# Dimensional Inspection Planning Based on Product Data Standards

Shaw C. Feng
Factory Automation Systems Division
Manufacturing Engineering Laboratory
National Institute of Standards and Technology
Gaithersburg, Maryland 20899

**Abstract**

*This paper describes an activity model for dimensional inspection planning that bridges the gap between product design and the dimensional measurement of manufactured products. Functionally, this model specifies requirements for developing a part of a product data exchange standard that enables design, inspection resource, and measurement data to be exchanged among computer aided design systems, computer aided process planning systems, and coordinate measuring systems. A set of diagrams has been generated to represent the activity and its sub-activities, inputs, outputs, controls, and mechanisms, when such inspection planning is based on technologies of product data exchange, process planning, and information modeling.*

## 1 Introduction

Dimensional inspection planning is an activity to generate specific instructions to inspect manufactured parts based on the product design. Properly developed inspection plans will ensure consistency of measurement results. Inspection planning activity and data models are necessary to enable inspection planners and product designers to effectively communicate during product design and inspection process planning.

The model described in this paper is a proposal to develop an international standard, ISO 10303 [1], also referred to as STEP, Application Protocol (AP) [2] for "Dimensional Inspection Plan for Coordinate Measuring Using Tactile and Video Sensors". The development of this model is a part of the work within ISO Technical Committee 184 (Industrial Automation Systems and Integration), Subcommittee 4 (Industrial Data and Global Manufacturing Programming Languages). This AP is to harmonize STEP with DMIS (Dimensional Measuring Interface Standard) [3] which is a U.S. national standard that provides interface formats for linking computer aided design (CAD) systems and coordinate measuring machines (CMMs).

The objective of the development of this activity model is to specify the information requirements for the exchange and use of product data for dimensional inspection planning when manufactured parts are inspected using CMMs and vision systems. The relationship between inspection planning, STEP, and DMIS is graphically presented in Figure 1.

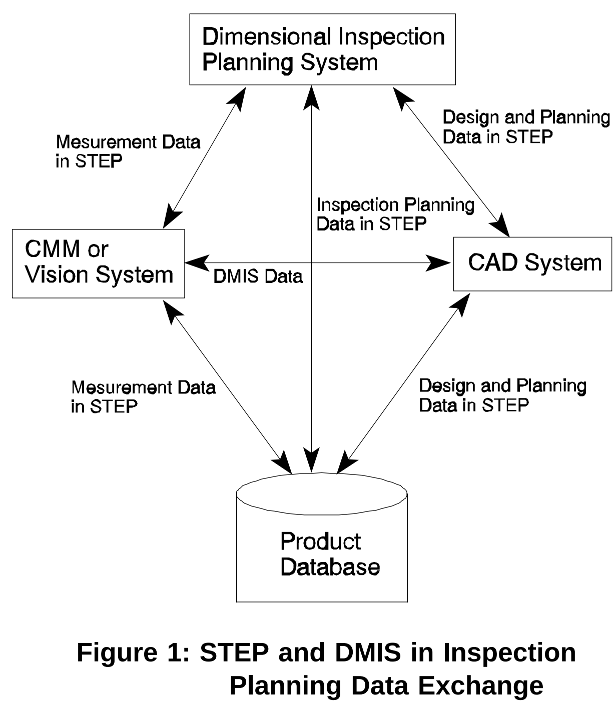


**Figure 1: STEP and DMIS in Inspection Planning Data Exchange**

The intended audience of this paper includes dimensional inspection planning system developers, product data standards developers, process information modeler, and those who are interested in facilitating design and process planning integration.

The model presented in this paper will provide standard and system developers with a basis for developing product data exchange standards and inspection planning systems.

# 2 Review of Fundamental Standards and Methodologies

Standards provide common language and data formats to exchange process plans between different application systems. Process planning methodologies provide the means to efficiently generate process plans that are consistent and effective.

