Methodology for Internal Traceability Support in Foundry Manufacturing

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Abstract. Appropriate description and implementation of internal part traceability in manufacturing is a complex task. Accurate and real-time traceability from a part, or a part feature, to a manufacture, storage, or transport issue is essential to efficient and high-quality operations. With the increasing amount of machine status and product quality information coming from the manufacturing lines, certain questions arise. When there is a problem with the process or product quality what information can be utilized to enable effective traceability to the foundry batch lot? Also, what aggregate information values are needed to enable real-time problem solutions? In this paper a systems-based approach is used to propose a method to define and implement internal part traceability in two participating foundries.

Keywords: Foundry Traceability, Foundry Process Automation, Internal Traceability

1 Introduction

Similar to existing *flexibility* definitions[1]; *traceability* in literature also results in a number of definitions and its types and its applications being in areas ranging from part recall, part-liability-prevention, process improvement, logistic applications etc. Traceability in the context described in this work, can be defined, as the ability to retain and trace the identification of the part, its originating melt batch and value added operations [2]. The two industrial implementation discussed relates to the traceability in a passive sense [3]. Traceability in the passive sense helps in providing visibility to which melt batch do the parts come from, where the items are and their respective dispositions.

There has been very limited academic literature published in the area of foundry traceability, and almost non-existing in traceability related to data collection supporting manufacturing control plan, and hence the novelty of this paper. Vedel-Smith et al. presented a methodology for enabling traceability cast iron foundries by part number marking on individual castings [4]. Arabatzis et al. described the issue of traceability in aluminium foundry [5]. The paper rest of the paper is organized as follows : Section 2 describes the usage requirements of internal traceability system for iron foundry. Section 3 describes the methodology for iron foundry traceability. The de-

adfa, p. 1, 2011.

scribed methodology and the data collection activity can be extended to the capture data from processes (see process sequence in the Appendix) through the entire foundry manufacturing enterprise. The methodology and procedure were applied to an iron foundry business described as case study I and were also found applicable to an aerospace foundry business described as case study II. Section 4 presents the conclusions.

2 Usage requirements for internal traceability system in an iron foundry

The Implementation of a traceability system in the manufacturing process is a complex task. Several problems exist at different stages throughout the process. In order to achieve traceability goals the manufacturing firms should focus both on internal plant traceability. Determination of the usage requirements of the traceability system is the first step in implementing the system. Each manufacturing sub-process should determine their traceability plan based on the driving factors like the regulatory need, business need and the customer preferences. Relational database management system could be used to implement internal traceability system by each process step. All batch manufacturing information should be recorded in a centralized database system and only relevant lot/batch information should be passed on to the next link in the process. Additional information can be requested by the authorized users (such as regulatory agencies) in case of a part non-conformance. This additional information should be provided in a timely manner

Below is a proposal for a standard traceability procedure which contains the following elements:

• ***Users****:* People (at some level of the organization and with certain limitations) who are able to input and extract data from the system.
• ***Actors:*** An actor is a person or organization that plays a role in one or more interactions with the system.
• ***Associations*****:** An association exists whenever an actor is involved with an interaction in the traceability system procedure.
• ***System boundary:*** The boundary indicates the scope of the system.

The following procedures and use case actors are proposed for iron foundry traceability systems:

Process Traceability**:** The foundry should be able to record the raw material batch, metal composition, the complete manufacturing process of the part including automated machining and the handling processes used by them internally in the facility.

Machine Status Traceability: The operator working on the part should be able to record (depending on the downstream and final customer requirements) the manufacturing processes and parameters used in the system. Depending on the machine it may include heat lot number, metal batch number, holding time etc.

Authentication Support: The manufacturing system and its users must be able to use the data stored in the system to authenticate their claims based on the complete data set.

Customer Regulations Compliance: Using the traceability system, the manufacturing system actors should be able to retrieve data to show that the manufacturing processes comply with the customer requirements.

