databases to store the data. And also on request of the production company, this system can be extended by implementing advanced data capturing techniques such as bar-code or RFID tags and tools to hide the company secrets.

3.1 Target Business Model

In this work the authors mainly target the health food sales and marketing company (SMC) for implementing the total traceability system. Such company neither they have their own production company nor they have their own delivery services to transport the products to the consumers. The

production company is producing the products under SMC's brand name; hence the CMC has to make a continuous look up the production process and the supply chain in order to main the quality, safety and reliability of the products. Also the SMC has a facility to back trace the production process history in case of any claims on products by the consumers. Therefore the proposed Total traceability provides the overall facility to store the supply chain information in systematic way by vertically analyzing the process in deep and horizontally analyzing the sub processes. The target business model can be shown in Figure 3.

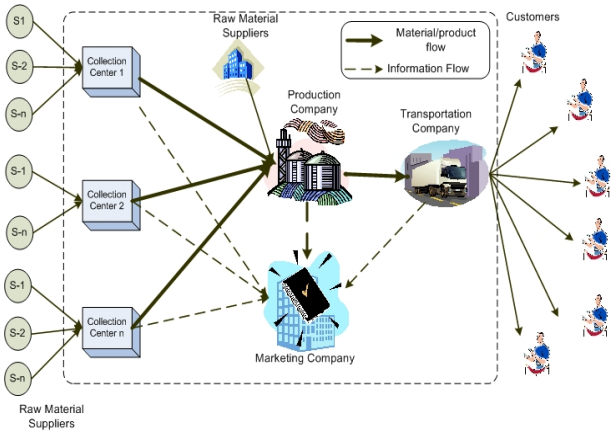

Figure 3 : Business Model of the Sales and Marketing Company

In this business model the information communication path is indicated by dotted line and the physical products transportation is shown in solid lines. As the SMC is only handling the product information, each day the related companies have to send all the information to the SMC. Hence the SMC is having up-to-date finished product information along with the traceable information.

3.2 Benefits to the Marketing Company

In addition to more conventional goal of complying with legal requirements, we envision that a production system will appreciate the value of a traceability system with following potential benefits that we plan as major goals of the designed TTS.

- Market requirements:

  In addition to legislative measures, wining customer trust is on the existence of a traceability system. In regulated market, traceability becomes essential to the survival of business. Food or feed products placed on the market shall be adequately labeled or identified to facilitate its traceability to the customer, which is norm in most supermarkets in developed countries. Here, traceability becomes a requirement for market entry and a marketing tool, which creates brand name for the product as well as other products of the same distribution company.

- Quality and Safety Management:

  The introduction of food traceability can be viewed as a strategic response by the food industry to the impact of an increase to consumers' overall risk perceptions of food products. In the event of food safety and quality alert, it requires sufficient data to adequately evaluate the type, origin and location of the source of safety concerns to enable corrective actions to be taken. Traceability itself does not change the safety and quality of a food product, but it provides the information and keeps tracking of products during all stages of the production, processing and distribution. Accurate traceability effectively reduces risk exposure by enabling food producers to identify, isolate and correct the problem quickly and efficiently, so that the public health is protected and the economic fallout from such incidents can be minimized.

- Product Recall:

  All traceability systems must have a product recall tools to enhance the food safety of the products and to protect the customers. Recalls are complex initiatives built upon a foundation of bad news, but companies that successfully manage a recall can turn bad news good by effectively managing the many facets of a crisis Traceability systems are useful tools to identify the problem lots, isolate and locate the products associated with potential public health concerns. An effective traceability system helps reduce the potential scope of a food recall, and the volume of product that must be withdrawn. Faster, more thorough and precise food traceability can lessen the impact of a product recall by enabling the producer to quickly pinpoint where in the supply chain the problem originated and implement an appropriate remedy.

- Reduced cost of production :

  With the benefits of having a traceability system, brand name establishments would reduce the production cost (economies of scale). Ability to do focus product recall avoids market agitation and waste of the faulty volume. Integration of traceability recordings to production system would reduce running cost. More importantly, by establishing localized traceability systems at a certain segment of the production chain, the end nodes are motivated to run their own traceability systems to comply with the requirements of the host nodes. Hence, costly investment required for quality controlling will not be necessary when each end supply node will adhere to a certain quality criteria.