## 2.1 Product data model standards: STEP and DMIS

STEP provides a data model capable of capturing product information necessary to applications throughout a product's life cycle. Product data is a general term used to refer to some or all of the pieces of information captured in the model. Product data includes shape definitions, properties of a product, assembly of the product, and application-specific constraints to the data. Examples of product data are geometry, topology, material, dimensions, tolerances and assembled structure. Application protocols are composed of specifications of information requirements for application domains to define and use the generic data model. The objective of STEP is to provide a mechanism to clearly, unambiguously and completely represent products. Industries use the product data to develop product models and process plans in an integrated manufacturing environment.

The fundamental structure of STEP, represented in Figure 2, has six major components: principles, implementation methods, description methods, conformance testing methods, integrated resources and application protocols.

Similar to STEP, but with a smaller scope, DMIS provides neutral formats for the exchange of some part design data, inspection data, and measured values of manufactured parts between CAD and CMMs. DMIS specifies data structures of information on part design and the inspection process (dimensions, tolerances, features of discrete manufactured parts, inspection process parameters and measurement results such as actual dimensions and tolerances of features). Like STEP, DMIS is computer interpretable as well as human interpretable. However, there is currently no link between STEP and DMIS. The work represented in this paper is an attempt to provide the first step in linking the two standards.

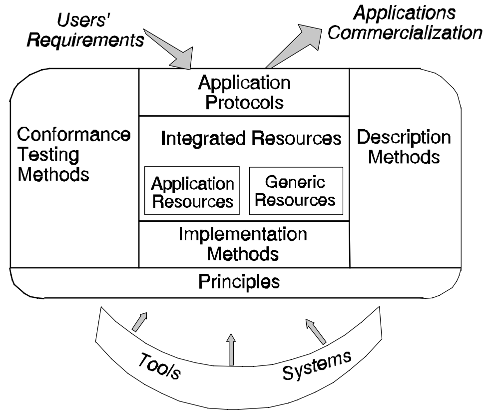


**Figure 2: Fundamental Structure of STEP**

## 2.2 Process Planning Methodologies

Process planning [4, 5, 6] is an activity to devise means and specify instructions for manufacturing parts to achieve productivity and quality goals under given constraints of limited resources and capability. The quality goals are specified in product design. For example, in a machining process plan, specific activities include selection of machine tools, selection of cutters, determination of set-ups and fixtures, determination of machining operations and their sequence, calculation of cutting conditions, generation of tool paths, and generation of NC programs. Specific goals include manufacturing parts to be within tolerances and surface conditions specified in the design, optimizing process parameters, reducing the number of scrap parts and increasing productivity.

Computer aided process planning (CAPP) provides flexible ways of generating process plans. CAPP is based on knowledge acquisition and processing technology, which aids the planning activities to generate more consistent and effective plans than the ones created manually. There are three major approaches in CAPP: variant, generative, and semi-generative. The variant approach is based on group technology. In group technology, various similar parts are grouped together and a coding system is developed to describe the relationships of parts in and between groups. Standard process plans are first developed and stored in a computer for groups. A new part will be given a code to show which group of parts it belongs to and then a standard process plan is retrieved and modified to suit the new part. The generative approach automatically synthesizes the process information to develop a plan for a part directly from the part model and process logic. The manufacturing knowledge, manufacturing process databases (containing data on machines and their capabilities, tools, jigs, fixtures, etc.) and process planning algorithms are stored in the computer and used when a new part model is available. The semi-generative approach combines both the variant approach and the generative approach. For a new part coded according to group technology, a standard plan is retrieved first. The retrieved plan is then modified and completed using a generative approach.

In dimensional inspection planning methodologies, Hopp and Lau [7] developed a hierarchical model and surface decomposition method for automated inspection. In this approach, toleranced features to be inspected are decomposed into datum features and inspection features. A datum feature can be a compound feature. Similarly, an inspection feature can be a composite feature. Compound datum features and composite features are decomposed into simple features (individual surfaces). Probing points and probing paths are then generated on the surfaces of features for inspecting the feature and surfaces of datum features for establishing datums. This tolerance decomposition technique provides a basis for dealing with toleranced features in inspection planning.