Company Integrity Protection: The system users must be able to protect the integrity of their company through the traceability in the system. For example, if the part is claimed to be produced under controlled process parameters the system should support traceability to those parameter values.

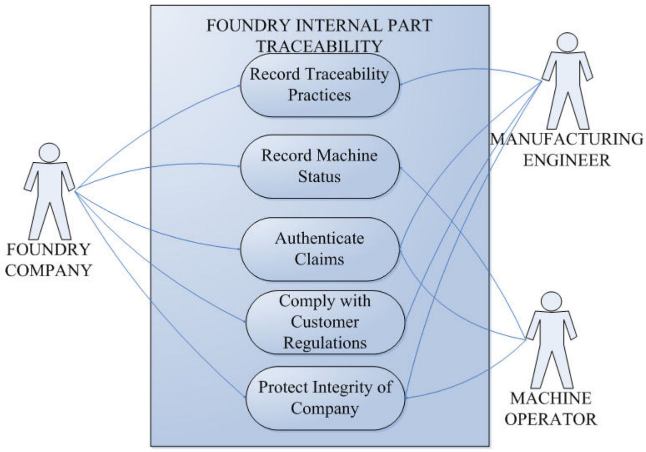

Figure 1 General usage requirements for an iron foundry process

3 Methodology for iron foundry traceability

The following methodology is described from the perspective of a part's journey in the foundry internal manufacturing process. The main purpose of the methodology is to enable quick identification, collection and integration of traceability data using automation enablers following the parts journey in a manufacturing facility. [12] The methodology can be extended and applied to the entire enterprise.

Step 1: Investigate the system and build the functional model

At this stage the model builder identifies the characteristics and operations of the system under investigation. Through a variety of methods available for this purpose, such as: interviews with stakeholders, a walk-through the system, use of company's operating manuals etc. The primary task is to identify the operating rules. The next step is to translate these operating rules into a series of IDEF diagrams. The main objective of this step is to develop a complete functional model of the system under investigation. The IDEF modules are assembled in hierarchical fashion so more details can be shown at lower levels. The resulting functional model forms the basis for identifying the data requirements.

The functional (IDEF0) model

The IDEF0 functional modelling methods are designed to model the decisions, actions and activities of the system.[125] The methodology permits a system to be described as completely as desired. A series of standard IDEF0 functional model diagrams for the system elements in sand casting flexible automation cell were developed which were suitable to Jøtul. (selective details disclosed on request) For example, the figure below shows one of the standard IDEF0 functional model diagrams that describes the requirements to develop inetrnal traceability at the flexible automation cell.

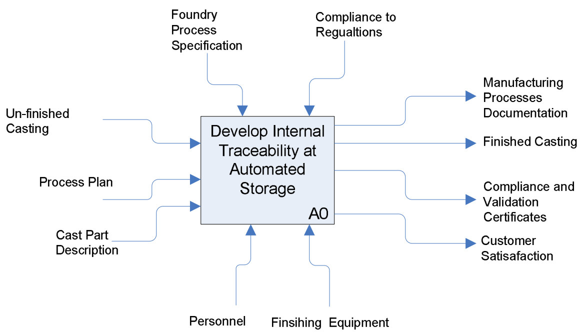

Figure 2 Model for developing internal traceability

Although IDEF0 models are good at providing an initial view of activity development it is unable to describe the integration among various components. Based on the traceability information requirements, a foundry manufacturer, for example, is supposed to develop a control plan with all process details and raw materials along with the tools being used. The control plan is to be approved by the customer by means of technical audit. This control plan becomes the basis on which quality system is developed. A control plan also gives various values of parameters within which it needs to be controlled, frequency of checks, composition of the melt, sand properties, core sand properties, recycling metal properties, recycling sand properties, critical dimensions, reference surface, mechanical properties, and any other special customer requirements. This eventually leads to process control, which is the basis for product consistency.

