Fixturing Information Models in Data Model Driven Product Design and Manufacture

By

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Do not look forward to the changes and chances of this life in fear; rather look to them with full hope that as they arise, God - whose own you are - will deliver you out of them. He has kept you hitherto, do you but hold fast to His dear hand and He will lead you safely through all things; and when you cannot stand He will bear you safely in His arms. What need you fear, my child, remembering that you are God's and that He said, "All things work together for good to those who love Him". Do not look forward to what may happen tomorrow. The same everlasting Father whom cares for you today will take care of you tomorrow and every day. Either He will shield you from suffering or He will give you unfailing strength to bear it. Be at peace then. Put aside all anxious thoughts and imaginations and say continually, "The Lord is my strength and my shield, my heart has trusted in Him and I am helped; He is not only with me but in me and I in Him". What can a child fear surrounded by such a Father's arm?

Saint Francis de Sales

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sa inyong lahat Maraming Salamat Po!

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Abstract

In order to ensure effective decisions are made at each stage in the design and manufacture process, it is important that software tools should provide sufficient information to support the decision making of both designers and manufacturing engineers. This requirement can be applied to fixturing where research to date has typically focused on narrow functional support issues in fixture design and planning. The research reported in this thesis has explored how models of fixturing information can be defined, within an integrated information environment, and utilised across product design as well as manufacture.

The work has focused on the definition of fixturing information within the context of a wide-ranging model that can capture the full capability of a manufacturing facility. Models of information relating to fixturing resources and to fixturing processes have been defined and implemented in an object-oriented database. The work has explored how this information model, in conjunction with a product model can be utilised to support the particular design and manufacture functions of fixture planning, process planning and design for fixturing.

An experimental system has been implemented on a Windows NT4 PC using the C++ programming language and the UniSQL/X object-oriented database. This has been used to explore the research concept by assessing its ability to support design for fixturing as well as fixture planning for a range of selected prismatic workpieces. The work has shown that a fixturing information model can provide a common source of information to support a range of activities across design and manufacture.

Keywords: Fixturing Information Models, Fixture Planning, Decision Support, Manufacturing Model, Product Model, Concurrent Engineering, Integrated Information System

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Chapter 1

INTRODUCTION

1.1 Introduction

This chapter presents the introduction of the thesis. Section 1.2 discussed the context for the research. Section 1.3 explained the aims and objectives, section 1.4 discussed the scope of the research and section 1.5 described the structure of the thesis.

1.2 Context for the Research

The fixturing process is an important part in the decision making related to manufacturing of a product. It plays a vital role in product manufacturing and can affect product design. It is a critical activity in manufacturing because all machined workpieces are to be held appropriately on a machine table and the job to plan and design fixture affects the manufacturing lead-time. A well-designed fixture can reduced non-productive time that is 70% of the total time on the machine [Gouldson 1982].

A good fixturing system would eventually reduce the manufacturing lead-time, manufacturing cost, improvement of the efficiency in manufacturing productivity and the accuracy of machining. Therefore, a significant improvement in manufacturing lead-time is to be expected if effective fixturing decisions can be made. Making the right decision about fixturing in the early stage of design and manufacture of product will eventually end up with the benefit in terms of manufacturing lead-time.

An important part of modern design and manufacture is to ensure that effective manufacturing decisions are made early in the product development process. Concurrent Engineering supports teamwork, i.e. people of different backgrounds expertise of product life cycle activities to simultaneous consideration of other product life cycle concerns as design is evolving.

A common source of well-defined and structured information is essential to support decision-making in these activities [Al-Ashaab 1994]. The software tools that can support the broad decision-making needs of engineers by providing them with appropriate information require further investigation. Current commercial tools do not provide that kind of support.

Commercial CAD/CAM systems are the closest software tools to the area of fixturing. These tools provide the link from design by CAD geometry to the generation of NC codes for manufacture. Any relationship to fixturing is typically in considering collision avoidance between cutting tools and fixture elements. Commercial tools do not provide any decision support for fixture planning or link to other activities such as process planning.

Fixturing research has generally been focused on the automation of specific tasks in fixturing, rather than providing information to support the decision making of people who are concerned with the broader design and manufacturing requirements of a product. A major area of research into providing information-supported decision-making is in product and manufacturing modelling.

Product modelling is a major theme of a wide range of research around the world to understand and define product data structure to support the life cycle development of a product. Work also has been pursued in understanding information structures to define manufacturing capability. It is in this area that the research reported in this thesis makes a contribution by exploring how fixturing information can fit into this kind of environment to support decisions at different points in the design and manufacturing process.

1.3 Aim and Objectives of the Research

The aim of this research is to explore the hypothesis that fixturing information can be structured in an information modelling environment such that this information be made available to a range of design and manufacture applications to provide information support at different stages of product development process. In order to explore the research hypothesis, the objectives of the research can be stated as follows:

- To identify the capability of a range of alternative fixturing methods.
- To define a manufacturing model representation to capture the capability of these fixturing methods.
- To investigate how the manufacturing model can be used to provide helpful support to fixture planning, process planning and product design.
- To build an experimental software system that will enable the research ideas to be explored.
- To perform experiments to assess the value of the approach taken.

1.4 Scope of the Research

The work presented in this thesis is set in the context the Model Oriented Simultaneous Engineering System (MOSES) research project [MOSES, 1992]. This project was undertaken jointly by Loughborough University and the University of Leeds and explored the applications of information models in computational support to Concurrent Engineering.

The specification of the research into MOSES focused on a computer based system that provides product and manufacturing information, enables decision support based on these information sources and is co-ordinated in a manner that makes it suitable for in a simultaneous engineering environment. The product model captures the information related to a product throughout its life cycle. The manufacturing model describes and captures the information about the manufacturing facility and capabilities at different levels of abstraction.

The MOSES concept of information modelling has been used as a basis for researching a computer-aided fixture planning decision support system. A software support environment is investigated in this research that consist three key areas: product information, manufacturing capability information and a set of fixturing decision support applications.

The fixturing application will interact with the information models to provide helpful support to fixture planning, process planning and product design and the work is based on modular fixturing elements for locating and clamping a workpiece. The research has used prismatic workpieces in rectangular block form and assumed a three-axis machine tool, however, this does not limit the use of other multi-axes machine tool, but the machine tool is used to illustrate this research concept. The information models resulting from the research are implemented as object-oriented database using UniSQL/X. The complete experimental system is implemented on a Windows NT4 PC platform and the programs are written in C++ programming language.

1.5 Structure of the Thesis

The thesis is organised into eight chapters and the overall structure and main contents are depicted in Figure 1.1. The context of the research and its aim and objectives are discussed in Chapter 1. Chapter 2 provides the literature survey on computer-aided fixturing systems and the fixturing fundamentals.

Chapter 3 describes the MOSES context and discussed the information associated with computer-aided simultaneous engineering and information modelling that was relevant to this research work. It also discussed the research tools used in this research.

Chapter 4 presents the issues related to computer-aided fixturing systems and highlights the issues that have been addressed. It discussed specific issues on how information models can provide the source of information to a range of design and manufacture applications.

Chapter 5 describes the work done to explore how the fixturing information within a manufacturing model can be defined and structured in an information modelling environment in order that this information be available to support product design and manufacture applications.

The use of a manufacturing model to support particular design and manufacture functions of fixture planning, process planning and design for fixturing is discussed in Chapter 6. Chapter 7 describes the experimental software that was built to enable the research ideas to be explored and the experiments that had been performed and evaluation of the results. Chapter 8 presents the discussions, conclusions and the recommendations for further work of this research.

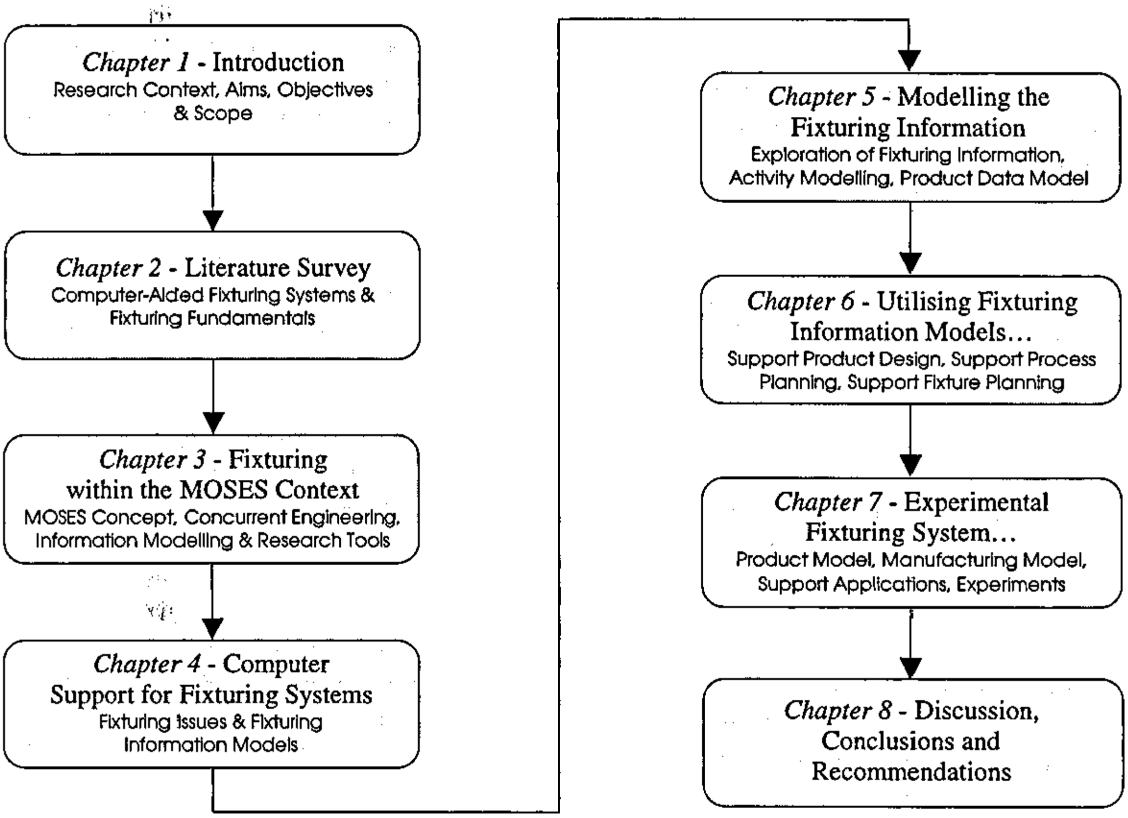


Figure 1.1 – Thesis Structure Description

Chapter 2

LITERATURE SURVEY

2.1 Introduction

This chapter presents the literature survey that is significant to computer aided fixturing systems and information modelling. Section 2.2 discusses the past and current researches involved in computer support in fixturing process. Section 2.3 presented the fixturing fundamentals such as fixture definition, locating and clamping principles, fixture requirements and fixturing hardware. Section 2.4 present the author's point of view in a summarised form.

2.2 Computer-Aided Fixturing Systems

The origin of fixtures can be traced back to the Swiss Watch and clock industry from which after proving their usefulness, they spread throughout the entire metalworking industry [Henriksen 1973]. Collvin & Hass (1948) did pioneering work on fixtures, while Hoffman (1985) and Kempster (1987) wrote the first books on fixtures. Before the numerical control (NC) machine was developed, the function of a jig in drilling was not only to hold and locate the workpiece but also to position and guide tool during the operation. With the increase in using the NC machines, the requirement to guide tools has been reduced. However, in selected cases, to add the rigidity of the tool, the function of guiding the drill in NC machining is still important when the machining surface is not flat or vertical with the axis of the cutter. Before the use of NC machining, a profiling fixture was used to guide tools for manufacturing contours, which the machine could not normally, follow [Hoffman 1985]. Profiling fixtures have the same function of guiding tools as jigs do.

The requirements of mass production introduced automatic fixtures, like pneumatic fixtures and hydraulic fixtures are the examples. Pallet fixtures have been used in automated flow lines. With the trend toward high variety, low volume production, modular fixtures have emerged as a result of the requirements for flexible manufacturing. With the modern technology in industry, the principle of fixture design is continuously being improved. After the computers have been introduced into industry, the great impact on the production systems was seen for a numbers of years.

There are many mathematical and scientific formulae, which can be used to calculate cutting forces, deflection of structural members, tolerance analysis of locating datum and others. However, many good fixture design features such as ease of loading/unloading, safety considerations, ingenuity in securing the workpieces and others, come from the experience of the designers. Due to the extensive requirements of heuristic knowledge and craftsmanship, the automation of fixture design has not been considered possible in the past. Recent developments in artificial intelligence techniques and in particular, knowledge representation have provided great opportunities in automating this field [Nee *et al.*, 1995].

2.2.1 Role in Computer Integrated Manufacturing

Integration of design and manufacturing is vital for achieving better product quality, lower production cost and higher productivity and for the realisation of Computer Integrated Manufacturing (CIM). Computer integrated manufacturing is an application of computer technology and plays an important role in the automation of discrete product manufacturing. In recent years, the automation technologies around the globe have enjoyed continuous advancement, leading to fierce competition in the market place. Product design has also diversified with ever more innovations, which have shortened product cycles [Lin & Huang 1997].

Fixture planning and design has a special place in CIM systems. It is carried out based on the requirements given by process planning for certain operations. Fixture planning includes locating and clamping in which, it can be considered as a part of process planning. However, design of fixture is a specialised design job in manufacturing. It requires the tool designer to have a some background knowledge in design optimisation related to changing part design and process planning as well as their experience and know how in designing fixture. The reason for that is in many case improvements to a fixturing system necessitates the change in the process plan and in the part drawing [Pham *et al.*, 1989].

CAD/CAM as a principal part of CIM has been applied in the area of design, manufacturing and production. It is a common knowledge that Computer-Aided Process Planning has been recognised as one of the key factor in CIM. However, the role of Computer-Aided Fixturing System is still ambiguous. Chou (1988) and Chang & Wysk (1985) classified fixture design as a part process planning. Pham *et al.*, (1989), Hayashi *et al.*, (1988) and Trappey & Liu (1988) illustrated that fixture design is separate from process planning but it interfaces with process planning and part design of fixtures. Liu & Strong (1993) suggested that fixture design work must be closely allied to process planning. However, tool designers with special technology must do this design task itself and tool designers must work closely with process planners. Fuh *et al.*, (1993) presented an integrated approach to Computer-Aided Fixture Planning with Computer-Aided Process Planning and linked to a commercial CAD system.

Figure 2.1 shows an outline of fixture design activities in manufacturing systems. This includes three steps; set-up planning, fixture planning and fixture configuration design. The objective of set-up planning is to determine the number of set-ups needed the orientation of workpiece in each set-up and the machining surfaces in each set-up. The set-up planning could be a sub-set of process planning. Fixture planning is to determine the locating, supporting and clamping points on workpiece surfaces. The task of fixture configuration design is to select fixture elements and place them into a final configuration to locate and clamp the workpiece [Rong *et al.*, 1995].