3.3 Designed system Architecture

To transmit the information and efficiently store the product information, total traceability system provides the following database architecture (Figure 4).

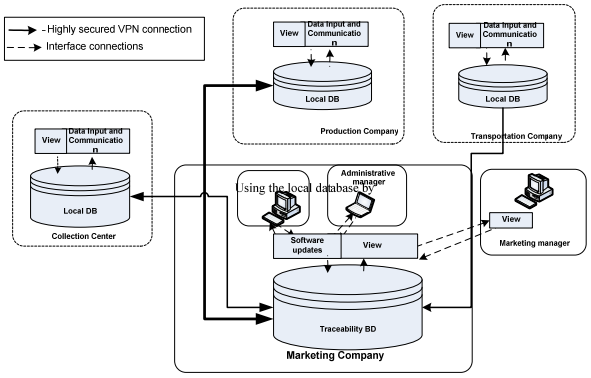

Figure 4 : Database Architecture of the Total Traceability System

Each direct traceable companies is having a local database and all they are connected using highly secured VPN network connection with the central database (Traceability DB) which is located in the SMC. Interfaces of the total traceability system provides the facility such companies to efficiently store the traceability information, retrieve such information and to transmit the relevant information to the SMC. Moreover, each of these traceable companies is using the ACCESS database system to store the data and Traceability DB is using the Microsoft SQL Server database to store the data that are transmitted by the nodes. With this database architecture the direct traceable companies and the SMC could be able to achieve the following advantages.

- The nodes can store the data locally before transmitting to the Traceability DB.
- As data is stored in locally, the nodes can be transmitted the data at any time.
- They can efficiently retrieve the required data from the local database.
- The employees could be gradually understood the importance of such systems through the experience and this will help for the future enhancement of the system.

The authors believe that the selected health food marketing business model represents a microcosm of industry which immensely feels the requirement of traceability systems. Some main features of this business model can be given as follows.

3.4 Implementation of TTS

The TTS implementation can be considered as a collection of several locations connected to a centralized database system as shown in Figure 4. This centralized system that takes inputs from such locations and stores in a one central database. Similarly, each end system node may have its own centralized traceability system with suitable interfacing to its host. All direct traceable locations are connected through secured VPN connections (Japan NTT VPN) and monitors connected locally or through secured web access. The monitors can be observed the traceability in visual as well as tabular representations.

The TTS pilot system has been implemented for windows plat forms which uses Microsoft access database which can be distributed with free license.

4. Deployment of TTS and Practical Issues

We implemented this system in a Health Food and Supplement Marketing company in Japan. The company is having a big share in health food market and it wants to enhance the consumers' trust and reliability on products. Hence the SMC wanted an efficient monitoring and tracing system to continuously monitor all direct traceable companies from the SMC and to trace production information in case of any claim on products. But monitoring without visiting to the related companies was difficult as most of such companies are still using paper based recording system to store product process information. Hence, we tried to accommodate the SMC requirements and supporting to the direct traceable companies to store the existing paper-based data efficiently and safely in a local database and to transmit the related and necessary information to the SMC's central database. Therefore the SMC would be able to monitor and trace the supply chain from the company very effective way without visiting to factories.

TTS has been scheduled to implement in three phases and phase 1 already implemented, phase 2 is in progress and phase 3 will be implemented after successful completion of the phase 1 and 2. When these two phases work well and having understood the necessity and advantages of such system by the employees, they may want a more sophisticated traceability system. In such situations, on client request, the phase 3 is introduced with some advanced techniques. Each of the phases with its characteristics is explained bellow:

A. Phase 1

In phase 1, the TTS fully accommodates existing paper-based recording keeping system which may have several disadvantages and hardships for the companies, make slight modifications and introduce an efficient interface to store and retrieve the information.. Phase-1 system can simply be implemented as shown in Figure 5.