Step 2: Build the reference model of the system

The reference data model’s purpose was to describe the integration among various components such as parts, resources, and the manufacturing logic into a single system to describe the flexible automation cell database implementation conceptually. The reference data model shows the major entities with their attributes and relationships. For a relational DBMS (database management system), each entity in the reference model becomes a table and each attribute becomes a column. Primary (PK) and foreign keys (FK) are declared for each relationship.
Everytime a part transformation (*finishing, rework or scrap*) takes place, the resulting dispositions are recorded. The information regarding the part handling (picking and placing) position and orientation using various grippers is also recorded.

Step 3: Collect and store data

The internal database to this finishing cell is required to maintain information about the operations performed on the part, the operation outcome and automated storage entry/exit movement date and time, the operator, machining status, outcome of the machining process, and the time of movement out from the automated storage. By utilizing the relational database design, the developed model can store, manage, and retrieve cast part processing data and make it available to the plant-wide ERP system. As long as all the relevant information is recorded in the local database of the cell the retrieval of all necessary information in the production process becomes easier. In appropriate manufacturing environments, it is possible to link data tables directly to the data sources, such the robots, the vision system, etc. via standard protocols.

Step 4: Validate and handle non-conformances

A quality assurance plan should be developed which ensures the data quality and personnel assigned who monitor the system and establish a process to maintain the quality of data stored and the equipment. Any non-conformance should be submitted to the appropriate non-conformance authority for part disposition.

Case Study I

A series of IDEF diagrams were created to support the implementation of part traceability at an automated cell at company 1 (a commercial product cast iron foundry manufacturer). The foundry wanted to look into automating traceability data collection at the CNC finishing and thereby reducing the manual handling of heavy parts with flash on its edges.

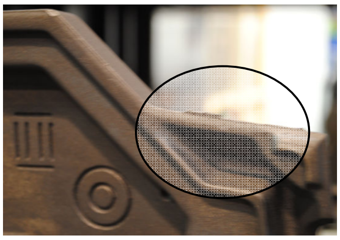

Figure 3 Cast iron parts with flash on the edges

A series of standard IDEF0 functional model diagrams for the system elements in sand casting flexible automation cell were developed which were suitable to the manufacturing needs. The manufacturing automation installation consists of the following modules: (1) the vision module, (2) the robot module (3) the robot end effecter part handling module (4) the automated storage lift, (5) the CNC machine (6) RFID tags placed on the (7) part family fixtures. When there is an order from ERP system to meet a request downstream, the HMI requests the bin selection from storage lift. When the requested bin is available at the exit of the lift the robot receives a signal notifying that the bin is in place under the vision system, and notifies the camera through PLC, to take the picture. The position and orientation of the part/fixture is transferred to the robot via the PLC, which then proceeds to orient the gripper accordingly to pick the part. Different grippers and configuration for part pick-up and delivery position to the basket were programmed by the foundry engineers to make them available for possible use. After the part is loaded by the robot on the CNC the delivery of the part on the fixture is confirmed by the inductive sensors located on the fixture. The part is located on the fixture via rotation and sliding locators. A sliding locator ensures that the variation in part linear dimensions during the casting process is properly compensated. If the part is in the correct position the clamps are activated and the machining starts.

Step2 and Step 3

The entity-relationship (E-R) technique was used to develop the internal traceability database model for the automation cell. The E-R model is represented in terms of entities in the manufacturing environment, the relationship among the entities and their attributes. [16] The implementation of the database, the human-machine software interface and its performance testing was conducted by an external vendor and is proprietary on request. A control plan was developed for use at the automation cell by the manufacturing engineers under the supervision of the Quality director at the company. Initial validation of the installed automation cell was done internally in the company. Due to company's reorganization and facility layout restructuring, any further validation of the cell could not be conducted.