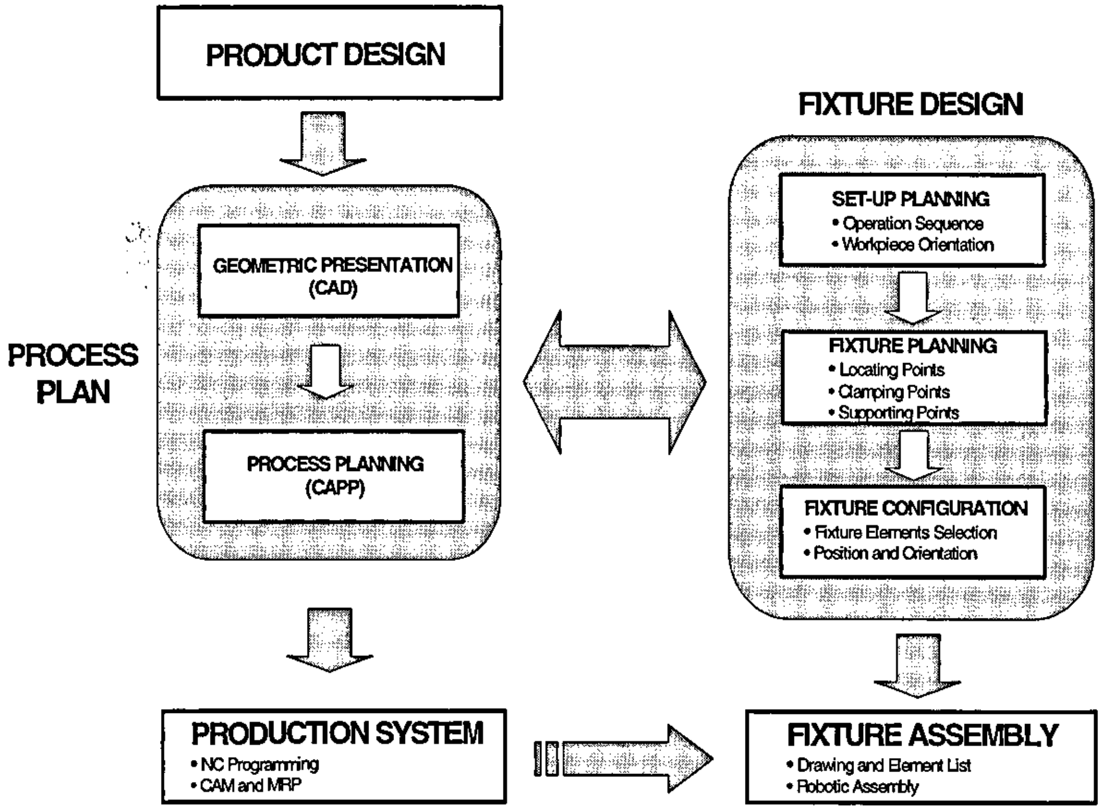


Figure 2.1 - Fixture Design in Manufacturing Systems
[Ref: Rong *et al.*, 1995]

2.2.2 Categories of Computer-Aided Fixturing Research

Research in computer-aided fixturing systems began in the mid-seventy's and a number of papers have been published. Research in this field can be classified broadly into the following categories based on the techniques and methods used; artificial intelligence with geometric modelling, mathematical methods, kinematics and dynamics methods, finite element analysis and feature-based reasoning.

2.2.2.1 Artificial Intelligence

Most of the automated fixture design systems have used artificial intelligence (AI) techniques to achieve a semi or full automatic functions. The functions will automatically configure and construct the fixture in the screen. Some of the systems have also automatic verification. An expert system is composed of a knowledge-based, an inference engine and a user interface. The knowledge-based contains the actual expert's knowledge that is specific to the domain of the application, such as facts, rules and databases. The inference engine is the control mechanism that drives the system to reach a conclusion by using the knowledge in a base. The user interface is for communication between the user and the language of the system.

- Markus *et al.,* (1984) developed "Fixture Design Using Prolog", an expert that automatically select the fixture components and generate the fixtures configuration by using Prolog. Ingrand & Latombe (1984) developed the "Functional Reasoning for Automatic Fixture Design", also an expert system for automatic fixture design that was based on functional reasoning. Although the two systems had limited capabilities, they were the first attempts to automate the fixture design process.

- In 1985, another expert system was developed by Ferreira *et al.,* the "AIFIX: An Expert System Approach to Fixture Design". LISP and the numerical analysis done in FORTRAN represent the expert system. This is the system that considers the information related to process planning.

- Nnaji *et al.,* (1990) developed the "Expert Computer Aided Flexible Fixturing System" (E-CAFFS). The rule-based expert system is implemented and classified in four functional engines: i) The PROLOG program was used as the source for accepting the input and utilises the input data to activate the necessary fixturing rules and the information gathering for fixturing. ii) The External Data File (EDF) brings all the information the base geometry interface. iii) The CATGEO, the base geometry interface of the CAD system and it's the responsible for creating the solid models. iv) The CATIA, a CAD/CAM system that is responsible for the fixture configuration. The E-CAFFS is a well-developed CAFD, in which the three dimensional view of the workpiece being clamped completely with the fixture can be shown in the CAD screen. The limitation of this system is that, it cannot be used for fixturing workpieces other than a regular polygonal prism because six pins are used as locators.

- In 1991, "MOFDEX: Computer Integrated Expert System for Modular Fixture Design with Pricing and Inventory Control", was developed by Lim *et al.,* The system is an integration of knowledge-based and 3D solid CAD technique for modular fixture design, pricing and inventory control. The MOFDEX system has seventeen different modules for achieving the complete information for fixturing design process. With this system, it opens to new avenues for research in the field of Computer-Aided Fixture Design. The system was developed in collaboration between Imao Corporation of Japan and Gintic Institute of CIM, Singapore. It was noted that the system has a wide capabilities compared with the previous systems.

- Ngoi & Leow (1992), developed the "Modular Fixture Design: A Designer's Assistant", a software to assist the tool designer for fixturing assembly. The software comprises a knowledge-based adviser, a fixturing component program and a CAD system. The adviser assists the tool designers in selecting from a modular fixturing system through the use of Venlic block jig system, which is in the different modules; locators, clamps and stops. A C language program is written to determine the exact size and position of the fixturing components with the aid of the 3-2-1 locating principles. The workholder assembly is then automatically displayed in a CAD software using Drawbase programming language. This work can greatly reduce the workload of a designer by eliminating the trial and error method, although the system can only do simple workpiece.

- The "Expert Fixture-Design System for an Automated Manufacturing Environment", developed by Kumar *et al.,* (1992) is recognised to be the first complete fixturing design system that integrates CAD with an expert system shell. This system also demonstrates a feature-based classification scheme for workpieces and fixtures using a goal dependency network [Nee *et al.,* 1991].

- The application of neural networks and group technology to develop modular fixture planning for cutting was presented by Lin & Huang (1997). The concept of group technology is used to classify workpieces of different or similar patterns having similar or the same fixture allocation into the same group and analyse and develop the fixture mode required by this group. Then the pattern classification capability of the back-propagation neural networks is used to develop the fixture planning. When a workplace is classified by neural networks as a certain fixture model, the fixture planning suitable for the workpiece can be quickly obtained through a heuristic algorithm. The approach not only saves the time spent in fixture planning but also lays the way for computer aided process planning.

2.2.2.2 Mathematical Methods

- Chou *et al.,* (1989) developed, "A Mathematical Approach to Automatic Design of Fixtures: Analysis and Synthesis" for prismatic parts instead of using an expert system or a ruled-based system. The mathematical theory formulated by them using the screw and engineering mechanics to automate the design of fixture configuration consists of two parts; analysis and synthesis. The analysis of fixtures includes the deterministic location and clamping stability and total restraint. The synthesis of the fixtures includes the determination of locating and clamping points on workpiece surfaces and the determination of clamping forces. A fixture functional configuration is stated as a mathematical formula based on the method of workpiece equilibrium applying the screw theory. Using the state space representation and a linear programming model can automatically generate the fixture configuration. A program for automatic configuration of fixture for prismatic parts was achieved using LISP. The input is all feasible fixturing areas as a workpiece with machining operations. The output is the locating and clamping points and clamping forces in the form of characters list on the computer screen.

- In 1989, Trappey and Liu developed the "Projective Spatial Occupancy Enumeration (PSOE). This is another mathematical method for automatic fixture configuration in which it is the combination of Projection and "Spatial Occupancy Enumeration" (SOE) has done by Mortenson (1985). The workpiece and fixture elements are projected on a working plane of the fixture base plate as a representational scheme to acquire knowledge about the fixture design. The SOE decomposes and represents an object as a set of cells after the object is projected into a two-dimensional. The elements of a matrix represent the resolved cells of a workpiece and modular fixture elements. By manipulating the properties of the elements in the matrix, the fixture element types and their locations are automatically generated by heuristic algorithm derived from applying the PSOE method.

2.2.2.3 Kinematics and Dynamics Techniques

- Asada & By (1985) developed the "Kinematics Analysis of Workpart Fixturing for Flexible Assembly with Automatically Reconfigurable Fixtures" system through the kinematics analysis and characterisation of workpiece fixturing. The characteristics of workpiece fixturing, such as deterministic positioning, accessibility, detachability, bilateral constraints and total constraints are formulated as geometric constraints. The constraints are structured in terms of a boundary Jacobian matrix and a fixture displacement. A robot manipulator does the complete fixture element layout and a fixture base (magnetic chuck). The task of the loading and unloading of the workpiece on the fixture and the controller of the robot manipulator is not only used to analyse and design a desirable fixture layout but also used to generate the robot motion commands for implementing the layout.

- The "Automated Design of Workholding Fixtures Using Kinematics Constraint Synthesis" for automatic fixture design was developed by Mani & Wilson (1988). This system was achieved by using the kinematics formalism. In the formalism, lines of restraint represent individual contacts between objects and stationary fixture elements. The set of three lines of restraint is called generalised triangles. Different types of clockwise and counter-clockwise rotational and non-rotational triangles form the kinematics constraint in a two-dimensional plane. The formalism is applicable to reasoning on kinematics constraint. In this automated fixture planning system: First, the user creates a workpiece cross-section from a CAD model. Second, the edge rating of the cross-section used to guide the search for best restraint sets, which is done by computer with some inputs of the user. Third, the construction of triangles, restraint set generation, layout and loading sequence. Finally, the alternative fixture plans; the restraint sets in a two-dimensional plane are automatically generated with the best plans.

- In 1990, Bausch & Youcef-Toumi developed the "Kinematics Methods for Automated Fixture Reconfiguration Planning" for an automated fixture reconfiguration planning, layout planning, set-up planning and assembly planning. This kinematics method is mainly based on the concept of a motion stop, defined as a scalar quantity, which indicates the effectiveness of a specific point contact in the prevention of a specific motion. The motion stops value M is derived from a screw motion equation. The concept of the motion stop is used for kinematics constraint analysis and configuration synthesis of a fixture configuration. This method is only capable for a simple two-dimensional and three-dimensional geometry like sheet metal parts.

- A dynamic method for fixture design of prismatic or box shaped workpiece was developed by Mittal *et al.,* (1991), "Dynamic Modelling of the Fixture Workpiece System". This dynamic simulation model for a fixture-workpiece, fixture configuration system which is consists of six pins as locators applied on the planes and the three clamps, one against each locating plane. Assuming the points of contacts between workpieces and clamps, the deflections of those points are expressed as a function of the load. The relationship between deflection and load is modelled by a Translational Spring-Damper-Actuator (TSDA) element for every contact points. The dynamic model contains workpiece, pseudo-body (which contacts with the workpiece at one end in a planar joint), a TSDA element (connecting the pseudo-body to the fixture body) and the fixture body. Then, the model is expressed in the form of dynamic equations of motion in a sparse matrix and coded in a computer by using the Dynamic Analysis and Design System (DADS) software. The reaction forces at the locators and clamps versus time are the main output results after running the system. The system finds the minimum clamping force required evaluates the performance of a fixture and evaluates various locating and clamping alternatives so that the optimum design of fixture configuration is obtained.

2.2.2.4 Finite Element Analysis

- Using the finite element analysis (FEA) and the Broyden-Fletcher-Goldfarb-Shanno (BFGS) optimisation algorithm, Menassa & DeVries (1988) developed the "Optimisation Methods Applied to Selecting Support Positions in Fixture Design". This optimisation method consists of two parts: First part, the determination of the optimal position of the support using BFGS optimisation algorithm. Second part, the FEA to evaluate the objective function by calculating the deflections. In order to move the original node generated to the point of the optimisation solution, remeshing of the workpiece is applied. The final fixture layout, three supports location for bottom surface of apart is obtained with the minimisation of the workpiece deflections under a load.

- An automatic fixture design system, "AUTOFIX: An Expert CAD System for Jig and Fixtures" was developed by Pham & Lazaro (1990). The system incorporates FEA to calculate the deflections of the fixtured workpiece and to determine the optimum position of the supports. The task of repositioning supports for the forming fixture configuration is automatically generated by the system according to the deflection analysis that is given by the FEA.

- Pong, *et al.*, (1993), presented the "Optimum Fixture Design", a systematic approach to optimally configure the layout of machining fixtures for prismatic parts. This finite element analysis is incorporated in optimum design scheme to model the work fixture-workpiece system and to calculate the workpiece deflections. The design optimisation model is well defined from machining precision considerations and feasible for three-dimensional applications. As simple but effective optimisation technique, the ellipsoid method is employed to solve this design problem.

2.2.2.5 Feature-Based Reasoning

- Rong, *et al.*, (1991), presented a paper "Fixturing Feature Recognition for Computer Aided Fixture Design". This system provides a tool in Computer-Aided Fixture Design by using the Group Technology (GT) concept in order to acquire, accumulate and store the expert knowledge of fixture designs in the form of a standard fixture design database. The authors used a new coding system with fixturing information is developed for fixturing feature classification and fixture design retrieving. When fixturing features of a manufactured part is in a fixture design database is searched and retrieved, therefore the fixture design becomes easier, and the quality of fixture design is improved because of the use of expert knowledge presented in the existing fixture designs. The required fixture components for the construction of fixture designs are provided to the user. The modular fixture CAD system is a practical-oriented, and to deal with more complex fixturing problems.

- Dong, X. *et al.,* (1991), investigates the use of features for fixture design, concentrating on the selection of locating elements and the identification of locating surfaces for workpiece positioning with their paper entitled, "Feature-Based Reasoning in Fixture Design". They investigated the used of features in the domain of fixture design. The system developed a representation scheme to describe a machined part, intermediate workpiece geometry & material properties, machined features and their intermediate states. This information represented about the intermediate workpiece and the features enables a fixture design program to determine the surfaces available for locating and supporting and will facilitate the detection of interference between the workpiece, the cutting tool and the fixture. The representation of machining processes describe the operations between intermediate workpiece states and provides the process information that allows the generation of such information as cutting force directions. A sample part has been used to demonstrate the uses of features in two fixture design tasks. It has been shown that the feature information is very useful for the selection of locating elements and surfaces.

- Young & Bell (1991), presented the "Fixturing Strategies and Geometric Queries in Set-up Planning", a strategy for producing a Spatially Divided Solid Model (SDSM) through cell decomposition from geometric presentation to provide feature interaction data. This was completed in a product modelling environment. They suggested that using more flexible knowledge-based tools and more comprehensive set of geometric queries could provide concurrent interactions between design for function and design for manufacture.