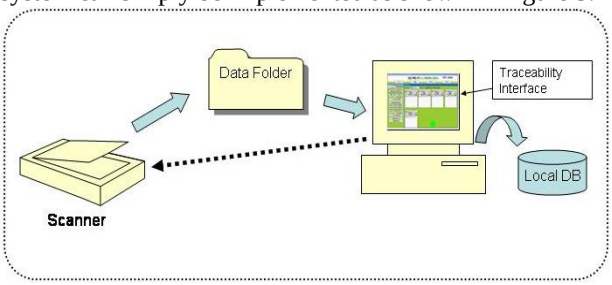

Figure 5 : Phase-1 paper based record keeping system

Hand-written paper records are scanned and store in a temporary data folder in the local computer. Then using TTS interface the scanned papers are stored in a local database under a product lot number facilitating efficient retrieval of the information from the database when they are needed. Phase -1 is an ideal solution for the small and medium scale industries that do not have much capital to invest for advanced systems and also they do not have enough computer skilled workers. In this method the employees may not want to input the data, only they have to scan the filled papers and store them in a database. Then these image data can be transmitted to the SMC for the monitoring and training purposes.

Here in this phase we introduce several methods and tools for collective scanning of the papers and to hide the company secret informations and production techniques before transmitting the image data to the SMC. Snapshot of the opening window of the phase-1 system can be shown in Figure 6 and Figure 7..

Figure 6 : Phase -1 Interfaces of Total Tracing System

Figure 7 : Phase -1 Interfaces of Total Tracing System

This window provides facility to scan the paper-based records (input) store the scanned records under the right name and view the records and transmit the stored data to the SMC's Traceability DB.

B. Phase 2

In this phase we are going to introduce electronic sheets with tabular forms, check boxes, listed boxes to input the data instead of printed document based record keeping system used in phase-1. In this phase the production condition can easily be analyzed with the standard conditions and could be introduced some safety methods for the production process to control the process. Moreover, the production information can be extracted easily and can provide some information to the consumers through the homepage.

Here in this phase the employees have to be trained gradually for the advanced system and could be understood the necessity of such systems.

C. Phase 3

In this phase we have planned to use high advanced techniques to input the data such as bar-code systems or RFID system, introduce some standards and quality control methods for minimizing the manufacturing risks.

Also to develop the trust on products, consumers are provided the maximum possible product information using the SMC's web site fascinating consumers to access even from their hand phones. (use QR code).

In this phase, the we are going to deploy a new system that using the existing system. Therefore sometimes the production company will have change the production floor and to install new machines for this new system. However for this phase, prior permission is necessary as the company has to bear high cost for the machines and to develop the system.

5. Conclusion and Future Works

In this work first we analyzed the existing traceability systems their strength and weakness, limitations and practical problem of using such systems. Then we introduced a novel traceability system for the small and medium scale industries and for the marketing companies to monitor the production process and to trace the process. Our Total Traceability system is a combination of vertical and horizontal traceability which can integrate whole supply chain of the company and having main characteristics of cost effectiveness and user friendliness.

Using this system SMC could achieve the following advantages.

- Reducing the regular inspection - before the introduction of new TTS, the SMC staff had to visit each production companies and the raw material warehouses both in Japan and overseas (China) once in two months and sometimes the SMC staff had to supervise the production regularly. After introducing this system the SMC could get the process information every day, hence the regular inspection could be gradually reduced up to maximum three times a year saving the company direct cost of visiting the production plants. This could reduce the plant inspection cost by 40 percent.
- Receiving the consistent information regularly. – as the information is received daily basis, the SMC could

maintain its databases on time and it will help to increase the safety, assurance and reliability of the products and to avoid any out of stock, over stock and out of order of the products conditions.

- Efficient back-trace in case of any claim from the consumers –as all the related companies are transmitting all production information to the SMC Traceability database, they can efficiently search all relevant information of the product code in case of making claims about the products by the consumers.

However, this is one network that one supply chain implemented the traceability system. But the direct traceable companies may have a set of suppliers and gets the services or intermediate products or row materials from outer companies. If such companies would implement such type of integrated traceability systems they can produce high quality products. Finally, all such traceability systems are connected together and create a traceability network,, each company can easily maintain the quality of their products.

But, before creating a traceability network , inter company trust and faith have to built as all most all companies do not like to provide their company production methods and secrets to the third party and to competitive companies.

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