e-Traceability: traceability for collaborative spread CAD-CAM-CNC manufacturing chains.

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Abstract: - On complex and flexible industrial collaboration environments, manufacturing traceability has to move from a traditional internal enterprise activity-based view to a collaborative and distributed one. The objective is to implement global traceability: traceability of the whole manufacturing process when performed by several partner companies (extended enterprise). The paper proposes a model to support e-traceability in CAD-CAM collaborative chains to assure that traceability data will be understandable and available whenever required, no matter the product or the manufacturing process complexity. The model tries to automate as much as possible traceability activities by defining an explicit link between the traceability data and the product structure defined in ISO STEP standard. This model provides data significance and drives the data transfer through industrial partners along the supply chain.

Key-Words: - Traceability, Extended Enterprise, Data Management, Quality Control, CAD/CAM, STEP.

1 Traceability and Collaborative Manufacturing: e-traceability

1.1 Traceability Definition.

Traceability can be defined as the set of practices that can be adopted by any production sector to make available all essential information about a product [1], or as defined in ISO 9000/2000 quality procedures: "as the ability to trace the history, application or location of an entity by means of recorded identifications" [2].

The objective of "manufacturing traceability" is to provide the information about the manufacturing process to be able to react against defects or wrong behaviours showed up in final products, but originated during manufacturing. With the review of the traceability data it may be possible to find, for instance, the lot identification of all components used to make a specific piece (Trace Back or Tracing). Then if a component lot is identified as suspected, the manufacturer can identify the final products made with components from that lot (Trace Forward or Tracking) [3].

1.2 Traceability for spread industrial collaborative manufacturing: E-Traceability.

As manufacturers try to be more "adaptive" and "collaborative" to better respond to customer needs and market forces, they increasingly outsource and partner with other companies to bring products to market. Collaboration is extended further beyond simple and traditional manufacturing contractor-supplier relations by considering all product life cycle stages along the whole supply chain [4] [5]. Companies shift internal manufacturing operations to distributed supply chain ones [6], establishing temporary alliances among enterprises to share resources and competencies. In these "extended enterprises", distributed activities performed along the supply chain become "e-activities" when new Information Technologies (IT) and standards for data exchange are applied.

In the same way, manufacturing traceability activities for extended enterprises has to evolve from an internal company focus to an external one [7]. The objective is enabling collaborative spread traceability activities over the whole product life cycle and along the whole supply chain: "e-traceability", when using new IT and standards for data exchange.

2 E-traceability Problems.

However even for simple products, e-traceability can be difficult to carry out in extended enterprises. Processing chains can be complex, because of the dynamic character of the relations between partners and the diversity of employed custom-enterprise traceability solutions. This difficulty may increase when manufacturing frequently changing and custom-made products (agile manufacturing), because traceability and quality requirements become dynamic [8]. Traceability implementation and traceability data management becomes complex and have the same data management problems as other collaborative supply chain tasks [9] [10]. In such environments, traceability has to overcome three important problems, summarized in Table 1.

Characteristics	Problem
Product or manufacturing processes are complex.	1. Interoperability: Traceability requirements and collected data are difficult to understand or interpret.
Multiple and changing subcontractor relations along the supply chain.	2. Availability: Traceability data are not always available when needed for the main company.
Traceability data is originated on different company systems with custom-made models.	3. Data Management: Traceability data are disaggregated, making full traceability difficult to achieve.

Table. 1 Extended enterprises and traceability associated problems.

First problem is the "interoperability" problem: or the ability of plant-level production applications and business systems to share information, exchange services with each other based on standards, and to cooperate using these information and services.

Second problem is the availability problem, coming from the temporary character of the relations between enterprises. Traceability data may be necessary after long periods of time, when some supply chain company may be no longer reachable.

And finally, the third problem points out the need for common traceability information models for the extended enterprise, to overcome the use of company custom models. Data can be lost or difficult to merge because companies use different data formats and organize information differently.

Although these problems are independent of the particular industrial sector, the way of addressing them may vary from one to other. This paper focuses in flexible CAD-CAM-CNC (Computer Aided Design – Computer Aided Manufacturing – Computerized Numerical Controllers) production chain scenarios for which new international standards as ISO STEP (ISO 10303; STandard for the Exchange of the Product data) [11] are being developed to improve industrial collaboration.