ElMaraghy and Gu [8] and Menq, Wang and Yao [9] developed methods to integrate a knowledge based capability into an inspection planning system to prove the concept of using a generative approach in inspection planning. Properties of manufactured features to be inspected are represented. Rules for the extraction of information from feature representations, the selection of CMM and the determination of measurement sequence are implemented. Knowledge-based inspection allows automatic decision-making for creating consistent plans.

Brown and Gyorog [10] developed an activity model for inspecting parts using CMMs with touch-trigger probes. The activity model is an IDEF0 diagram which represents input, output, control and mechanism (resource) data and planning activities. This work applies information modeling techniques to define and describe relationships between activities and data.

Applying video sensor technology to part inspection can increase the throughput and the flexibility of inspection. Vision-based inspection planning systems [11] that have video sensors are currently under development. The inspection planning capabilities include planning the inspection path, generation of a nominal image of the part, and determination of cameras and process parameters.

Inspection planning technology has been evolving. Methodologies have been developed in the areas of automatic tolerance decomposition, utilization of knowledge acquisition and processing capability, and modeling the information required in inspection process planning. For a successful dimensional inspection planning task, a part model must provide the necessary geometrical and functional descriptions of the part. STEP provides these descriptions. Knowledge acquisition and knowledge processing capabilities provide efficient and consistent planning. Knowledge-based technology assists process planners to best use the existing experience. The knowledge should include manufacturing process knowledge, inspection knowledge and resource utilization knowledge. DMIS provides a basis for transferring inspection plan data to dimensional measuring machines. Integration of CMM simulation with CAD systems facilitates verification of planned inspection paths.

## 3 Inspection Planning Activities

The Dimensional Inspection Planning activity model, represented using IDEF0 [12], is represented by eight diagrams showing activities at different levels of abstraction. Figures 3 to 10 represent diagrams for the following activities: A-0, A0, A1, A3, A4, A41, A42, and A43.

### 3.1 Performing Dimensional Inspection Planning

Activity A-0 shown in Figure 3 is for modeling the context in which the inspection planning activity takes place. The overall activity on level A-0 is decomposed into five activities (A1 — A5) shown in Figure 4. The A0 diagram shows the relationship between activities and data inherited from the upper level (A-0).

Activity A1, expanded in Figure 5, is for identifying what tolerances, dimensions and features (toleranced or untoleranced) are within the scope of the part inspection. This activity also includes determining the accuracy requirements — the probabilities of rejecting good parts or accepting bad parts — and machine accuracy.

Activity A2 is for decomposing the selected tolerances and features into composite features (if the toleranced feature has composite features) and into compound datum features (if the datum features are compound datum features). A composite feature is further decomposed into simple features, each of which is a single surface. Similarly, the compound datum feature is decomposed into simple datum features.

Activity A3 is for selecting dimensional measuring equipment and data analysis functions. Measuring machines and sensors are selected depending upon feature geometries, tolerances and accuracy requirements developed in Activity A1. The data analysis functions are selected for evaluation of actual features and tolerances based on design specifications.

Activity A4 is for developing the inspection process plan. Using previously developed data, Activity A4 will be for specifying the part set-up on the measuring machine, determining the inspection strategy, generating simulated inspection paths for verification, and approving the draft inspection plan. Instructions for the inspection process will be specified and documented in the approved inspection plan.

Activity A5 is for generating data for supporting the inspection, such as preparing work orders, equipment orders, etc. These orders are specified in support data.

### 3.2 Identification of Inspection Scope and Accuracy Requirements

Figure 5 shows the decomposition of activity A1 into four activities (A11 — A14). Activity A11 is for retrieving a product model from a STEP data file or a database into the inspection planning system. Information retrieved from the product model that is relevant to the inspection includes all the tolerances, toleranced features, associated datum features and untoleranced features for in-process inspection. These data will be processed in the next activity.