- Sakurai, (1992), developed the "Automated Set-up Planning and Fixture Design for Machining". This is a solid modeller that creates a symbolic feature-based model of the workpiece by recognising certain geometric characteristics. From the identified features, the proper set-ups are calculated through the simulation removal of cutter swept volumes. However, feature recognition of workpiece geometry is still a complex process for solid modelling system and largely based on heuristic and algorithmic methods.

- Chia, (1997) implemented a FixPlan, a fixture planning system that consists three separate modules; featured-based design system, geometric reasoner and fixture planner. The featured-based design module allows the engineer to design components with features such as blanks, holes and pockets. The geometric reasoning module enables the system to interrogate and analyse the product and is used extensively by both the feature-based design and fixture planning modules. The fixture planning module generates the set-ups and sequence of set-ups required, select the positioning, supporting and clamping faces as well as their corresponding points and select the appropriate fixture element for each point. The main strength of FixPlan lies in its ability to interrogate and analyse the product model through the use of geometric reasoning.

The fixturing fundamentals are discussed in the next section so that a proper understanding of the principles in fixturing process and fixturing resources is achieved.

2.3 Fixturing Fundamentals

2.3.1 Definition

A fixture or a workholding device may be defined as a system that provides positive locations and support while restricting the movement of a part subjected to the forces, associated with the manufacturing process. During any fixturing task, the essential ingredients, which govern accurate and efficient workholding, are location, support and clamping [Hoffman 1987]. Positive location and support provided by 3-2-1 locating principle sufficiently constrains the part and the remaining degrees of freedom maybe eliminated by clamping. This research study concentrates on fixturing for machining operations.

2.3.2 Locating and Clamping Principles

Locating and clamping are the critical functions of any fixtures. As such, the fundamental principles of locating and clamping, as well as the numerous standard components available for these operations, must be thoroughly understood. To perform properly, fixtures must accurately and consistently position the workpiece relative to the cutting tool, part after part. To accomplish this the locators must ensure that the workpiece is properly positioned relative to the fixture and the fixture relative to the cutting tool. A workpiece free in space can move in an infinite number of directions. For analysis, the motion can be broken down into twelve directional movements, or degrees of freedom [Hoffman 1985]. All twelve degrees of freedom must be restricted to ensure proper positioning of a workpiece. As shown in Figure 3.5, the twelve degrees of freedom all relate to the central axes of the workpiece. Notice the six axial degrees of freedom and radial degrees of freedom. The axial degrees of freedom permits straight-line movement in both directions along the three principal axes, shown as X, Y and Z. The radial degrees of freedom permit rotational movement, in both clockwise and counter clockwise radial directions around the same three axes.

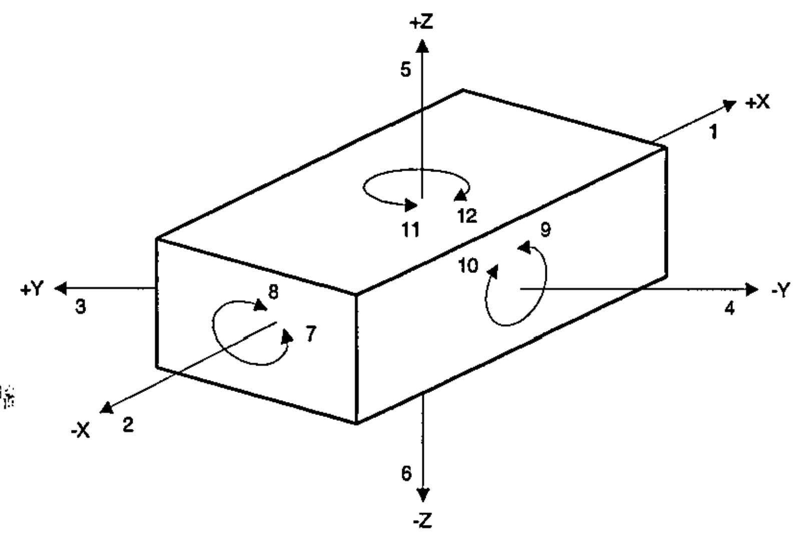


Figure 3.5 – The Degrees of Freedom for a Prismatic Workpiece
[Ref: Hoffman 1985]

A fixture design task can be initiated by constraining the motion of the workpiece along one of the Cartesian axes, say the Z-axis. Three supporting points, which constitute a plane, are positioned on the primary support surface of the part and this provides the reference position of the workpiece along the Z-axis. The reference position of the workpiece along the X and Y-axes is established by positioning locators around the perimeter of the part. Two locators positioned along the primary locating surface, restrict motion along one of the horizontal axes. The three support points located under the part and the two locating points along the part perimeter constitute the 3-2 portion of the 3-2-1 locating principle.

The final location is accomplished by placing a single locating point on the planar surface adjacent to the primary locating plane. Thus, part clamping provides the application of the 3-2-1 principle results in a properly supported and located part and the final constraint. The 3-2-1 method is shown on Figure 3.6. Part clamping holds the part securely against the locating and supporting points during the manufacturing process. The clamp must not only provide adequate clamping force for maintaining part rigidity, but also prevent distortion of the part, which may result in machining inaccuracies and damage at the workpiece and clamp interface. In order to minimise part-distortion and maximise part rigidity, it's advantageous to position the clamping device along the part surface so that the clamping force vector passes through a supporting or locating point [Ogerek 1985].

The clamping forces are primary dictated by the characteristics of the forces and the tolerance specifications associated with a given fixturing application. For example, the clamping requirements associated which machining operations involving high metal removal rates are significantly different from light machining, assembly and non-contact inspection applications [Strasser 1986].

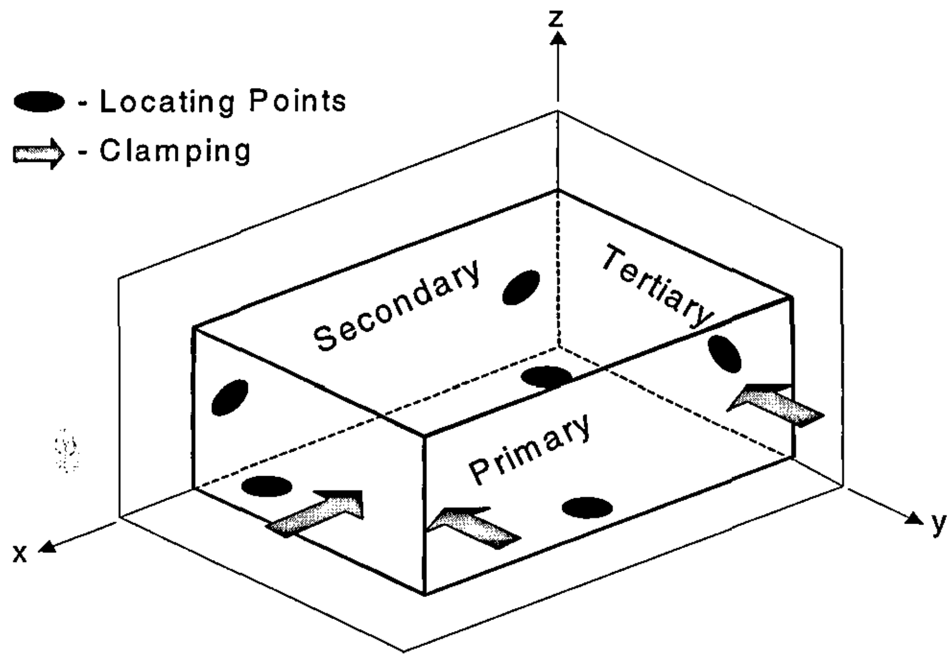


Figure 3.6 – The 3-2-1 Locating Method for a Prismatic Workpiece
[Ref: Wilson 1962]

2.3.3 Fixture Requirements

The basic requirement of a fixture is to locate and secure the workpiece in the correct orientation and relationship so the manufacturing process can be carried out according to design specifications [Nee & Kumar 1991]. Four general requirements of a fixture is recognised [Sakurai 1992] and discussed in the succeeding sections.

2.3.3.1 Accurate Locating of the Workpiece

To ensure that the workpiece meets its quality standards by tolerance specifications, a fixture must locate the part accurately in relation to the machine co-ordinate system and workpiece co-ordinate system. This discrepancy is usually recognised as the locating error and should be minimised. If the locating error is too large, a different locating face must be selected or the tolerance of the locating face must be tightened. Hence, accurate locating means holding the workpiece precisely in space to prevent each of the spatial movements, that is linear movement in either direction along x, y, and z axes and rotational movement in either direction about the axis [Gandhi & Thompson 1986].

2.3.3.2 Total Restraint of the Workpiece During Machining

The fixture must hold and restrain the workpiece from external forces such as generated during machining. Therefore strong clamping forces that act against locators are essential. Optimisation approaches have been developed to determine the number of fixture elements required and forces to oppose cutting conditions [Menassa & DeVries 1991]. Common locating rules in practice are the 3-2-1 or 4-2-1 methods for clamping [Henriksen 1973]. Both rules provide the minimum number of fixture elements and greatest rigidity. The 3-2-1 methods involve locating the workpiece in three orthogonal planes and clamping against the locating planes to ensure rigid fixturing. The 4-2-1 method simply applies four orthogonal planes instead of three.

2.3.3.3 Limited Deformation of the Workpiece

The fixture clamping forces or the cutting forces may deform the workpiece elastically or plastically. Strict requirements must make sure any deformation is within specified limits. These limits must be determined from the given tolerances of the workpiece. Finite element analysis is an excellent tool for this activity. Functional alternatives include additional fixturing supports in multiple locations.

2.3.3.4 No Machining Interference

It is important that none of the fixturing components or elements interfere with the cutting tool during machining. Obviously, this would cause damage to the tool as well as other contract surfaces. Two approaches were proposed for interference avoidance; the configuration spaces approach and the Generate and Test Approach. The Configuration Space Approach analyses the cutting process and fixture configuration around a finished workpiece and the surfaces not machined are possibly available for locating and clamping. The Generate and Test Approach is accomplished through solid modelling of the cutter-swept volume. Variations of these methods are used in numerical control programming.

2.3.4 Fixturing Hardware

Manufacturers have been designing fixtures, as long as there have been machining operations. Fixtures are required to hold parts and workpieces in order for certain manufacturing process to be performed. The fixturing hardware can be broadly classified into three groups; general-purpose workholding tool permanent or dedicated fixtures and flexible fixtures.

2.3.4.1 General Purpose Fixtures

These are the universal work holders such as collate chucks chucks, vices, machine vices and universal workholding systems. Using combinations of these simple devices, a skilled tradesman can construct a fixture for most workpieces. This fixturing strategy is common in low volume jobbing production, toolmaking, and in maintenance workshops. It has the advantage of using highly versatile equipment and low capital investment fixtures. Changing from one fixture to another is slow because the fixture must be rebuilt. This type of fixture is heavily reliant on operator skill to accurately load the workpiece and for alignment of the fixture with the machine tool axes.

2.3.4.2 Permanent Fixtures

The permanent or dedicated fixtures are specially designed and manufactured to hold and locate a specific component for a specific operation. They are completely non-versatile and generally cannot be used for other components or operations. They are used in large volume production where capital investment can be spread over large production numbers, and high levels of automation of clamping and workpiece location are economically viable. Such fixtures are specially designed to exactly match the requirements of the process plan and ensure that repeatable high accuracy is achieved. The drawback of this fixture is the high capital cost of the fixtures themselves and the cost of storing the enormous number of fixtures required for each and every operation [Nee *et al.*, 1995].

2.3.4.3 Flexible Fixtures

Flexible fixturing refers to fixtures, which are capable of accommodating a family of parts with different geometry and sizes. This concept is quite different from the conventional fixturing method where a dedicated fixture is developed for a specific operation. Several methodologies have been proposed as shown in Figure 3.7 [Kumar *et al.*, 1992].

A significant area of flexible fixturing is in the use of Modular Fixtures. The study focused in this area due to considerable advantages that modular fixturing systems could offer than other types of fixtures. The following are some of the major advantages:

- Reduced Lead-Time: The main advantage of modular fixtures is the reduced lead-time in the process. This type of fixture can usually be assembled in less than an hour's time with readily available standard components and eventually minimising the lead-time.

- Versatility: In modular fixtures, it is easy and fast to accommodate new products or modification of existing product. For many companies experiencing constant product improvement, new existing products not be held up waiting for fixtures since changes of existing fixtures can be made at once without interference in production.

- Reusability: Modular fixture kits may seem expensive; in they usually pay for themselves in one or two years. During the completion of a production run, the modular fixtures can be entirely disassembled and the components returned to the kit for reuse. In the conventional tooling is usually stripped of any reusable components and then scrapped at a fraction of its original cost.

- Backup Ability: Modular fixtures can be immediately assembled to temporarily replace a dedicated fixture while it is being repaired, reworked, or modified. With backup standard components available for emergencies may make modular fixtures well worth the investment.

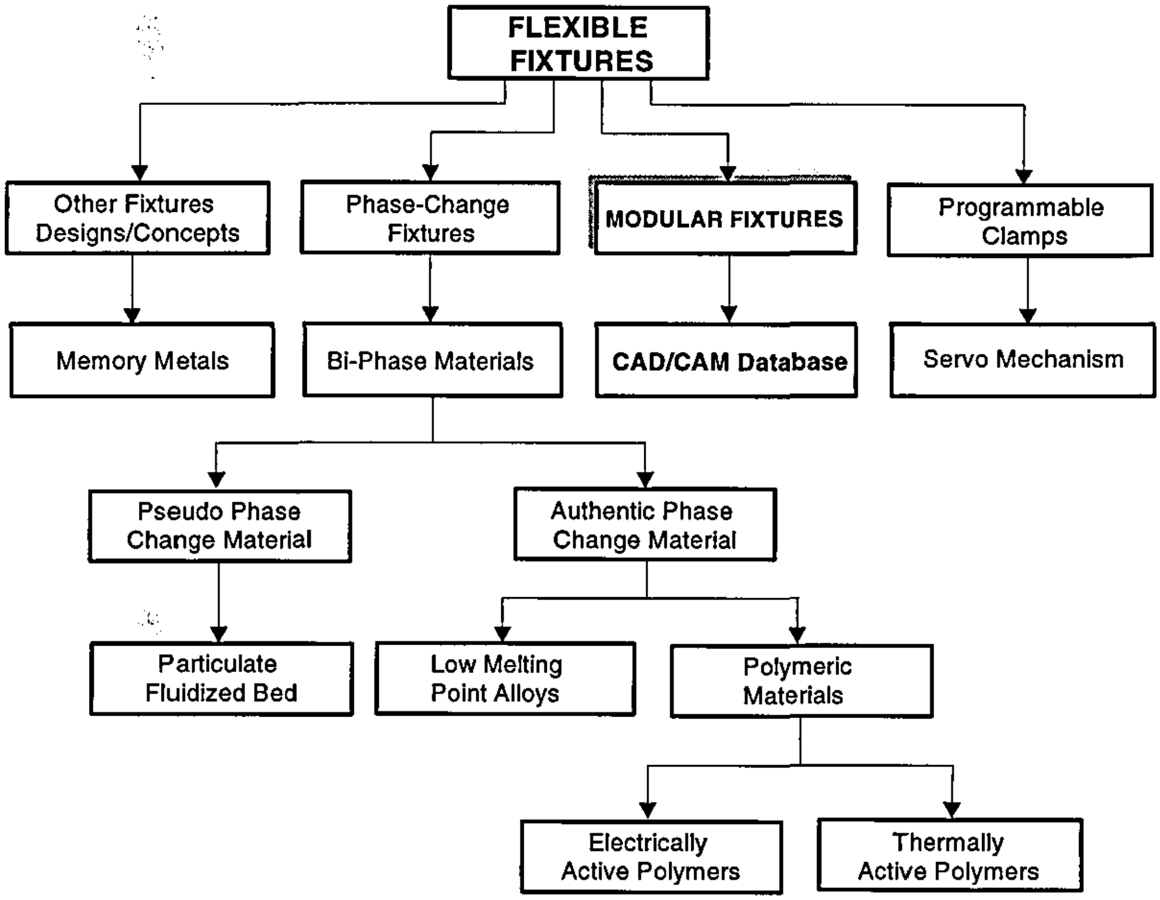


Figure 3.7 – An Overview of Flexible Fixturing Methodologies
[Ref: Kumar *et al.*, 1992]

Modular fixturing systems are perhaps the most widely known and commercially available. These systems are typically based on an extension of the classical machinists' approach to developing a variety of fixtures from a combination of elements such as V-blocks, toggle clamps and rectangular blocks which are traditionally located on a cast base-plate. Base plates are typically provided with a grid of holes or with 'T' slots. Figure 3.8 is an example modular fixture kits derive their flexibility from the large of different configurations of the elements, which may be fastened to the base plate. Modular fixturing systems are commercially available from a variety of vendors such as Halder, Bluco Technik, Venlic, Quco and others. These kits typically offer the following features: i) Variety of element groups such as basic carrier elements, locating, adapters, fasteners and attachment elements. ii) Hardened precision steel liners are employed to ensure high accuracy. iii) Locating and chucking elements are hardened and ground to ensure precise shape, accurate dimensioning and resistance to wear. Large mounting surfaces are employed to provide high stability and rigidity required to resist the large forces and vibrations associated with metal-removal operations.