3 Traceability for spread CAD-CAM-CNC manufacturing chains.

3.1 Collaborative CAD-CAM-CNC environments.

Research on industrial CAD-CAM-CNC collaboration methods has focused on fields like e-design [12] [13], e-assembly [14] [15], e-manufacturing [16] [17], e-management [18], etc., resulting into new collaborative enterprise tools and platforms for CAD, CAE (Computer-Aided Engineering), CAM and PDM (Product Data Management).

The rapid advance of information technology associated with Numerical Controls (NC) is making possible, with more or less level of efficiency and flexibility, the so-called DABA systems (Design-Anywhere-Build-Anywhere). An important factor for the development of CAD-CAM e-manufacturing scenarios is the use of standards like STEP, which makes possible to share standardized manufacturing product data among different enterprises, and achieve effective levels of collaboration and interoperability from design to manufacturing. This is achieved through the use of several product models or views, describing its physical and functional characteristics and called Application Protocols (AP's). So for example, AP-203 [19] can be used by CAD applications to specify product design properties like geometry or tolerances. CAM applications can use AP-238 [20] to specify the operations and technology needed to manufacture the product, giving a mechanical view of the product. Different views of the same product share common product information. This make possible to link geometric (CAD), mechanical (CAM) or other AP data to obtain a complete description or model of the product needed in collaborative supply chain networks.

The paper proposal for addressing traceability problems in CAD-CAM collaborative manufacturing takes advantage of this emerging standard through the integration of traceability information with the STEP models for CAD (AP-203) and CAM (AP-238). This will allow not only traceability data to be exchanged between partners using existing frameworks for product data exchange but also to integrate and automate "traceability" with other e-manufacturing activities and processes.

3.2 E-Traceability Activities.

Figure 1 presents a simplified example of an extended e-manufacturing enterprise, where main e-traceability activities are identified: (1) requirement configuration, (2) traceability data collection and (3) traceability data management and analysis.

As figure 1 shows (part 1) the head company designs products composed by assembled parts which will be made by different suppliers. As it is the responsible for the product in the market, it sets up traceability requirements. Traceability configuration is a key activity when dealing with complex supply chains as it is the way to make traceability requirements clear to all involved partners.

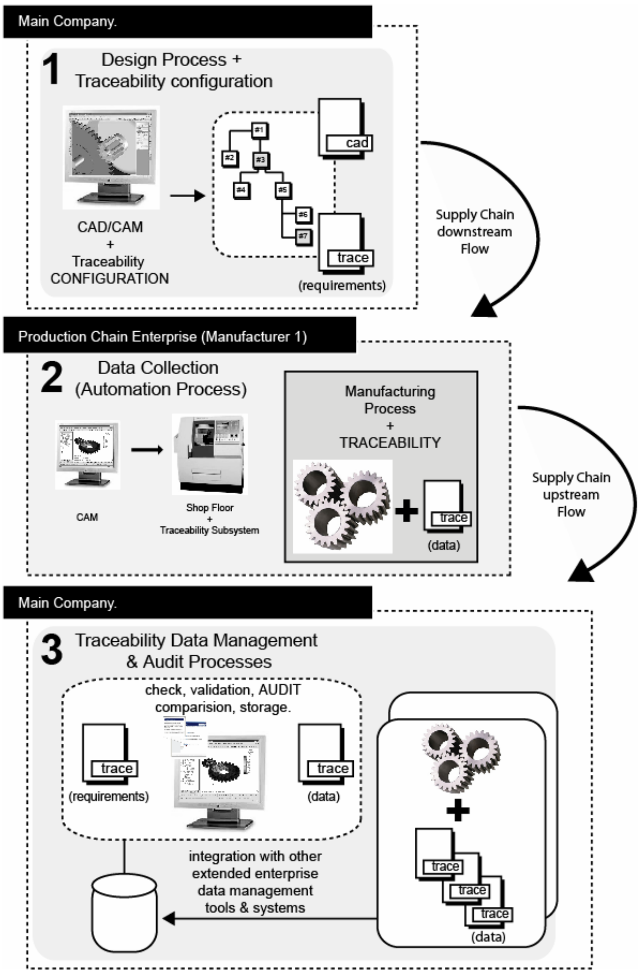

Fig. 1 SC Spread Traceability Activities.