Activity A12 is for selecting tolerances to be inspected. The inspection planner selects toleranced features that are critical to parts functional requirements within the inspection scope.

Activity A13 is for selecting features to be checked for their completeness during in-process inspection, such as using video sensor to check the existence of features.

Activity A14 is for specifying accuracy requirements of the inspection results. Statistical distribution of measurements is commonly used to quantify the measurement uncertainty of inspection results [13].

Activity A2 has no decomposition.

### 3.3 Selection of Dimensional Measuring Equipment and Functions

In Figure 6, Activity A3 is further decomposed into three activities (A31 — A33).

Activity A31 is for selecting measuring machine(s). Based on inspection accuracy requirements and complexity of part features, the inspection planner selects a primary measuring and, perhaps, one or more alternative measuring machines for the part inspection.

Activity A32 is for selecting sensors to be used in the part inspection. Sensors are selected based upon several factors, such as inspection type, accuracy requirements, complexity of the part, sensor’s characteristic, etc. More than one sensor can be selected to perform the inspection.

Activity A33 is for selecting data analysis functions that are provided for tolerance evaluations. The inspection planner generates a list of data analysis functions for tolerance evaluations.

### 3.4 Development of Inspection Process Plan

In Figure 7, Activity A4 is further decomposed into four activities (A41 — A44) for detailed generation of an inspection process plan.

Activity A41 is for determining part set-up on the measuring machine table. The set-up of the part includes the part orientations, fixtures, and clamping devices to make every feature accessible by sensors without interference of the sensor or the inspection machine motion.

Activity A42 is for specifying inspection methods which can then be converted into inspection instructions directly. The inspection methods include sampling strategies (if the sensor is a touch-trigger probe), the measuring sequence and the process parameters.

Activity A43 is for validating and approving the draft inspection plan. The approval takes place as soon as all the elements of the inspection plan are developed and validated.

Activity A44 generates DMIS inspection programs for actual inspection of the part according to the approved inspection plan.

### 3.5 Determining Set-up

In Figure 8, Activity A41 is further decomposed into three activities (A411 — A413) for detailed specifications. Activity A411 determines part orientation to be fixed on the measuring machine. The part has to be oriented so that every toleranced feature can be reached and measured by sensors.

Activity A412 is for determining fixture specification. Available fixtures can be selected from a fixture database. If an appropriate fixture is not available, a new fixture may be purchased or designed and made. The make-or-buy decision depends on part geometry and the capability of selected sensors and machine.

Activity A413 is for determining whether clamping devices are needed. It also determines type, quantity and configuration of clamping devices.

### 3.6 Specifying Inspection Plan

In Figure 9, Activity A42 is further decomposed into three activities (A421 — A423) for the detailed specification. Activity A421 determines the measurement position, e.g., points to measure using touch-trigger probe or camera positions using video camera to inspect surface. No matter what sensor is used, discrete points (samples) on part surfaces are taken from a surface.

These measured points are then used to evaluate the feature, whether it is within tolerance specification.

Activity A422 is for determining the inspection sequence. The considerations in this activity include sequence of orientations in measurement, sequence of measuring tolerances in each orientation, sequence of measuring features in each tolerance, sequence of measuring surfaces in each feature and sequence of taking sample points on each surface. Also, the transitions of probe (or sensor) from orientation to orientation, tolerance to tolerance, feature to feature, surface to surface, and point to point are specified.

Activity A423 is for determining process parameters. The process parameters are values that influence the inspection process, such as machine speed, ambient light, room temperature, machine mode, sensor orientation, etc. The process parameters are set initially and reset as necessary in the measurement sequence.

### 3.7 Validating and Approving the Inspection Plan

In Figure 10, Activity A43 is further decomposed into two activities (A431 — A432) for the detailed specification. Activity A431 is for generating machine-and-probe motion simulation. This simulation is for verification purposes. The simulation determines whether the probe collides with part, fixture or machine.