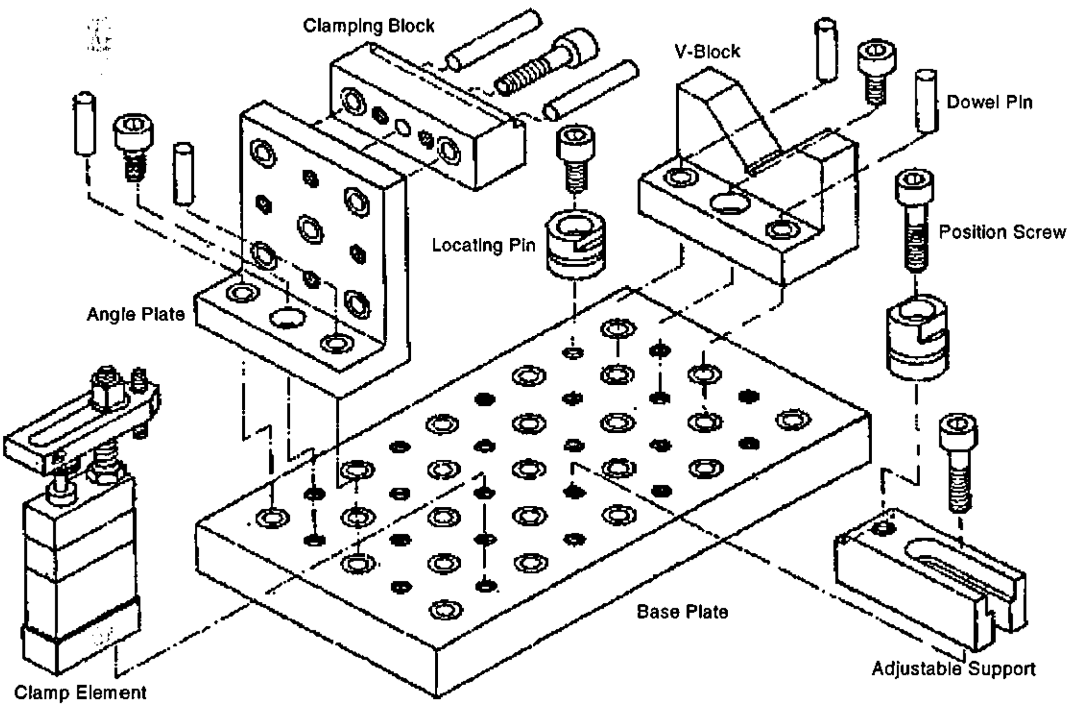


Figure 3.8 – The Modular Fixture Kits
[Ref: Rong *et al.*, 1995]

Modular fixturing systems are ideal for small batch machining production where rapid changeover is critical. Such systems also provide accurate and locating fixturing for non-machining applications such as assembly, materials handling and inspection. Use of modular fixturing systems can often eliminate most dedicated fixtures as well greatly reduce fixturing production and lead-time. The design of modular fixture configurations may be represented by a decision making process where many technical factors need to be considered, such as the shape, dimensions, tolerances of the part to be fixtured, locating and clamping methods, as well as the rigidity of fixture structure and the machine tool to be used. Modular fixture components can be dis-assembled after a batch of parts are produced and re-used for new parts [Rong *et al.*, 1995]. A sample of the modular fixture elements is shown in Figure 3.8. Most modular fixtures can be classified as with the T-Slot base plate, Grid Holes base plate and Dowel Pin base plate systems. For assembly, the grid holes or dowel pinholes are located on all the faces of the base plate. The construction sets similar to Lego blocks are fastened together with bolts held in T-nuts or with capped screws.

2.4 Summary

This chapter has presented a survey of related literature that is relevant to this research. The research in computer-aided fixture design and planning is grouped in five categories. These are the artificial intelligence, mathematical methods, kinematics and dynamics, finite element analysis and feature-based reasoning. Significantly while the importance of fixture planning and design process has been identified by various researchers, no work has been done to explore in the area of fixturing information models, which can provide information support to a range of design and manufacture applications.

The fixturing fundamentals are also discussed and illustrated in this chapter. The knowledge of the process being utilised is important in order to assess the concept of the research. A fixture or a workholding device may be defined as a system that provides positive locations and support while restricting the movement of a part subjected to the forces, associated with manufacturing process. During any fixturing task, the essential ingredients, which govern accurate and efficient workholding, are location, support and clamping. Fixtures are required to hold parts and workpieces in order for certain manufacturing process to be performed. The fixturing hardware can be broadly classified into three groups; general-purpose workholding tool permanent or dedicated fixtures and flexible fixtures. A significant area of flexible fixturing is in the use of Modular Fixtures. The research study focused in this area due to considerable advantages that modular fixturing systems could offer than other types of fixtures.

The issues related in computer aided fixture design and planning is discussed in Chapter 4, while the context of this research work is discussed in the next chapter.

Chapter 3

RESEARCH ENVIRONMENT

3.1 Introduction

This chapter provides the discussions on the research context of this thesis. The author has been working in a research group that is concerned with information systems to support design and manufacture. The major thrust in this work has been pursued under a research concept called MOSES (Model Oriented Simultaneous Engineering System) and the author has effectively required working within this environment. Section 3.2 described the MOSES research concept to set the context of this research. Section 3.3 introduces the information modelling techniques and reviews some researches dealing with product and manufacturing modelling. Section 3.4 discussed the research tools used in this research.

3.2 MOSES Research Project

3.2.1 MOSES Research Concept

The MOSES research has its roots in EPSRC funded projects that investigated architecture for Information Support Systems for design and manufacture. This project, undertaken jointly by Loughborough University and Leeds University, concentrated on developing structures for a Product Model that would be capable of representing more than the geometric elements of a product. The project also looked at how the information within this model could be used by manufacturing applications in order to generate process plans for prismatic parts. The outcome of the work was a contribution the evolving STEP standard, a greater a understanding of the need for a single source of manufacturing information, and a requirement to investigate architectures more suitable for supporting a diverse range of applications and data models [Corrigal *et al.*, 1992 and Young & Bell 1992]. The results of this project encouraged the EPSRC to fund the MOSES research project, which was again a joint undertaking between Loughborough and Leeds Universities. The specification of the research in to focus on a CAE (Computer-Aided Engineering) system that provides product and manufacturing information, enables decision support based on these information sources and is co-ordinated in a manner that makes it suitable for operation in a SE environment.

3.2.2 CAE Reference Model of MOSES

A principal research issue in MOSES was the development of a CAE Reference Model to provide a framework to support the development of existing and new CAE systems by establishing a generic set of viewpoints. Methodologies and tools such as IDEF0, EXPRESS and Booch are recommended to assist in the specification, development and analysis of each viewpoint. This ensures that key aspects are considered and that standardised methods are used for the design and documentation of the systems. MOSES has defined a combination of reference models, methodologies and computer tools in order to enable the achievement of these important issues in a CAE Reference Model [Molina 1994a]. A CAE system to support Simultaneous Engineering must be open in nature to allow the incorporation of a wide range of technologies and distributed to enable the interaction among remotely located people. The Reference Model for Open Distributed Processing covers these issues.

The CIM-OSA (Open System Architecture for Computer Integrated Manufacture) is a reference model developed to be used in information and manufacturing systems development. It is suitable for describing an integrated system, life cycle and methodology for its application. It consists a modelling framework supporting the representation of enterprise operation requirements, design and implementation. MOSES used

Reference Model for Open Distributed Processing extended by CIM-OSA to develop its CAE Reference Model [Molina *et al.*, 1994a]. The purpose of the CAE Reference Model is to provide a framework in which elements can be classified, compared and evaluated. The CIM-OSA modelling framework provides a context for CAE Reference Model. This framework has three instantiation levels namely; generic, partial and particular. In CIM-OSA the enterprise is represented in terms of the information, function, organisation and resources which are needed to realise the enterprise operations [Molina *et al.*, 1994b].

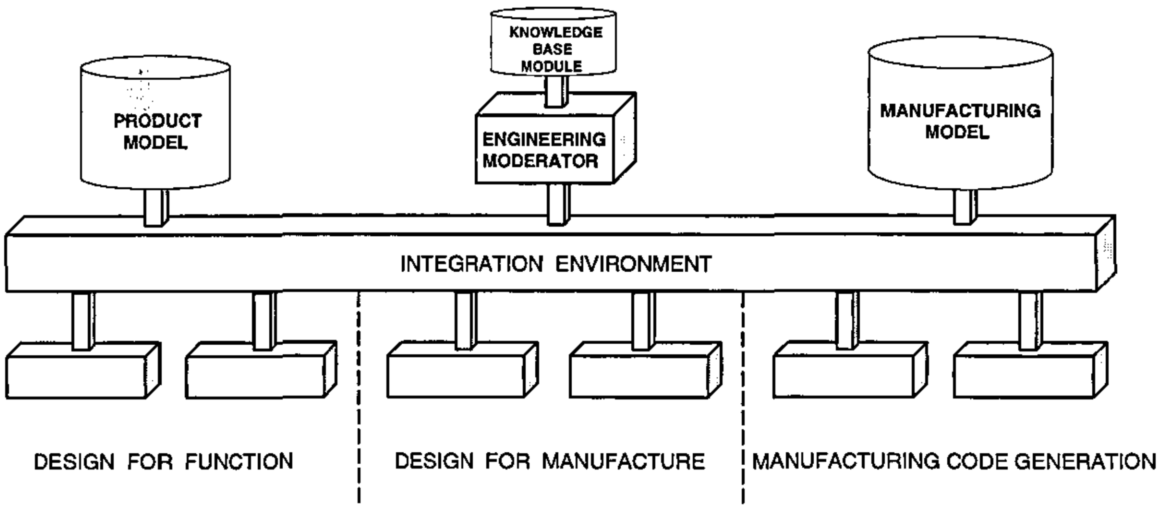


Figure 3.1 – The MOSES Architecture
[Ref: Molina 1995]

3.2.3 MOSES CAE System Architecture

The MOSES CAE system concept is shown Figure 3.1 that consists of two information models, the Product Model and Manufacturing Model are linked by an Integration Environment to a number of Application Environments such as Design for Function, Design for Manufacture and others. The operation of MOSES is such that any number of applications environments may be supported. Application Environments are set of data-driven applications and software tools used to provide computer support to a particular activity of the life cycle of a product. These application environments are sometimes referred as Design For 'X' applications. All products related information is stored within the Product Model as a design evolves. This is the sole consistent source of product information. Should an application be triggered, then it operates on product information from the product model and any product information that it generates is added to that model.

The Manufacturing Model is the sole source for manufacturing information and hence all applications obtain their manufacturing information is derived from it. The MOSES framework allows the sharing of common data between a diverse range of design teams and software applications. An Engineering Moderator identifies the conflicts within the Product Model that may arise due to conflicting outputs from the different application environments that populate the Product Model.

In developing the MOSES system it is intended that the information and procedures necessary to support that part of the simultaneous engineering process concerned with concurrent design for manufacture be identified, and that a prototype knowledge and software environment be used to demonstrate this. To this end an application environment for the support of design for manufacture is being developed. This makes extensive use of both product and manufacturing data and hence exercises and tests the validity of the information models [Molina 1995].

3.2.4 Elements of MOSES System

In the research of each MOSES' element current standards for the representation of information and object oriented techniques for analysis and designs have been used. Booch methodology with EXPRESS has been employed for documentation and object orientated database (DEC Objectivity) and C++ programming language for the development of testing software. These models and applications are all feature oriented.

The specification of the research into MOSES focused on a computer-based system. These consist of two information models, an engineering moderator and applications environment. The information models provide product and manufacturing information to the application environments to support decision-making. The moderator is a special application that assists the development of a product by ensuring that adequate application environments are considered in a proper time. The elements are the following:

3.2.4.1 Product Model

A Product Model can be considered to be a computer representation of a product, which should hold a complete depiction of the information concerning a product. The product model therefore becomes a source and repository for information for all applications and allows information to be shared between the users and software components of the CAE systems.

The aim of the research on MOSES' product model was to develop a generic data model capable of depicting all the product life cycle information relating to discrete product. The first STEP release was still a draft at the time the research was initiated even though some of its definitions were used, but the main structure of the product model proposes a different approach from the suggested by STEP, linking the product life information to the elements of the product structure. One of the main contributions of the research undertaken was the framework of the data model that has been used for different purposes [McKay *et al.*, 1996].

3.2.4.2 Manufacturing Model

The Manufacturing Model describes and captures the information about the manufacturing situation of a company in terms of its manufacturing facility and capabilities at different levels of abstraction [Molina 1995]. Three entities can be regarded to be basic elements in the definition of any manufacturing environment: resources, processes and strategies. The relations and interaction among them defines the manufacturing environment of a company. Manufacturing resources are all the physical elements within a facility that enable product manufacture e.g. production machinery, production tools, etc. A description of the resources based on their physical properties and functional composition allows the capture of their capabilities. Being able to represent resource capability enables the support of design decisions e.g. designs for manufacture and manufacturing functions e.g. process planning. Manufacturing processes are those processes carried out in a facility in order to produce a product. Strategies are decisions made on the use and the organization of resources and processes.

3.2.4.3 Engineering Moderator

The Engineering Moderator was based on the Knowledge Representation Model that has been explored to facilitate the creation of the applications environment [Harding 1996]. The model was developed using object-oriented analysis and has three main elements; knowledge base, inference engine and working memory. This application monitors the development of the design. It has sufficient information about the application environments to know when each one of them may support the development of the product. So, when a decision is taken, the moderator checks if any application may conflict to each other or it needs to be consulted. In this aspect, it will trigger the participation in the process and gives the designer the choice to consider its advice or not.