Configuration is done at design level and electronically delivered along the supply chain at the same time CAD-CAM manufacturing designs are also communicated. Traceability configuration data follow a downstream information path that could be extended into several levels depth. Once at the final manufacturing enterprises (figure 1, part 2), manufacturing data is registered during components machining according to configuration requirements. When these components are assembled, the manufacturing traceability data follows an inverse upstream path.

Finally, the linkage between product traceability and product structure (CAD-CAM data) makes possible to merge up components traceability data creating complete and complex, but organized and self-understandable, traceability data blocks corresponding to assembled parts of the product.

This upstream information path continues along the supply chain, until the final product is delivered to the head company (figure 1, part 3). As a result, each manufacturing product (or lot) has full traceability information in digital format, and can be stored, reviewed, audited or verified…closing the traceability loop.

3.3 A Data Model for E-traceability Activities.

An STEP compliant traceability data model is proposed in this and next sections to accomplish these traceability e-activities in CAD-CAM-CNC spread manufacturing environments. The objective of the model is to give traceability information (both traceability configuration and collected data), geometric understandability and meaning (significance), by linking traceability information with the standardized STEP product data structure.

The STEP standard [21] defines products as hierarchical aggregations of assemblies and parts with features or attributes. These entities are uniquely identified and can be referenced across STEP APs and files. The use of a STEP compliant data model for traceability, besides of guarantee interoperability, provides the implicit mechanism to link traceability data and product data structure. The proposed STEP compliant traceability model incorporates these links as references contained in the "Trace Manufacturing Operation Relationship" entity from figure 2 (part A). This entity can reference parts or assemblies (Assembly Manufacturing Operations entity), features (CNC Manufacturing Operations entity) or any kind of part attributes (Process Manufacturing Operations entity).

Traceability information requirements and specifications about how the traceability data should be registered may vary a lot from one product to another. However, some general traceability data should always be present to allow answer essential traceability questions [22]: 6W-question approach [23]. It should allow answering, among other, basic traceability questions like:

- **W**hat and with **W**hat has been done?
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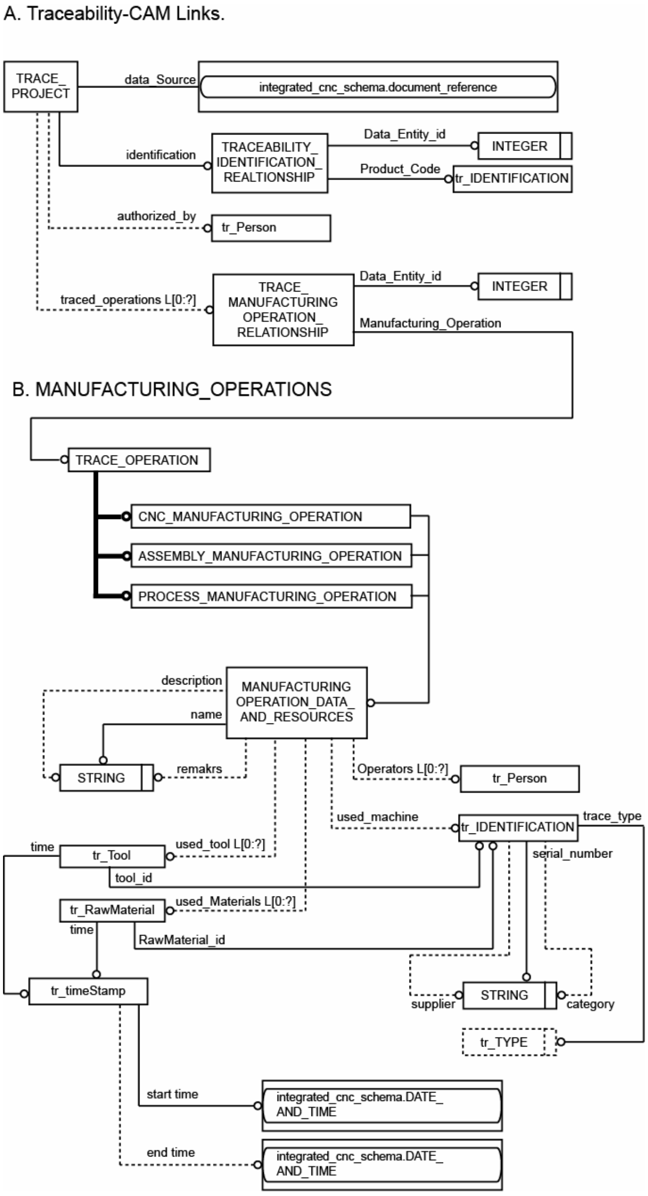