Case Study II

Case company 2 is an aerospace metalcasting components manufacturer with lifelong data traceability requirements. (Selective details disclosed on request) At the manufacturer, the process starts when an operator loads a part into a fixture and puts it on the incoming conveyor line. The operator then keys in the part number and serial number using the HMI. This will send the message to the machining center and CMM for the process that is required for the loaded part or parts. The Fanuc robot then comes to the incoming conveyor and retrieves a pallet, moves it to the CMM for a pre-alignment part offset location. This information is then sent to the machining center, the Fanuc robot moves the pallet from the CMM to the machining center, and the machining cycle starts.

After the machining is finished the Fanuc robot moves the pallet from the machining center to the blow-off clean booth. The robot then moves the part back to the CMM for the inspection process. After the part inspection is, finished the data is sent to a database, it moves the pallet to the correct outgoing conveyor, and the process starts over for the next part.

4 Conclusions

From the literature it is apparent that the use of traceability data is not limited to crisis situations, where defective products need to be identified and recalled, and situations where evidence needs to be provided. It is very clear to many authors that the necessity for traceability exists throughout a variety of manufacturing businesses whether it is a foundry or an aerospace manufacturer. The methodology could be generalized and applied to the case of an aerospace manufacturer, as the data collection process supporting traceability remains the same but the regulatory requirements on data storage may be longer, for example 50-60 years or longer, as compared to the short term requirements in commercial product manufacturing foundries. There is a wealth of data present in the new automated systems and it can be used to provide the status of each component in the system as well as the condition of the systems components. From the business side of the organization the data can be fed to an internal database and determine if the performance of the manufacturing operations is in line with the planed output and to know the quality of the parts as they come off the end of the line. The data is valuable and can be utilized for as many of the process indicators that are possible. As the processes are developed, the traceability element will need to be part of the design. This type of innovation will keep the organization on the leading edge of the competition.

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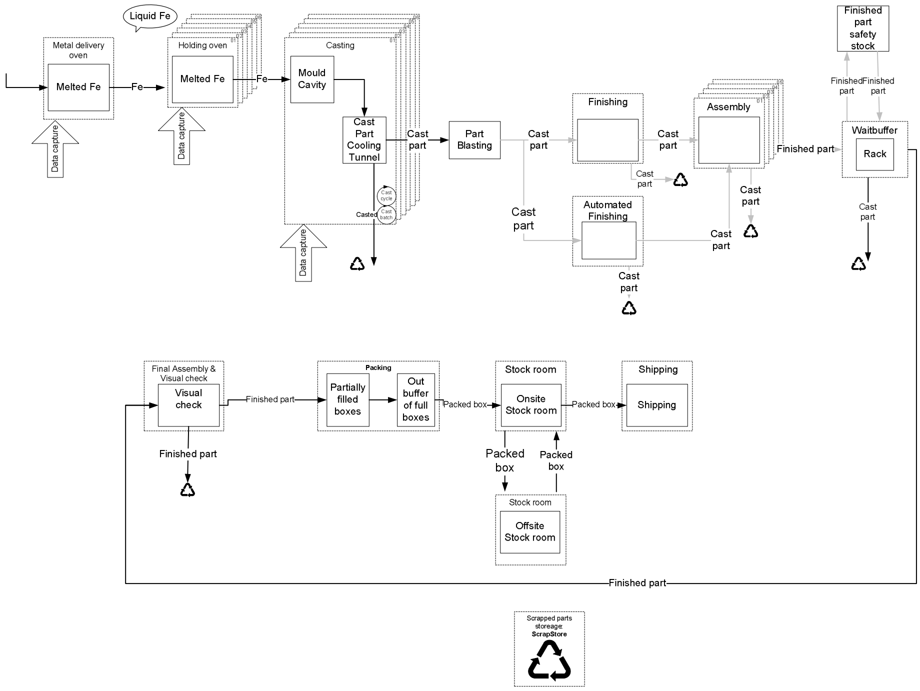
APPENDIX



An Iron Foundry Process Sequence