3.2.4.4 Application Environment

The Applications Environment or the design for 'X' environments assists the designer to develop a product. These are the experts in their specific field embracing one or more expert systems, sharing the data of the information models with other applications and evolving the product model as decisions are made. The main application explored in the MOSES project is the Design for Manufacture Environment, but Design for Function is also being explored. With the MOSES' architecture, it can hold more applications simultaneously. In order to demonstrate the principles involved in the research a much-restricted implementation of the Design for Manufacture Environment was developed that communicates with the product and manufacturing models [Ellis *et al.*, 1994].

3.2.5 MOSES Manufacturing Model

The manufacturing model describes and captures the information regarding the manufacturing facility of a particular enterprise in terms of its organisation, composition and processes capabilities. Among all the different types of manufacturing facilities MOSES has focused in modelling the facilities used in batch manufacture, although it can be extended to cover other types of manufacturing organisations. The manufacturing model represents the necessary information required to provide reliable manufacturing capability information for the support of life cycle activities in particular the interaction between designs for function and design for manufacture activities. It can also provide reliable information to support activities, which generate information for manufacturing such as process planning, machining planning, pre-processing proving and scheduling [Molina 1995].

3.2.5.1 Framework of the Manufacturing Model

The Booch Object-Oriented Methodology was used for the development and guides the modelling of the data in order to build the presentation of the manufacturing model. The discussion on how to use this methodology can be found in Section 3.3 in this chapter. The presentation is illustrated in Figure 3.2 where the "Manufacturing Model" *describes* a "Facility", which is composed of resources, processes and strategies. Therefore, a facility *has* resources, process and strategies. All different types of facilities such as stations, cells, shops, and factories will be consisted of these three manufacturing entities.

A facility has been defined as any type of system that allows the manufacture of products and can be classified according of how a manufacturing firm organises their resources and processes. Thus in the manufacturing model, in accordance with the levels, the facilities can be stations, cells, shops or factories. This is described using Booch notation in the following manner: factory "*is_a*" facility, shop "*is_a*" facility, cell "*is_a*" facility and station *is_a* facility. The use of the concept of inheritance (relation "*is_a*") allows any subclass of facility to be composed of resources, processes as well s strategies. Then a station "*has*" resources, processes, and strategies, so the shop, cell and factory. In addition, because of the organisation of facilities within company, a factory "*includes*" shops, a shop "*includes*" cells and a cell "*includes*" stations. These relations enable the manufacturing sites by combining and reusing these definitions. A clear distinction between the levels of the manufacturing model and the elements, which are represented at those levels. A level allows to describe a set of facilities and their capability that is at the station level where a set of stations can be described and not necessarily just one [Molina 1995].

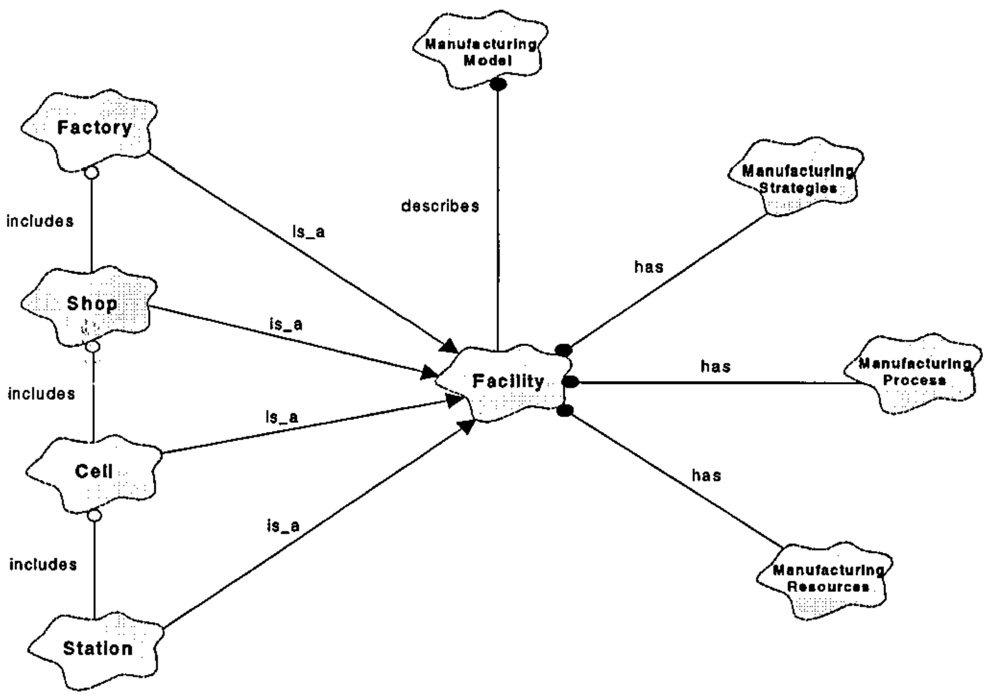


Figure 3.2 – The Framework of the Manufacturing Model
[Ref: Molina 1995]

3.2.5.1 Manufacturing Processes Representation

In Molina's (1995) work on modelling process has been influenced firstly, by Alting (1982) classification of processes groups according to material they work on, energy they use and type of process and secondly, by BSI DD 203:Part 1(1991) classification of processes groups according to function they perform transformation, transportation, storage and inspection. The taxonomy of the processes is based on the above classifications. Figure 3.3 illustrates a section of the taxonomy, where multiple inheritance is used to define the properties of the processes. For example, the Turning process "*is_a*" Solid_Material_Process because it works on solid materials, "*is_a*" Mechanical_Process, because its energy flow is mechanical and finally "*is_a*" Chip_Forming_Process because produces chips and therefore "*is_a*" Mass_Reducing_Process because its a transformation process [Molina 1995].

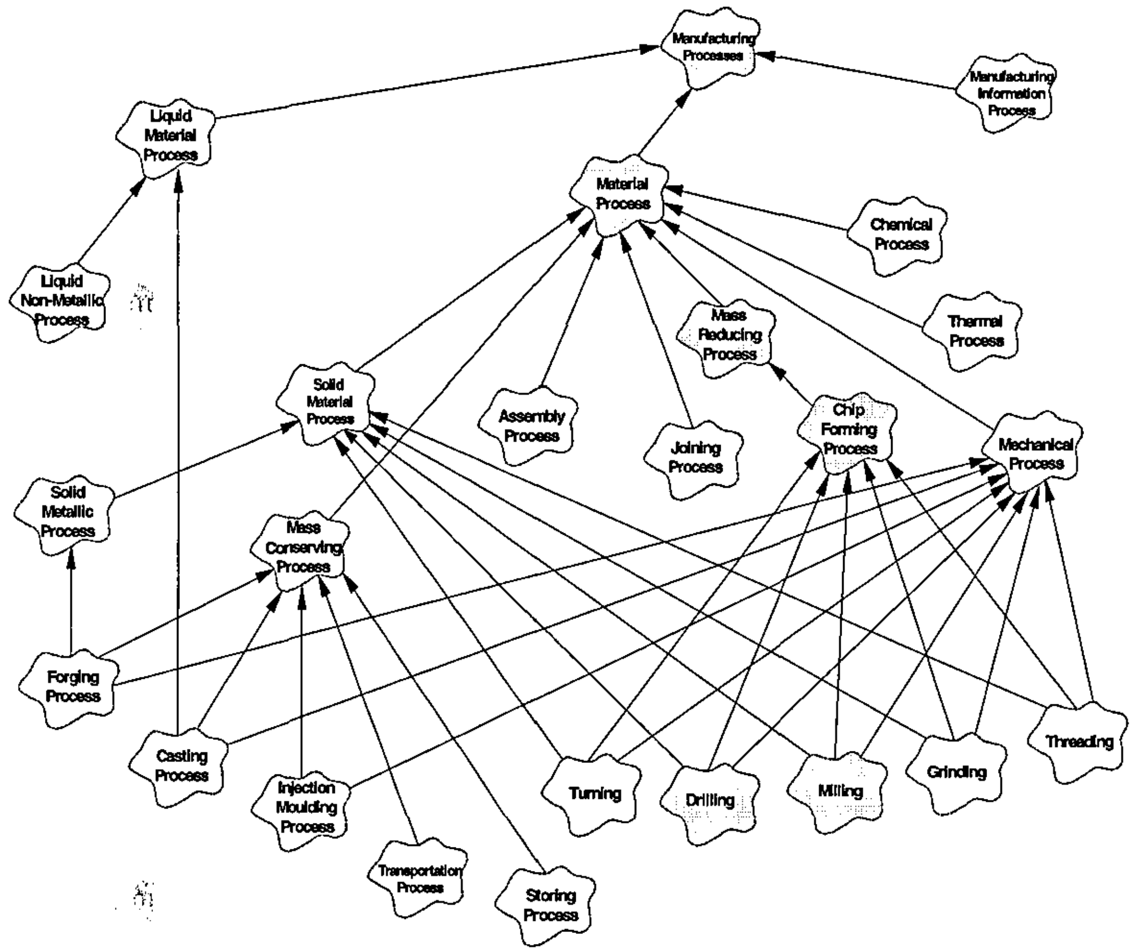


Figure 3.3 – The MOSES Manufacturing Process Representation
[Ref: Molina 1995]

3.2.5.2 Manufacturing Resources Representation

The manufacturing resources are all the physical elements within a facility that enable the product realisation such as production machinery, production tools, material handling equipment, storage systems, human, supply and disposal units and others. The resources can be organised in-groups to create manufacturing facilities such as stations, cells or shop floors. Molina's (1995) research work recognised the need to represent the resources in a function-oriented manner in order to describe their role in supporting the design and manufacturing activities. Thus, the description of the resources is based on their physical properties and functional composition, which allows to capture their capabilities.

This work on modelling resources has been influenced by different elements of other related research such as CIMOSA, [ESPRIT 688/5288 1993], IMPACT [Gielingh & Suhm 1993]. The resources groups in this research were furniture and fittings, human resources, information processing resources, material handling resources, measuring and testing resources, production resources, supply and disposal units and storage resources.

Figure 3.4 shows an example of the resources group and taxonomies. The production resources have been defined to be the resources that are required for processing supplies, work in progress and products. Other manufacturing resources or/and operated by a human automatically control production resources.

The following two main classes of production resources were defined: i) Production machinery is non-movable machinery that is for processing work in progress. These are two subtypes: Discrete part machinery and Continuous part machinery. At lower level the class machine tool is defined, other examples of production machinery are assembly lines, welding, oven and others. ii) Production tools are movable equipment that must be present while processing work-in-progress. There are five subtypes of production tools: processing tool, tool assembly, tool guide, tool holder and workholding tool [Molina 1995].

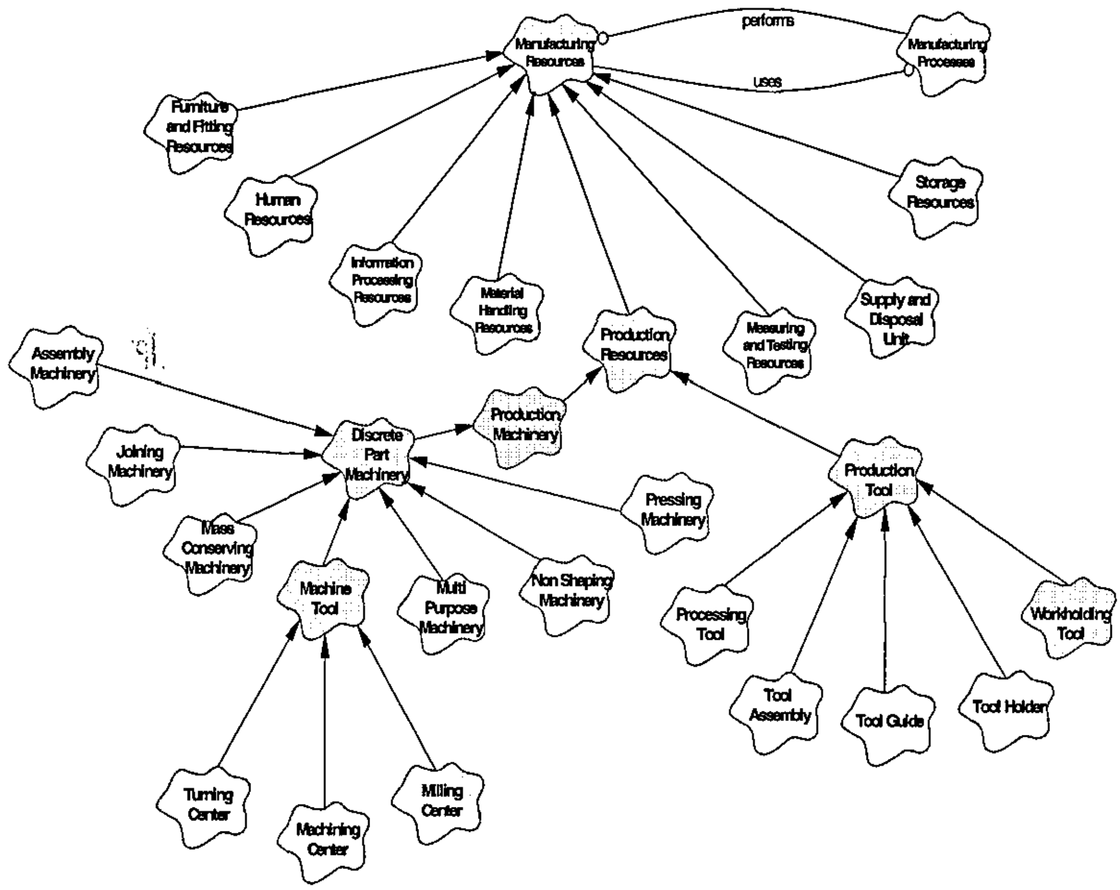


Figure 3.4 – The MOSES Manufacturing Resources Representation
[Ref: Molina 1995]

The concept of simultaneous engineering and the review of related literatures that are significant in this research work are discussed in the next section.

3.3 Simultaneous Engineering

3.3.1 Definition

Winner *et al.*, (1988), defined Simultaneous Engineering (SE) or Concurrent Engineering (CE) as a systematic approach to the integrated, concurrent design of products and their related process including manufacture supports. It is implied in this definition to consider all elements of the product life cycle from concept through disposal, including quality, cost, scheduling and customer requirements.