Fig. 2 STEP Compliant traceability Model.

Figure 2 (part B) shows part of the STEP-compliant data model which handles this information. This has been modeled for a sample CAD-CAM STEP-NC manufacturing environments, and includes data like: raw materials, parts, subassemblies and operations to transform them into final products, data about used tools, operators, time, etc.

Next sections will explain e-traceability activities: how traceability data can be configured –section 3.4-, populated during manufacturing –section 3.5-, used for auditing purposes –section 3.6–, and finally how the proposed model can help facing problems like aggregation and disaggregation on hierarchical data in complex manufacturing environments –section 3.7-.

3.4 Traceability Configuration.

Traceability configuration means first gathering the geometric product data from the CAD-CAM product design to set up the link between traceability configuration data and the product structure. And second, to set up traceability requirements on product parts or components. This can be graphically done over the CAD-CAM at design level.

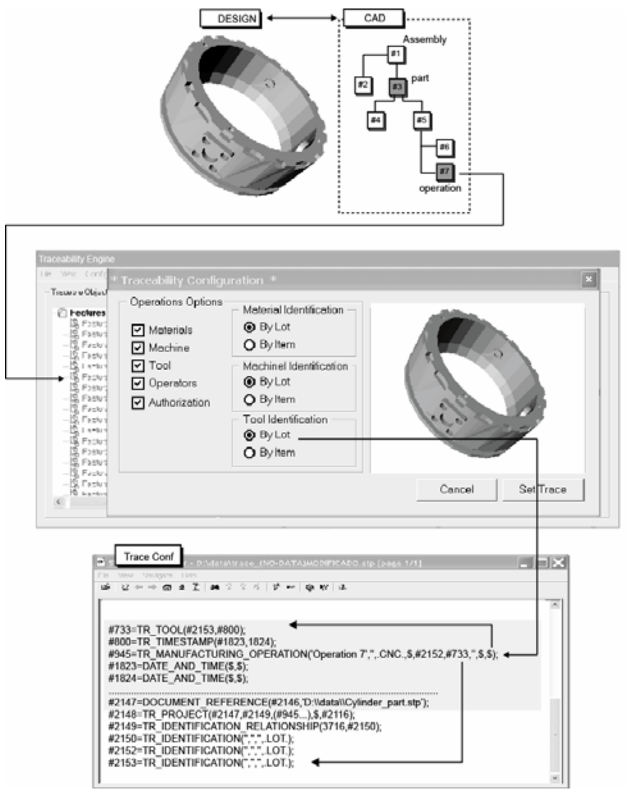

Fig. 3 Setting up traceability requirements.

An example of the configuration process is schematically depicted in figure 3, where the bottom window corresponds to a developed application to graphically configure traceability over STEP AP-238 data. In this example, it is needed to trace, among other data, the “lot” of the tools employed to machine a piece. The Configuring application has the product graphic structure knowledge from CAD-CAM data to allow the user selecting the specific components (piece feature). After the selection has been made, settled traceability requirements are translated into STEP part 21 physical format [24], so they can be exchanged and interpreted by supply chain partners when they receive both: CAD/CAM product designs and the attached traceability configuration files.

3.5 Traceability Data Collection.

Many quality control and traceability processes are still based on manual operations for collection and management of manufacturing data. This information can get lost, it may have typographic errors, it may be difficult to find and it may be misunderstood or corrupted during communication, as data collection and management are not automated.