Activity A432 is for approving or disapproving the draft plan by an inspection plan validator based on the draft plan and simulation. Change requests may be sent to the inspection planner by the plan validator to modify and improve the draft plan. A draft plan is approved when this verification process shows that there are neither collisions nor interference with sensor operation.

## 4 Summary

The inspection process planning activity model described in this paper is a proposal of requirements for developing a part of the ISO 10303 standard. The purpose of this activity model is to capture information required in the dimensional inspection planning process based on STEP and DMIS. The activity model was specifically developed for coordinate measuring using tactile probes and video sensors which are commonly used in industry. The IDEF0 diagram is a model which specifies activities of inspection planning that use and access the design data retrieved from a STEP database. The planning activities produce an inspection plan which can be exchanged among different inspection planning systems, CAD systems or CIM systems.

The next phase in the development of an inspection planning AP will be to generate a data model to characterize the structure of the information identified in the activity model.


## Acknowledgement

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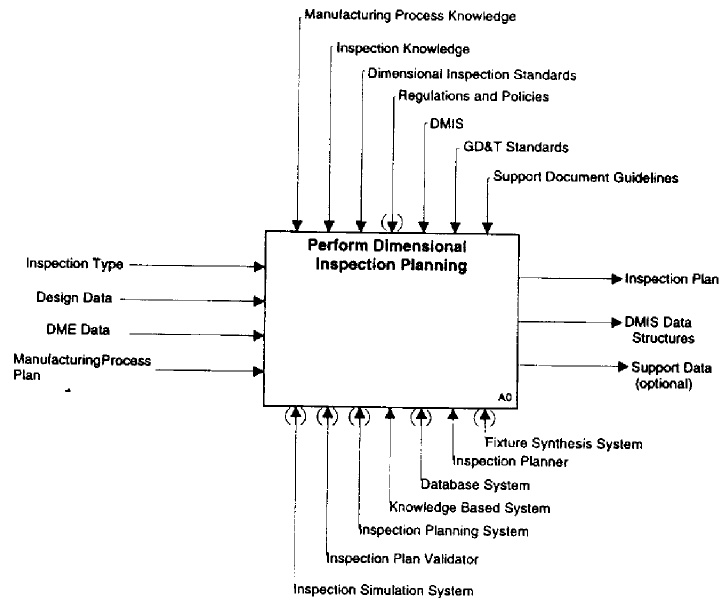