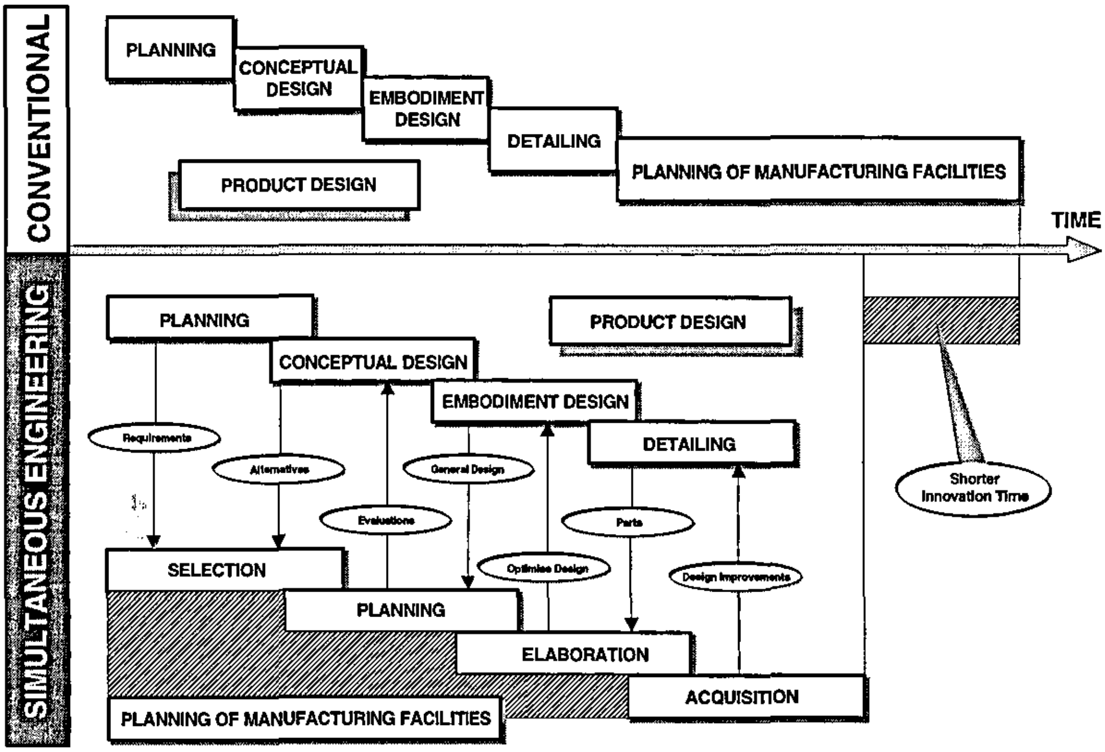


Figure 2.2 – Simultaneous Engineering
[Ref: Weck *et al.*, 1991]

Another definition by Cleetus (1992) states, Concurrent Engineering is a systematic approach to integrated product development, which emphasises response to customer expectations and embodies team values of co-operation, trust, and sharing in such a manner that decision making proceeds with large intervals of parallel working by all life-cycle perspectives and synchronised by comparatively brief exchanges to produce consensus. The Concurrent Engineering approach considers also the process design activities and manufacturing at the same time. It also enforces, considering all aspects of the product life cycle and performing other actions of the development of a product. For example, design of the manufacturing process while in the design stage of the product [Weck 1991]. The Figure 2.2 illustrates more on the approach.

The Simultaneous Engineering approach is to consider all aspects of the product life-cycle as early as possible process [Syan & Menon 1994 and Sohlenius 1992]. The quality of products and its processes is improved because designs fulfil customer's expectations, which are easy to produce and maintain. Important cost reductions can be achieved avoiding changes in the later stages of the design process (time to release a product to production) and to market (time to deliver the product to the customer) is shortened due to parallel activities and the integration of design of a product and its manufacturing process [Dowlatshahi 1994].

3.3.2 Requirements

The adoption of Simultaneous Engineering by company implies several changes, which are guided by three principles [Molina *et al.*, 1995a].

- Organisation Principles: New organisational structure, teamwork and customer focus attitude.
- Process Improvement Principles: Develop and continually improve product life-cycle activities so they are integrated and occur concurrently whenever possible.
- Information Management Principles: Higher levels of information and knowledge integration, enchancement of information and communication and management of corporate resources, which are people's knowledge, information technology and others.

Teamwork is one of the main elements of Simultaneous Engineering organisational structures. It enables the possibility of concurrent activities considering different aspects of the product life cycle. Simultaneous Engineering teams are integrated specialists of complimentary fields, the customer and suppliers. Efficient communication and organisation within the teams are very important to have consensus in decisions.

3.3.3 Computer-Aided Simultaneous Engineering

A detailed review of Computer-Aided Engineering Systems can be found in Molina *et al.*, (1994b), it considers a wide range of published research work on the enabling technologies. Two types of systems were analysed: Stand Alone and Integrated Environments.

3.3.3.1 Stand Alone System

The Stand-alone Engineering applications are the first generation of Simultaneous Engineering applications. These engineering applications are aimed at specific products, but do not support teamwork. These applications improve the product design by concurrently considering different aspects of its life cycle. Examples of such systems are the following: an object-oriented framework for Concurrent Engineering [Vujosevic & Kusiak 1991], life cycle engineering applications [Ishii & Mukherjee 1992], Computer-Aided Simultaneous Engineering System [Rehg *et al.*, 1988] and Intelligent Hybrid System for the design of injection moulded parts [Hambaba *et al.*, 1992]. Most of these applications use artificial intelligence techniques to capture life-cycle information.

Blackboard architectures are common to many of the systems analysed and are used to control the development process and share information modelling include knowledge representations [Gadh *et al.*, 1989], semantic nets and constraints rules [Ishii 1992], and constraints nets [Bowen & Bahler 1991 and O'Grady *et al.*, 1991]. Blackboard architectures are used to control and manage the design process [Lu 1992 and Finger *et al.*, 1992]. There are another types of research applications, which use process improvement principles to enhance the product design, such as design for assembly [Boothroyd & Alting 1992], design for manufacture [Stoll 1988] and design for injection moulding [Huh & Kim 1991].

3.3.3.2 Integrated Environment System

The Integrated Environments can be considered the second generations of Simultaneous Engineering applications, in which the support of Simultaneous Engineering teamwork to achieve product realisation is enchanced through the use of information models and integrated engineering applications. Two main issues must be addressed when assessing integrated environments for the support of Simultaneous Engineering teamwork [Molina *et al.*, 1995]:

- Information Modelling: This is related to the identification, representation and composition of the data, information and knowledge which completely describes a real object, or objects and enables the construction of information models that support the information needs of the product life cycle.

- Integrated Engineering Applications: This is related to the implementation and integration of a set of software tools to tackle specific design and manufacturing problems. These applications are based on information system architectures. The availability of relevant, consistent information at any time is the key to successful simultaneous engineering [Weck *et al.*, 1991]. Availability requires the capability to share common information models throughout the different phases of a product's life cycle. All the Computer Aided Simultaneous Engineering Systems have adopted a common source of information to support both applications and users and some of them have extended this idea to support the representation of knowledge, however, the ways in which this has been achieved varies [Sohlenius 1992].

3.4 Information Modelling

Simultaneous Engineering support teamwork, which are people of different backgrounds expertise of product life cycle activities to simultaneous consideration of other product life cycle concerns as design is evolving. A common source of well-defined structured information is essential to support decision making in these activities. This information must cover all relevant data concerning a company and its product requirements as well as manufacturing resources and process capabilities. The representation of such information in an information model which can support design and users decisions will provide the data integrity that is required to successfully support the range of design and manufacturing decisions.

3.3.2 Product Modelling

Models are representations of products that have evolved as a consequence of changes in design practices and supporting technology. Current design practices promote the use of methodologies, enforcing the documentation of product knowledge and the integration of the product development processes such as design, planning and manufacture which all of these required computational support.

In the early stages, computer-assisted designers solving complex equations were regarding the modelling of the shape of the products. Firstly, the computer programmes were able to represent products using two-dimensional (2D) drawings. Secondly, these drawings have been transformed to three-dimensional (3D) computer images, which enable the creation of numerical control (NC) patterns. Advances in databases facilitate the management of complex amounts of product data, so they were integrated to computer aided design (CAD) systems. Then, the extended facilities and new languages have been developed to store product knowledge. Therefore, product modelling has been the consequence of the demand of product knowledge representation within Computer-Aided Engineering Systems to support product realisation integrating different technical and management functions within companies. Product Modelling refers to the activities to represent and utilise information related to products [Mantyla 1989], through their whole life cycle from initial product planning until disposal [Kimura & Suzuki 1989].

A product model is a representation of all relevant information concerning a given product during its life cycle [Krause *et al.*, 1993]. It fulfils all information requirements for specified applications [Spur *et al.*, 1986] and for related sectors of engineering. In the context of Computer-Aided systems, product models are referred to product databases and their associated management and access algorithms. Product model is determined by its structure and its content specified by a product model [Mckay *et al.*, 1997]. The structure depends on the nature of the product and tools to model the information as well as to build the necessary schemes for the database. Frequently, product data models and product models are both referred as product models.

There are several proposals about the information that should be included in the product models. The information is determined by the product development processes to be supported by the model [Mckay *et al.*, 1997]. Three groups of product information could be identified among the proposals suggested by different authors:

- Information related to the descriptions of product: These are structure, economical information, geometry [Kimura & Suzuki 1989, Mckay 1989], technology, functionality and behaviour.

- Information related to the life cycles of product: These are methods the designers used [Bauert 1989], requirements, decisions and justifications to determine product descriptions, design intent [Kimura & Suzuki 1989], product development work flows, production work flows, maintenance tasks, recycling considerations [Krause *et al.*, 1993] and disposal considerations [Mckay 1989].

- Information related to the environments of product: These are information of participating companies, empirical product knowledge, innovative aspects of design and manufacturing [Mantyla 1989], information related to constraints, restrictions, newest findings and other principles about the product and its components as defined by market, environment, users behaviour or competitors strategies [Krause *et al.*, 1993].

The development of the ISO standard 10303 Standard for the Exchange of Product Model Data (STEP) which aims to enable data exchange and sharing among different CAD/CAM systems is strongly affecting research on the area, promoting a standard specification of information and defining modelling methodologies. STEP is the unofficial name of the international standard ISO 10303 - Industrial Automation Systems-Product Data Representation and Exchange [ISO 10303-1 1994].

It is the most important international effort for addressing the industrial needs of integration of software applications through data sharing. The major goals of STEP can be summarised as to allow a complete representation of a product through its life cycle, independent of any particular hardware and software [Owen 1993]. The standard aims to be suited for neutral file exchange to provide the basis for shared product databases and for archiving [Fowler 1995].

3.3.3 Manufacturing Modelling

A manufacturing model that addressed how the capabilities of the injection moulding process to support injection-moulding process were presented by Al-Ashaab (1994) and Al-Ashaab & Young, (1995). The manufacturing model captures information about mouldability features, mould elements and injection moulding machine elements. This can be used in the design stage to support for mouldability (plastic product), design of the mould and selection of injection machine.

Molina (1995) identifies two streams of research on manufacturing models. The first one consists on CIM models, which represent the business functions, software modules, control and information systems architectures that can be used to design and implement CIM systems. These models, some of which are discussed by Rembold and Nnaji (1991), have contributed to the development of new generic manufacturing models, and therefore influenced the work on enterprise modelling.

The second stream, are information models which represent the data and information that describe the factory in terms of either resources or processes, or both [ESPRIT Project 2165 and Gong & McGinnis, 1996]. These models are the ones that are necessary for undertaking design for manufacture. As in the case of product models, there are several proposals about the structure and information content of Manufacturing Models; they depend on the particular scenario in which they are intended to be used. This research adopted the Manufacturing Model proposed by the MOSES research project undertaken by Loughborough and Leeds Universities. The author analysed the model and considered it suitable for the purposes of this investigation.

Therefore, the Manufacturing Model is defined as [Molina 1995]: an information model, which identifies, represents and captures the data, information and knowledge that describes the manufacturing resources, processes, and strategies of a particular enterprise. This enables the provision of the necessary manufacturing information for the support of the manufacturing decision-making in concurrent design of products [Borja 1997].

3.4 Research Tools

The reason for using these research tools was that they were readily available in the laboratory to support the MOSES of research work. In this case the author was generally constraint to use these tools for this research work. The tools are discussed in the succeeding sections below.

3.4.1 IDEF0 Activity Modelling Methodology

The IDEF0 technique is an activity modelling which is very useful in providing an initial view of activity structures and relationships. To achieve an understanding of the interrelationships between support product design, support process planning and support fixture planning activities, the author performed an activity modelling of Use Fixturing Information using IDEF0 activity modelling methodology.

The IDEF0 stands for ICAM Definition Level 0 [Colquhoum *et al.*, 1993] is based upon a structured analysis and design technique to produce a function or activity model, which is a structured representation of the activities of a manufacturing system or environment, information and objects which interrelate those functions. IDEF0 methodology is a top-down hierarchical method describes a system by a series of functions and activities arranged sequentially. The hierarchical breakdown allows defining a system in any number of levels of detail and this makes it easier to understand complex systems [Chadha *et al.*, 1991].

The author has been working considerably for the initial activity model related in the Use of Fixturing Information using IDEF0 technique. With this activity model, the diagrams are made consistent as possible with the inputs, outputs, controls and mechanisms data flow. The benefit in using this methodology was getting a clear initial view of the interactions that enable to build the structure of this research work. A detailed discussion about IDEF0 activity modelling methodology is found in Appendix A.

3.4.2 Unified Modelling Language - UML

In order to have a well-implemented software system, it is necessary to have a good understanding to the problem that leads to the design of the information models that emphasised on the correct and effective structuring of a software system as well as the definition of the relationships and interactions between the systems. The designed models help to reason about the structure of the system and provide a requirement to implement [Booch 1994].

The object-oriented approach to software development is based on modelling objects from the real world (e.g. machine tool, clamps, locating devices) and offers several advantages to conventional approaches. Such advantages are better to understand the requirements, better handling of the complex systems, smaller systems through the re-use of common mechanisms as well as leading to less complex, easy to enchance and maintain software systems [Booch 1994 and Rumbaugh *et al.*, 1991]. In the MOSES research project, which this research work has been formed, Booch Object-Oriented Methodology of the Rational Rose software application was utilised to develop the Manufacturing Model structures.

The Rational Rose is a software application, which provides modelling tools such as Booch, OMT (Object Modelling Technique) and UML (Unified Modelling Language) to create and refine the views (logical and physical) within an overall model representing given problem domain and software system. A model also contains diagrams and specifications that provide a means of visualising and manipulating the model's elements and their model properties. In this research the author used the UML tool of Rational Rose software application to develop the fixturing information model structure on this work. Refer to Appendix B for a detailed description about UML diagrams used in this research work.

3.4.3 C++ Object-Oriented Programming Language and UniSQL/X Object-Oriented Database

The experimental fixturing system has been implemented using the object-oriented programming language C++ [Schildt, 1995] and SQL (Structure Query Language) of the UniSQL/X object-oriented database system [UniSQL/X 1996]. The UniSQL/X is an object-oriented unified database management system that extends the principles of relational database systems with features from C++ object-oriented programming language. It allows users to model real world object, constraints and relationships among objects through support for classes, instances, object identifiers, objects, arbitrary data types, methods, multiple inheritance and encapsulation. Using the data-modelling tool available within UniSQL/X users can define, store and manipulate multimedia data, including audio, video, graphics, text and images. It also provides full support for automatic optimisation and processing of queries. Then, the Graphical User Interface has been implemented using Visual C++ version 5.0 [Mueller, 1997] environment.

3.5 Summary

This chapter has discussed the context of the research work done in this thesis. This research environment adopted in this work is based on MOSES (Model Oriented Simultaneous Engineering Systems) concept. The main elements of the MOSES are described and the methodology utilised for design of system and the tools used in the exploration of the research project are presented.

The components of CAE, which supports concurrent engineering system, were discussed and the relevant research in the areas of data model driven systems, design for manufacture and features technology was presented. The CAE systems that support multi-processes were discussed in the context of information sharing. Then the importance and the structure of information sharing in design for manufacturing were discussed.