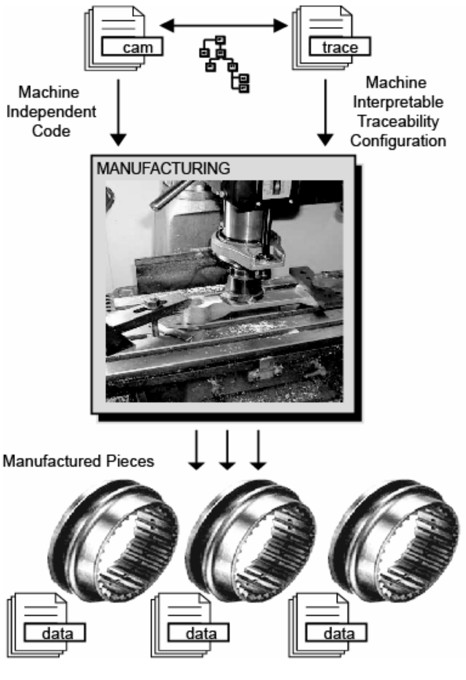

Fig. 4 Collecting shop-floor traceability data.

To automate data collection, traceability configuration files could play a similar role as CAM data have to define the machining automation. If traceability and product manufacturing data are successfully integrated, it will be then possible the complete automation of the traceability processes. This means having all traceability information available for the shop-floor machines at the same time the manufacturing information, so when the manufacturing machine interprets manufacturing codes, traceability instructions codes can be embedded, allowing the machines to automatically interpret them, driving the generation of traceability data and selecting when, how to, and which data must be collected for each of the manufacturing operations (figure 4).

Manufacturing data collection is done for each product, thus each individual product will have a unique traceability data file, corresponding to its particular manufacturing conditions.

3.6 Traceability Data Review & Auditing.

Once manufacturing traceability data has been collected and correctly communicated, the main company can carry out visualization and auditing processes. Data visualization, processing and management can be done through graphical user interfaces directly over CAD-CAM designs, allowing browsing traceability through complex product structures. The implicit linkage mechanism between traceability data and CAD-CAM product data plays an important role to simplify this task as explained in section 3.7. (figure 5).

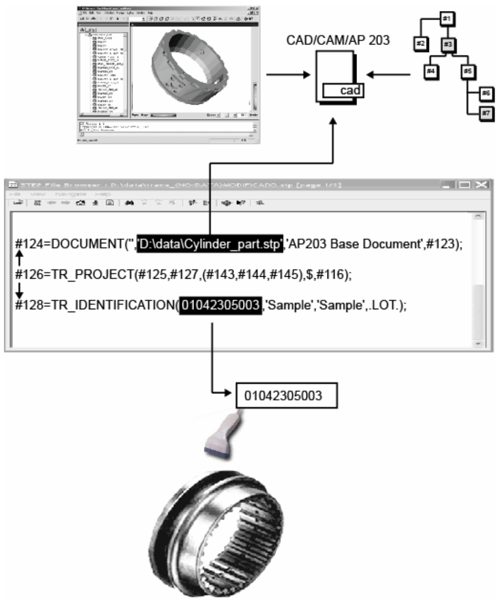

Fig. 5 Reviewing collected shop-floor traceability data.

It is important to distinguish data audit from data review. An efficient traceability implementation has to provide exactly the right information at exactly the right time, and this means the value of information is dependant on its relevance (fit for the purpose), its currency (timeliness), its accuracy, its availability and its accessibility (ease of use).

Audit lets the main company to examine traceability data and compare it with the traceability requirements. As traceability requirements and collected data share the same structure and format, it can be easily fulfilled and used to detect which data has not been filled or not correctly register by the manufacturers. This is an important traceability activity carry out by tools for confirming some essential data properties like completeness, accuracy and veracity.

3.7 Spread e-Traceability example implementation.

In extended enterprises, product manufacturing responsibility is spread along the supply chain manufacturing enterprises.

As figure 6 shows, the CAD-CAM product design is split to be delivered to the supply chain partners. Specific traceability requirements for each subpart are communicated with the subpart data and delivered to the corresponding supply chain nodes following a **downstream** information path from design companies to manufacturing facilities (figure 6, right arrow). As it happens with CAD-CAM data, a key capability for traceability data must be the possibility of “data fragmentation”.