**Figure 3: Activity A-0**

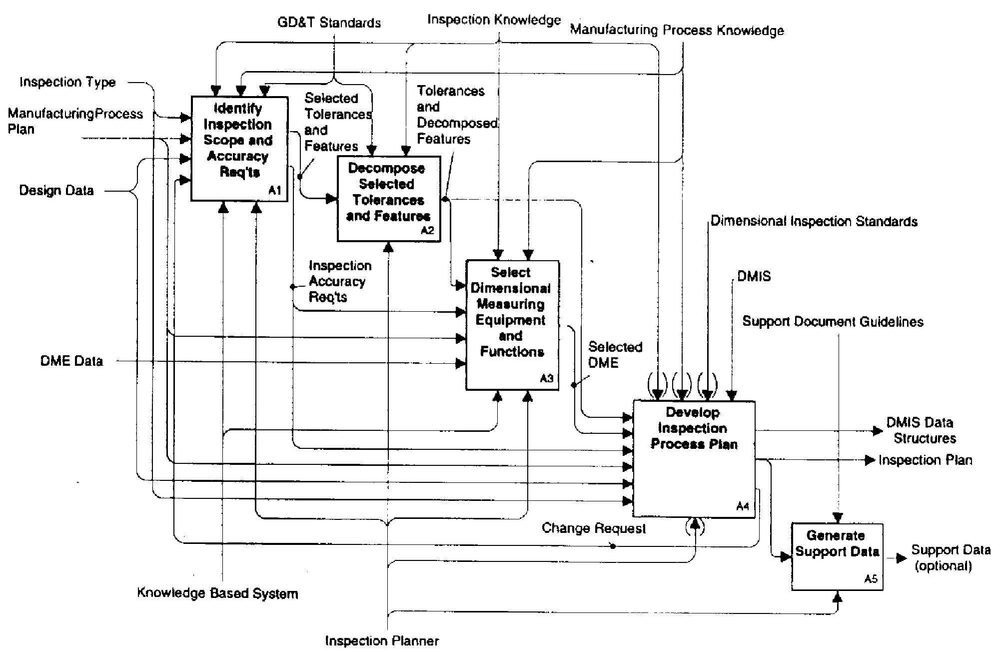



**Figure 4: Activity A0**

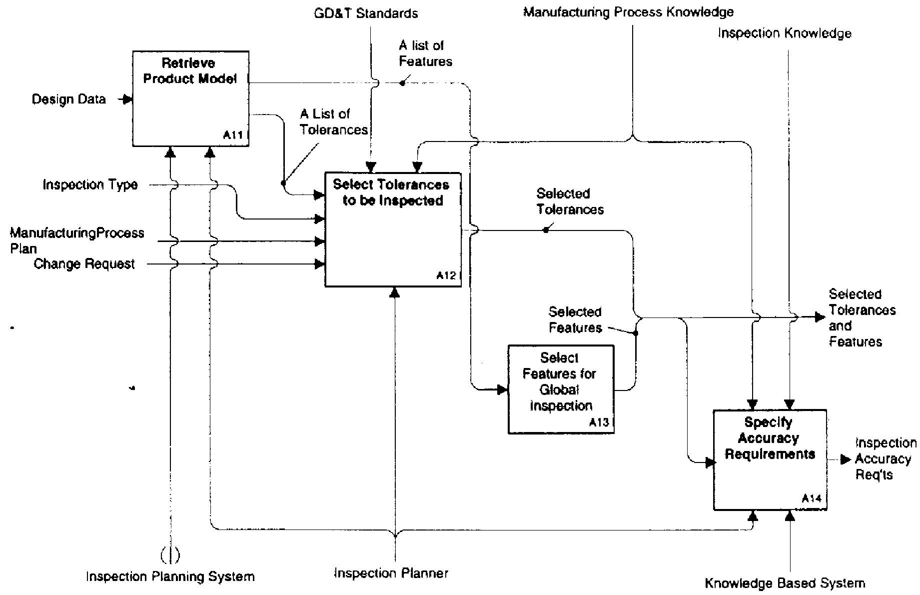