The research tools that are readily available in the laboratory to support the MOSES kind of research are presented and discussed. The author was generally constrained to use these tools for this research work. The IDEF0 modelling tool has been used to model fixturing information flows to provide initial view of the relationships between fixturing information and how it might support the activities across product design and manufacture. The Rational Rose is a software application, which provides modelling tools such as Booch, OMT (Object Modelling Technique) and UML (Unified Modelling Language) to create and refine the views (logical and physical) within an overall model representing given problem domain and software system. The experimental fixturing system has been implemented using the object-oriented programming language C++ and SQL (Structure Query Language) of the UniSQL/X object-oriented database system.

The issues to be resolved in order that fixturing information can be defined and structured in data model driven environment are discussed in the next chapter.

Chapter 4

COMPUTER SUPPORT FOR FIXTURING SYSTEMS

4.1 Introduction

This chapter presents the general issues of computer-aided fixture planning and the specific issues of relevance to the author's work in this area. This also highlights the research contribution made by this thesis.

4.2 Issues in Computer-Aided Fixture Design and Planning

As evident by the discussed research efforts in Chapter 2, much progress has been achieved within the last decade. However, although many specific research issues are being addressed at various stages of fixturing design and planning, a complete computer-aided fixturing system is not yet available.

Research investigations into fixture support systems can be classified broadly into the following categories based on the techniques used; artificial intelligence with geometric modelling, optimisation & mathematical methods, kinematics & dynamics methods, finite element analysis and group technology & feature-based reasoning. Markus *et al*, (1984) produced one of the first fixture design system to make use of the artificial intelligence while CAD/CAM techniques have been used in a knowledge-based fixturing system developed by Miller & Hannam (1985).

The first fixturing system developed using Group Technology was researched by Jiang *et al*, (1988), while Trappey & Liu (1992) developed a workholding verification system modelled as a quadratic optimisation problem. Each of these pieces of research is useful to their own area but there is a need for the provision of a general source of information to support decision-making. This research shows how information models can be structured to provide fixturing information to support decision-making across fixture planning, process planning and product design.

Investigations into fixture design systems can be classified from the point of view of their degree of automation; namely interactive, semi-automated and fully automated. Interactive fixture design is a process where a computer is used to aid the designer by displaying the appropriate fixture elements based on his knowledge. The designer in arriving at the final fixture configuration decides the correct position of the fixture elements.

A system can be said to be semi-automated if it does not require full knowledge or expertise from a designer while arriving at appropriate locating, clamping and supporting faces, points and elements. Ingrand & Latombe (1984) developed a semi-automated system incorporating the expertise of a designer into the fixture design system. The determination of appropriate faces for locating, clamping and supporting can be decided automatically [Markus *et al*, 1984]. Nevertheless, the selection of appropriate points and elements for building a fixture still depends on the user's expertise and knowledge.

An automated system is one that obtains information directly from a CAD model and makes use of the knowledge-based to decide on the appropriate fixturing points and fixturing elements. Design parameters such as orientation, stability, and deflection due to cutting forces, set-ups, tolerance relationships, assembly and interference must be considered while designing a fixture. Expert systems together with a good knowledge representation scheme were generally used in arriving at a fixture design [Nee *et al*, 1995].

While these various pieces of work have provided some progress towards improved fixture design systems, they have typically focused on specific issues. The identified issues needed to be resolved as listed below that is supported by the evidence in the literature's [Bi, Z.M. & Zhang, W.J., 2001, Ma *et al*, 1998, Rong & Bai 1997, Hargrove & Kusiak 1994 and Liu & Strong 1993]:

- Integration of solid modelling CAD systems that is capable of designing fixtures for complex workpiece.

- Integration of fixturing system with other systems such as process planning, product design and database systems.

- Investigation on the impact of tooling tolerance for locators on the workpiece tolerance before machining.

- Verification of the fixture configuration that there is no interference between the selected fixture elements and the cutting path.

- Determination of cutting force, clamping force and workpiece orientation for speed of assembly process of fixtures and minimising workpiece deformation.

- Fixturing system initiated by information models that describe the integration of shared databases.

- Future research on CAFD will put emphasis on cooperation with product design, process planning and the CAFD information system and should be fed back to the other system as early as possible in the product development stage.

It is particularly significant in order to ensure effective decisions are made at the early stage in the design and manufacture process; it is considered important that software tools should provide sufficient information to support the decision making of design and manufacturing engineers. Fixturing support systems therefore, need to provide information that will support the activities in design and manufacture, which may require fixturing inputs [Bugtai & Young 1998].

As stated in Chapter 3, the general type of information that is necessary to support design and manufacture can be captured in a product model and manufacturing model. The issues that were addressed in this research work are listed below:

- What fixturing information is stored in the manufacturing model?
- What are the different fixturing methods and their capabilities?
- How to define a manufacturing model representation to capture the capability of these fixturing methods?
- How the manufacturing model can provide a helpful information support to fixture planning, process planning and product design.
- How to build an experimental system to enable the research ideas to be explored and what experiments can be performed to assess the value of the approach taken?

4.3 Modelling the Fixturing Information

An increasing significance has been given to computer technologies that enable powerful information systems to be created and then make it possible to be integrated effectively into a modern factory. In these information systems an important aspect is the representation of a high quality data. Research work reported which is concerned with the definition and development of a manufacturing information model [Molina 1995] is described in chapter 3. Molina's work provides the general structure into which the research contribution of this thesis has been formed.

There are fixturing systems that stored standard fixturing elements in a database, Fuh *et al*, (1993) used a database containing the CAD models of the modular fixture elements that has been created based on the Qu-Co's Modular Fixture System (1990). Huang & Trappey (1990) utilised the modular fixture element database of Venlic Block Jig System, Catalogue (1987). The descriptions of how to define fixturing information within a manufacturing model and the resultant structure that represent fixturing information in conjunction with a product model are explained in Chapter 5.

Figure 4.1 shows the views of the fixturing information model structured in the MOSES concept. The product model captures the information of a specific work-pieces and the manufacturing model captures information of the fixturing resources and processes. In the figure, particular design and manufacture functions of fixture planning, process planning and product design for fixturing are supported with the use of the information models. The selection of these applications is based on the fact that in order an information model can be useful, it must support more than one application. The application that needs fixturing information inputs is fixture planning and other applications that may require fixturing information are product design and process planning.

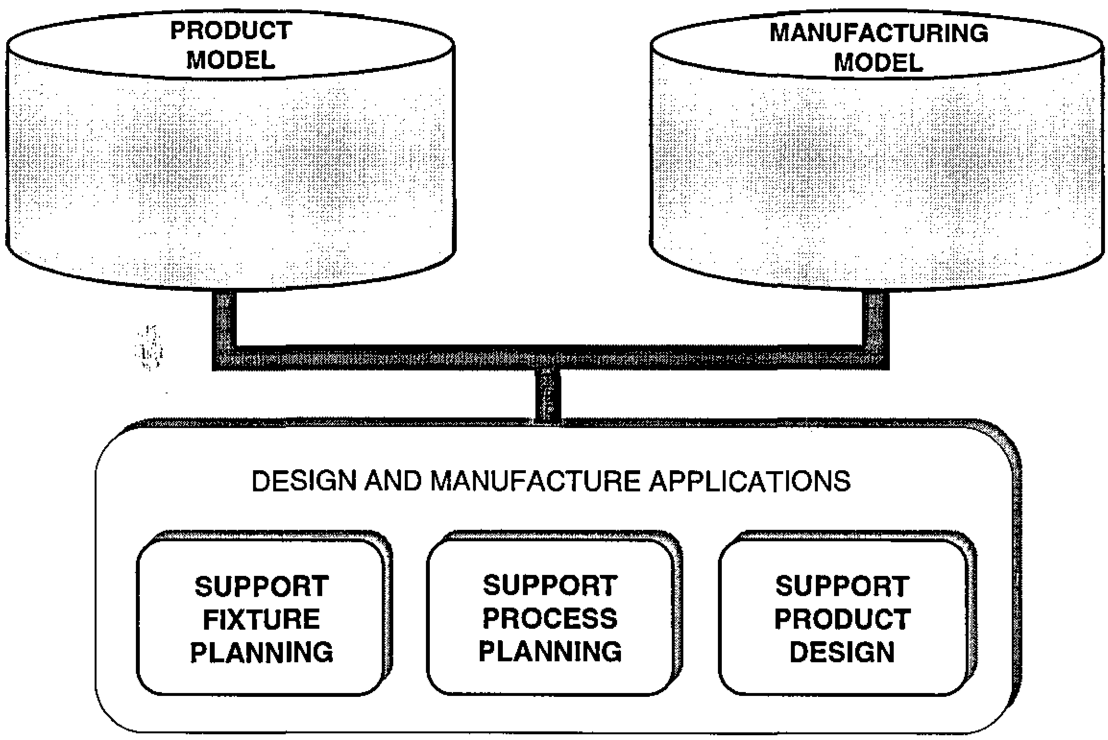


Figure 4.1 – A Fixturing Information Model within the MOSES Concept

4.4 Fixturing Information Models within an Integrated Information Environment

The main thrust of the research reported in this thesis is on the data structures required in a manufacturing model in conjunction with a product model to capture fixturing information. In order to be useful, it has been necessary to explore how the information can be used to support decision-making in different stages in the design and manufacture processes. The work has explored how these information models can be utilised to support the particular design and manufacture functions of fixture planning, process planning and product design for fixturing. The detail on this work is explained in Chapter 6.

Chapter 5

MODELLING FIXTURING INFORMATION

5.1 Introduction

This chapter provides the research done by the author in modelling fixturing information. Section 5.2 describes the activities and information flows involved in the use of fixturing information. The IDEF0 modelling tool has been used to model fixturing information flows to provide the author with an initial view of the relationships between fixturing information and how it might support the activities across product design and manufacture.

Section 5.3 describes the work performed to define the structure of the manufacturing model that captures a representation of the fixturing information model using the Unified Modelling Language (UML). Discussion on the problems involved in modelling the fixturing information is presented as well as the methods used to capture and represent the information. Section 5.1 describes the representation of the fixturing information model and how the interactions between the elements have been captured. Section 5.5 presents the product data model. This section discusses the definition of the general information structure and how this information of a specific workpiece has been captured in the product model.

The resulting structure of the manufacturing model for fixturing information model constitutes the basis for the object-oriented experimental software that is described in Chapter 7.

5.2 Exploration of Fixturing Information Requirements

As a result of the fixturing fundamentals in Chapter 2, the author has categorised into two classifications, which are the fixturing process and fixturing resources. The fixturing process cannot be considered independently of the machining process because the workpiece is located and held with respect to the machine tool axis. Thus, any representation of information related to fixturing must also be related to machining. In a similar way fixturing resources in terms of machine tool and cutting tool are used. An examination of the requirements for fixturing a workpiece and identification of the key aspects of related manufacturing information, led to the general hierarchy of data as illustrated in Figure 5.1. This shows a general view of manufacturing information for fixturing with an initial view of how it would be positioned in the manufacturing model.

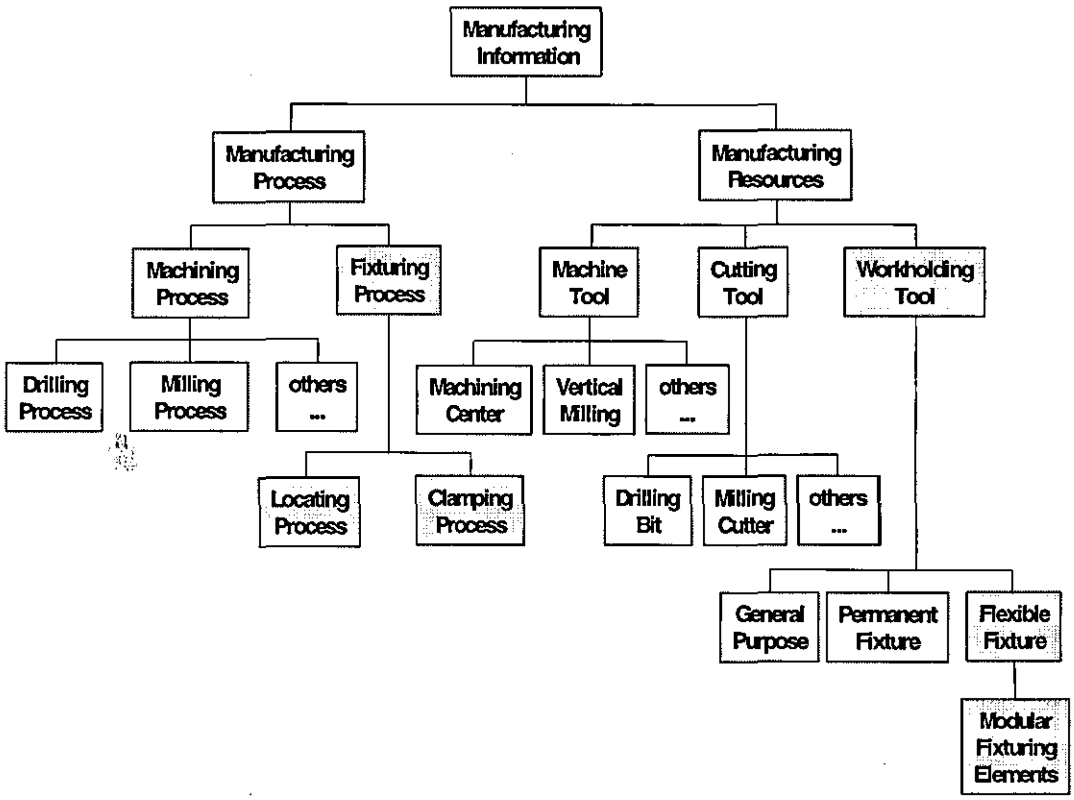


Figure 5.1 – A General Manufacturing Data Hierarchy

5.2.1 The Fixturing Processes

A fixturing process is needed whenever a workpiece must be located accurately and held with respect to a machine tool axis. It must ensure that the workpiece being machined is held in such a way that the design specification can be satisfied. It is considered that a fixturing process involves two sub-processes, these being locating a workpiece and clamping a workpiece. These sub-processes are discussed in the succeeding sections.

5.2.1.1 Locating Process

To insure the successful operation of a fixturing device, the workpiece must be accurately located to establish a definite relationship between the cutting tool and surfaces of the workpiece. Locators establish this relationship in the fixturing device, which position and restrict the movement of a workpiece. The locating device should be so designed that the workpiece when loaded and clamped will occupy the same position in the fixture as illustrate in Figure 5.2 [Rong, *et al.*, 1995].