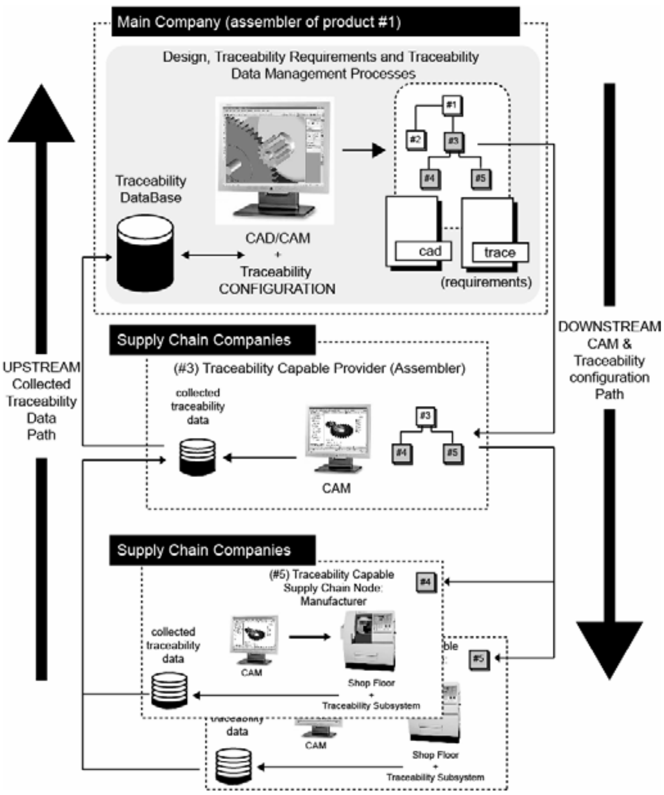

Fig. 6. Upstream and Downstream Traceability Data paths.

Thanks to its structured format, STEP simplifies these data splitting into subpart manufacturing data blocks. With an STEP-compliant traceability data model, it is then possible to logically break up full product traceability requirements into fragments for each product component and dynamically controlling the granularity of the traceability data to be shared. The objective is to guarantee that traceability requirements can be easily understood at shop-floor.

However, another characteristic to be considered is that traceability data flow must be **bidirectional**. Traceability data requirements are interpreted at the shop-floor, resulting in collected traceability data while manufacturing. These recorded data should be communicated back following an **upstream** (figure 6, left arrow) supply chain path. Despite the adopted solution for data communication, a key feature will be again the linkage between traceability data and product structure. This “data reassembly” process allows assembler partners or main companies to preserve full part traceability data available independent of the temporary character of the relations with its suppliers, or even though the partner does not have an own traceability database.

4 Conclusions and present work.

Within the extended enterprise, traceability has to evolve from an internal (within a company) paradigm to a collaborative one. The paper has presented a model to address problems of extended or collaborative traceability activities in spread manufacturing CAD-CAM-CNC chains. The proposed solutions are summarized in table 2.

Problems	Solution
1. Traceability data are difficult to understand and link with product parts and operations.	Traceability data can be linked with CAD-CAM product data.
2. Traceability data are not always available when required for the main company.	Traceability data will be electronically delivered with manufactured parts as part of already settled product data exchange.
3. Traceability data are disaggregated and not standardized making full traceability difficult to achieve.	Traceability data standardization integrated and shared with other product data management models.

Table. 2 Proposed solutions for traceability data problems in CAD-CAM collaborative environments.

Table 2 solutions have a common objective: “traceability activities automation”. But automation of traceability in flexible CAD-CAM-CNC environments has to face the frequent change of products specifications. For instance, an automatic recording data process, without human intervention, has to automatically adapt to changes in the product definition, changes in the traceability requirements, changes in the machining process specification etc. The authors of this paper are currently working in the definition of NC functions to be interpreted and performed by a CNC machines working with AP238 CAM specification. These works are being developed by the authors as members of the ISO TC184/SC4 manufacturing group, the group responsible for implementation AP238. Proposal and demos may be found at: http://www.aisa.uvigo.es/jgarrido/Etrace.

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