**Figure 5: Activity A1**

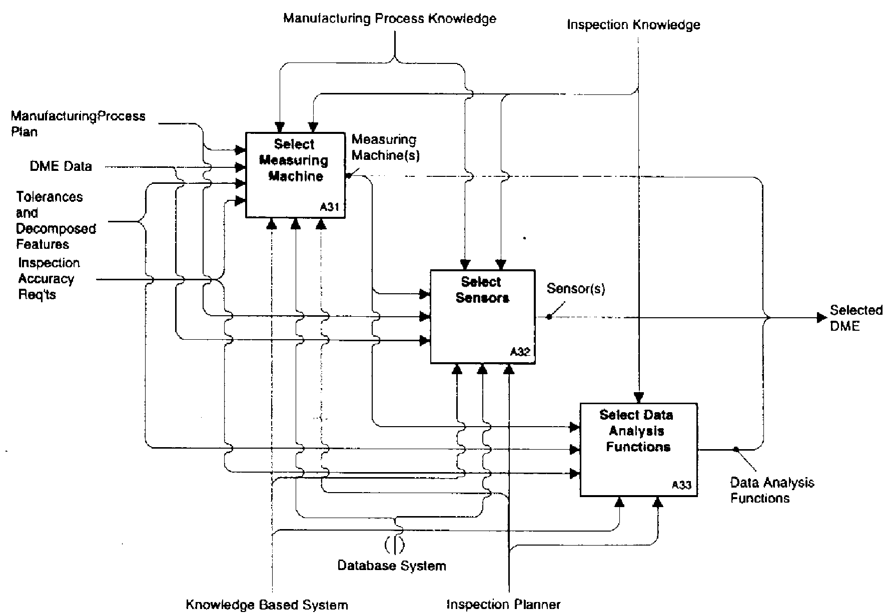



**Figure 6: Activity A3**

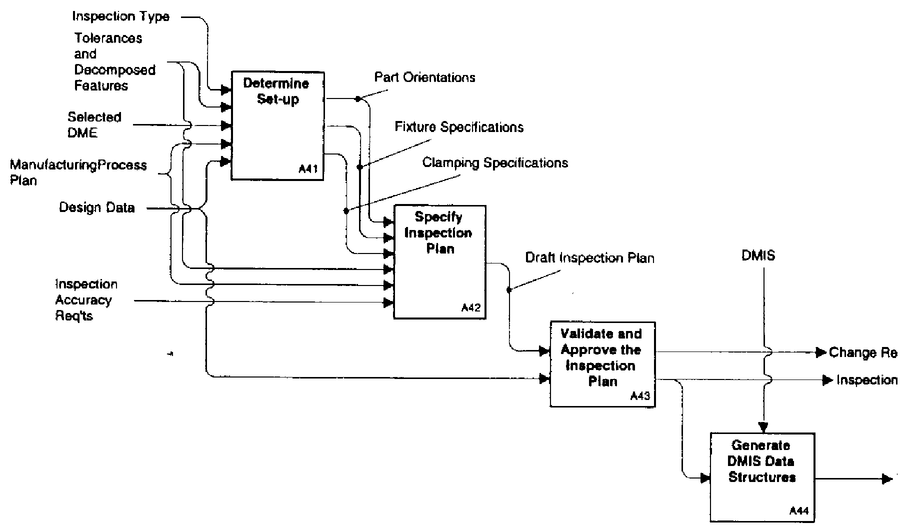



**Figure 7: Activity A4**

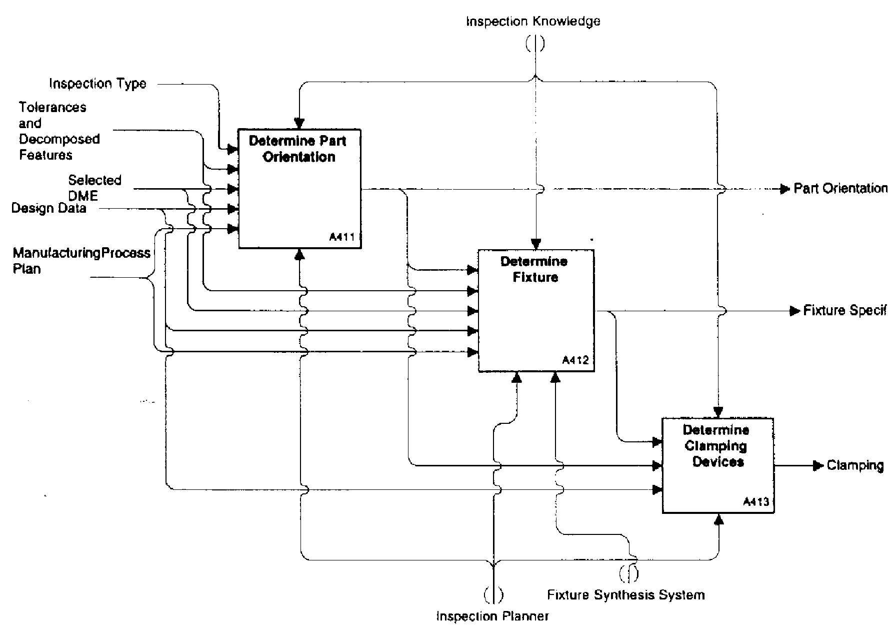
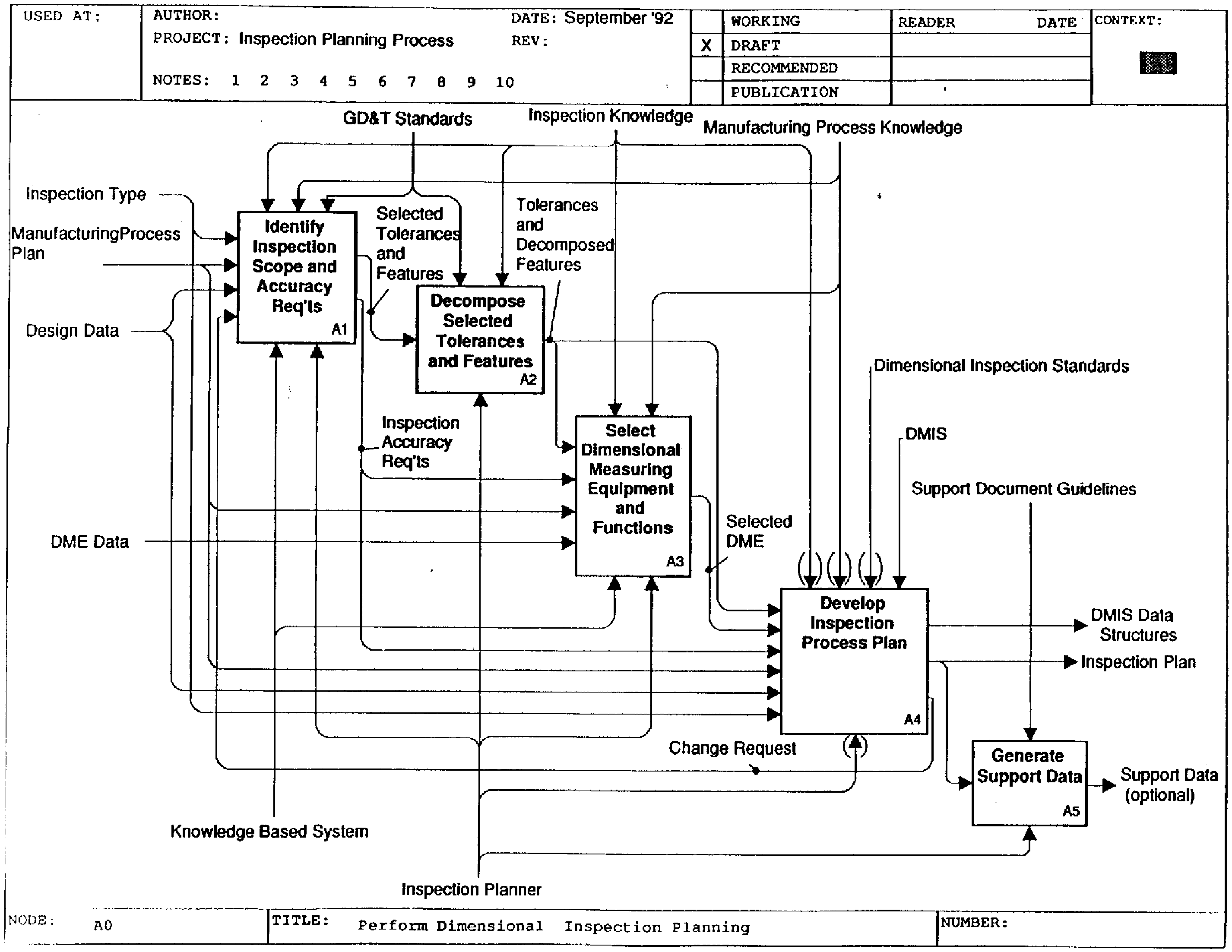



**Figure 8: Activity A41**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