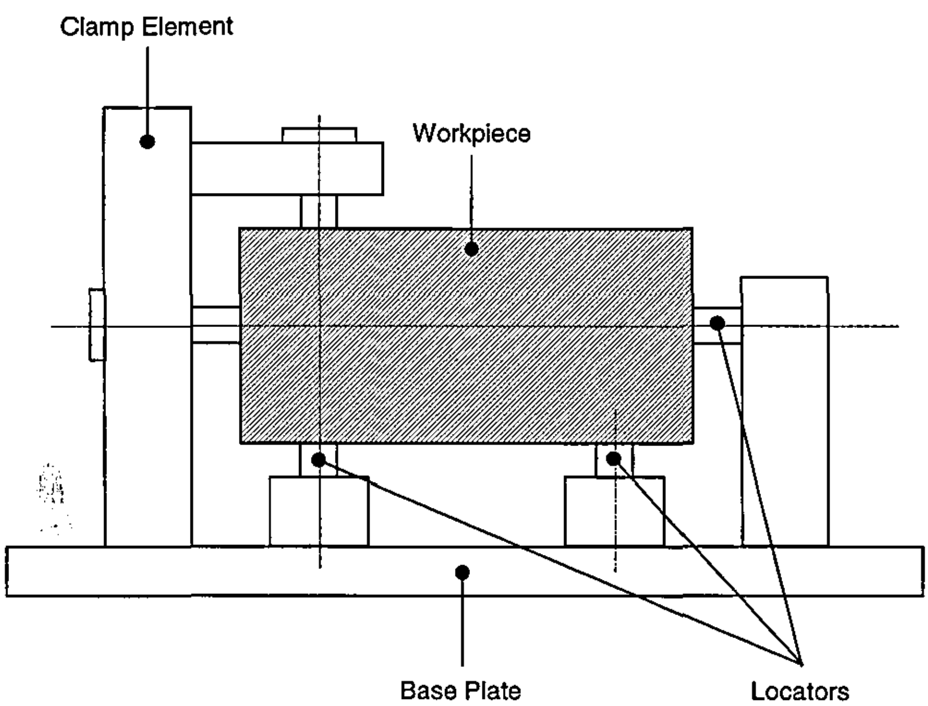


Figure 5.2 – A workpiece being Located and Clamped on a Fixture

Normally the locating requirement should be considered prior to clamping and the locating surface is usually a planar surface, although in some cases cylindrical surface or irregular surfaces can be chosen. The factors to be considered in order to define locating process are; machining features, workpiece surfaces, tolerances, machine tool configuration, and locating methods [Chang, 1992]. The following sub sections discuss each of these factors in order to identify how they influence the locating process. This leads to the specification of a model of the three locating processes defined in section 5.2.2.1.

5.3.1.1.1 Machining Features

The features to be machined and the initial and resulting forms of the workpiece influence the cutters to be used, the cutter paths and determine the workpiece orientation in relation to the machine spindle. The closer a fixture component or unit is placed to a machined feature; the more the machining operation is restricted [Chang, 1992]. Thus design and layout of a fixture has an impact on the cutting tools to be selected, the machining cycle time, the surface finish and the accuracy of the machined workpiece.

5.2.1.1.2 Workpiece Surfaces

One major consideration involved to locate a workpiece is the shape of the workpiece surfaces. All workpiece surfaces can be divided into three basic categories as far as location is concerned; flat surfaces, cylindrical surfaces and irregular surfaces. Flat surfaces are those surfaces regardless of their position have a flat bearing area for the locators [Chang, 1992]. Examples of features that provide flat surfaces, which can be used as locations, are steps, faces, shoulders and slots. The external surfaces on a prismatic workpiece are normally the candidates for possible locating surfaces. This research focuses on workpieces that have orthogonal faces. Workpieces that have angled faces require more complex fixturing, which would need further evaluation.

The interior or exterior cylindrical surfaces of a rotational workpiece are often located through the cylindrical surface by means of a v-block, chuck, mandrel or locating pin. Irregular surfaces are typically not used for workpiece location.

5.2.1.1.3 Workpiece Tolerances

The workpiece tolerance represents the total allowable variation from a specific dimension or specification. The designer specifies an ideal condition along with a margin of error that can be tolerated and must consider a number of factors such as the function of the workpiece for which the tolerance must be compatible [Rong, *et al.*, 1995]. These include for example, the tolerance of angularity, perpendicularly, parallelism, concentricity and locations of machining features. These factors define the maximum acceptable deviations from specified nominal relationships among features.

5.2.1.1.4 Machine Tool Configuration

The machine tool specified for the machining operation should also be examined. The information that might affect the mounting operation of the fixture must be addressed; such as the type of the machine tool, the number of axes, table size, spindle size and movement, spindle swing and distance between centres are typical points to consider [Rong, *et al.*, 1995]. This information from the machine tool has a significant effect on fixturing process. For example, in order to bore a hole on a vertical milling machine as shown in Figure 5.3A, an angle plate is required while, a machine table surface can be used to position the workpiece on a horizontal milling machine as shown in Figure 5.3B.

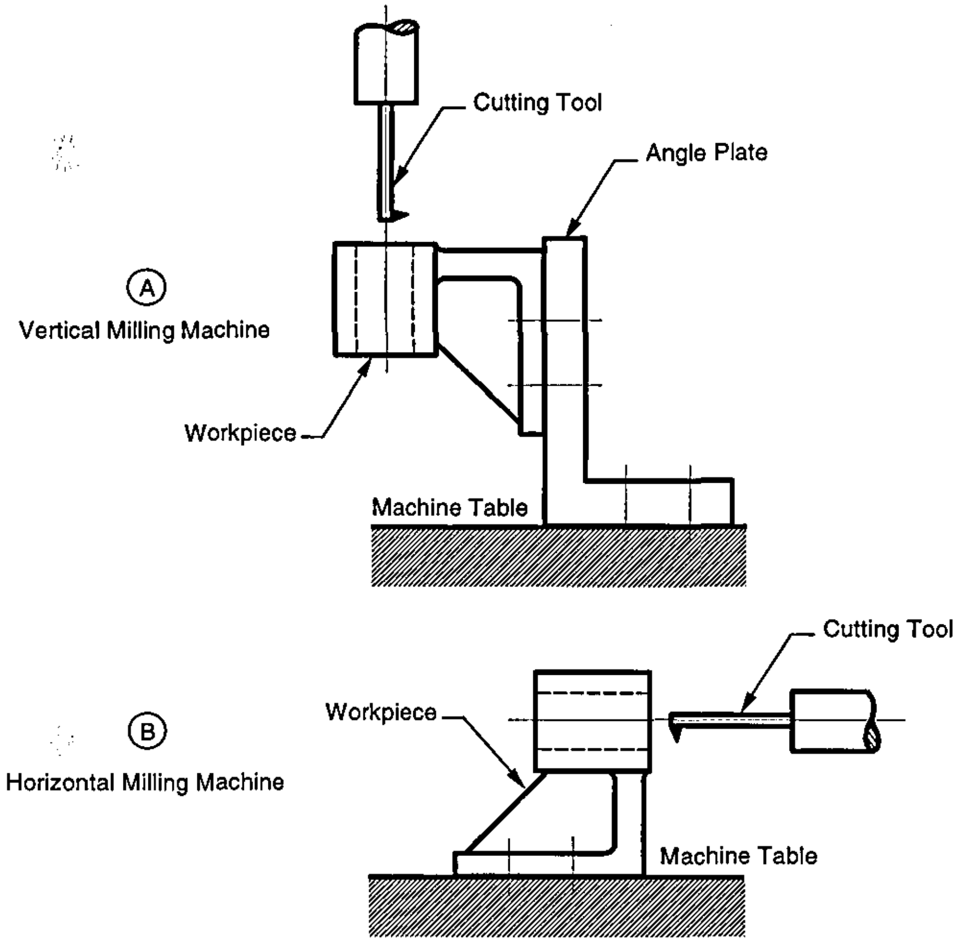


Figure 5.3 – The Vertical and Horizontal Milling Machine Spindle Axes

5.2.1.1.5 Locating Methods

Basic workpiece locating can be divided into three general methods; 3-2-1 location, concentric location and radial location. In many cases more than one methods of location may be used to locate a particular workpiece. However, for the purpose of identification and explanation, in the next sections each one will be discussed.

5.2.1.1.5.1 The 3-2-1 Locating Method

The basic method of locating a workpiece is the 3-2-1 method, also called the six-point method. With this method, the position of the vertical axis Z is established by locating the workpiece on three locators as shown in Figure 5.4. These three locators also restrict rotation around the X and Y-axes resulting in the restriction of the five degrees of freedom as it was discussed in section 2.4.2 of Chapter 2.

The addition of the fourth and fifth locators establishes the position of one of the horizontal axes and restricts rotation around the vertical axis resulting in restriction of eight of the twelve degrees of freedom. The addition of sixth locator in the remaining horizontal axis establishes the position along that axis resulting in a restriction of the nine of the twelve degrees of freedom. The six locators completely restrict movement of the workpiece and the three remaining degrees of freedom can be restricted with clamps.

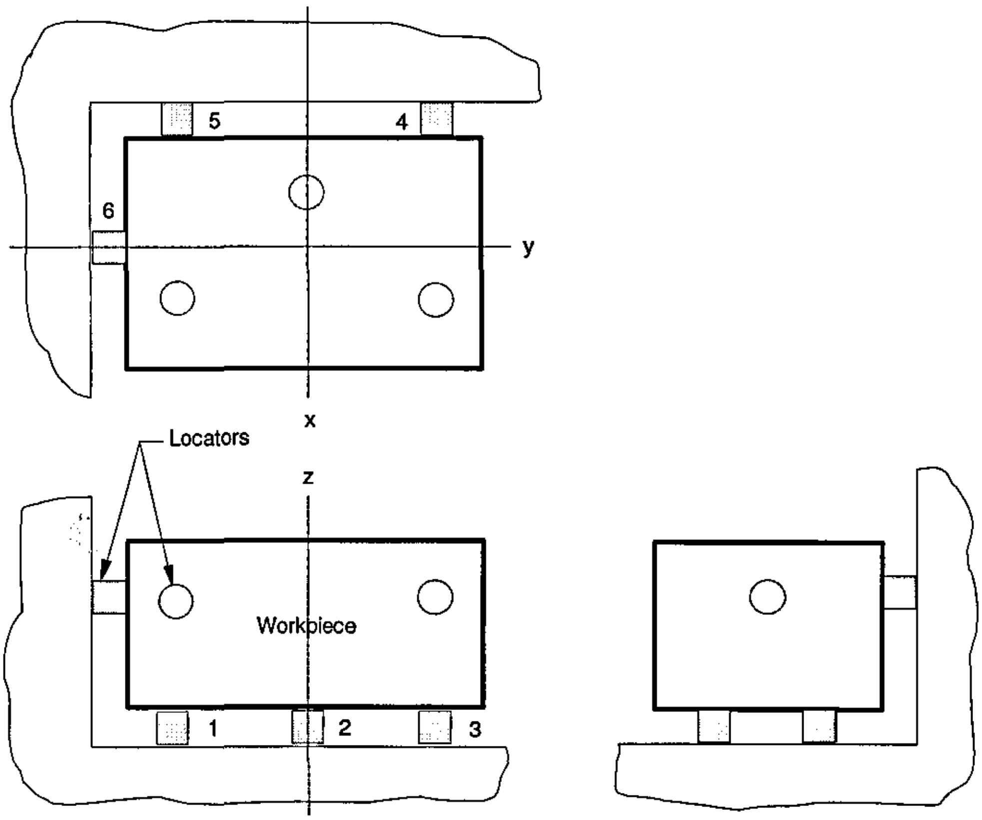


Figure 5.4 – The 3-2-1 Locating Method

For prismatic workpieces, the external surfaces are considered for possible locating surfaces. The largest surface opposite to face where the features are placed is generally selected as the primary locating surface in a 3-2-1 locating method. Figure 5.5A illustrates this method of selecting the primary locating surface for a simple prismatic workpiece.

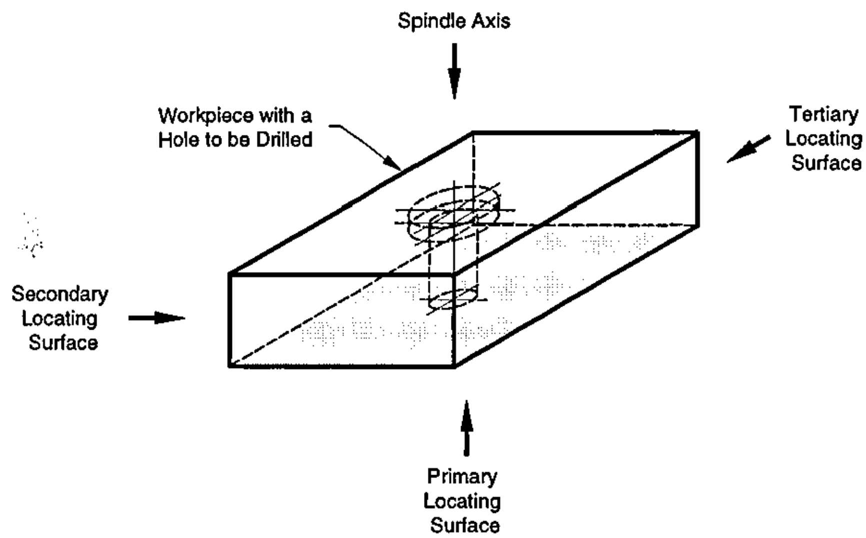


Figure 5.5A – A Prismatic Workpiece Using the 3-2-1 Locating Method

Figure 5.5B shows another example of a prismatic workpiece whose primary locating surface is selected from the surface opposite to the face where the features are placed and opposite to spindle axis.

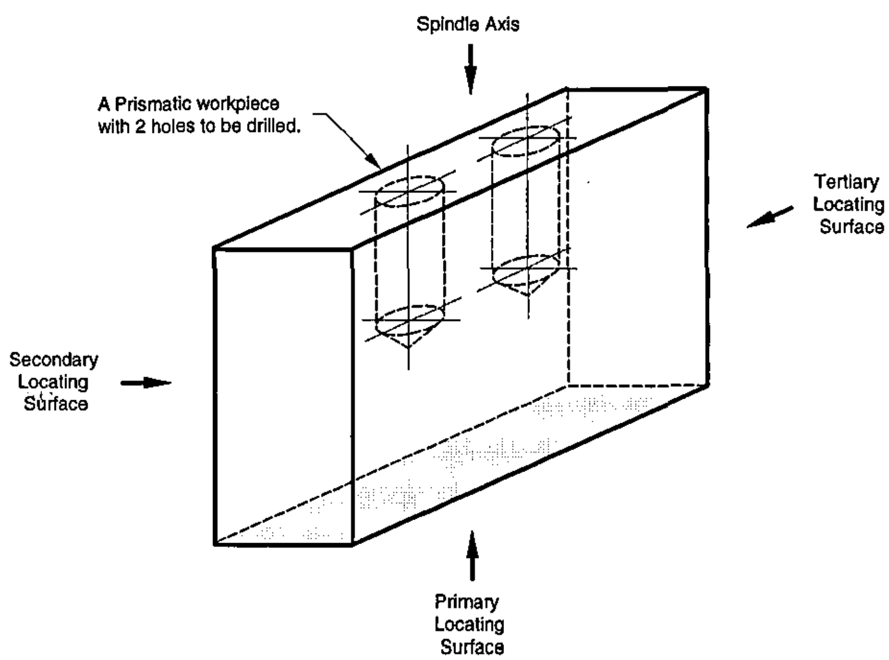


Figure 5.5B – A Prismatic Workpiece with Two Blind Holes Using the 3-2-1 Locating Method

Figure 5.6 shows a prismatic workpiece have three blind holes located near the edge of the top surface. The primary locating surface is selected from the surface opposite to the face where the features are placed and opposite to the spindle axis. In this case, supports are needed to counter the downward force of the cutting tool.

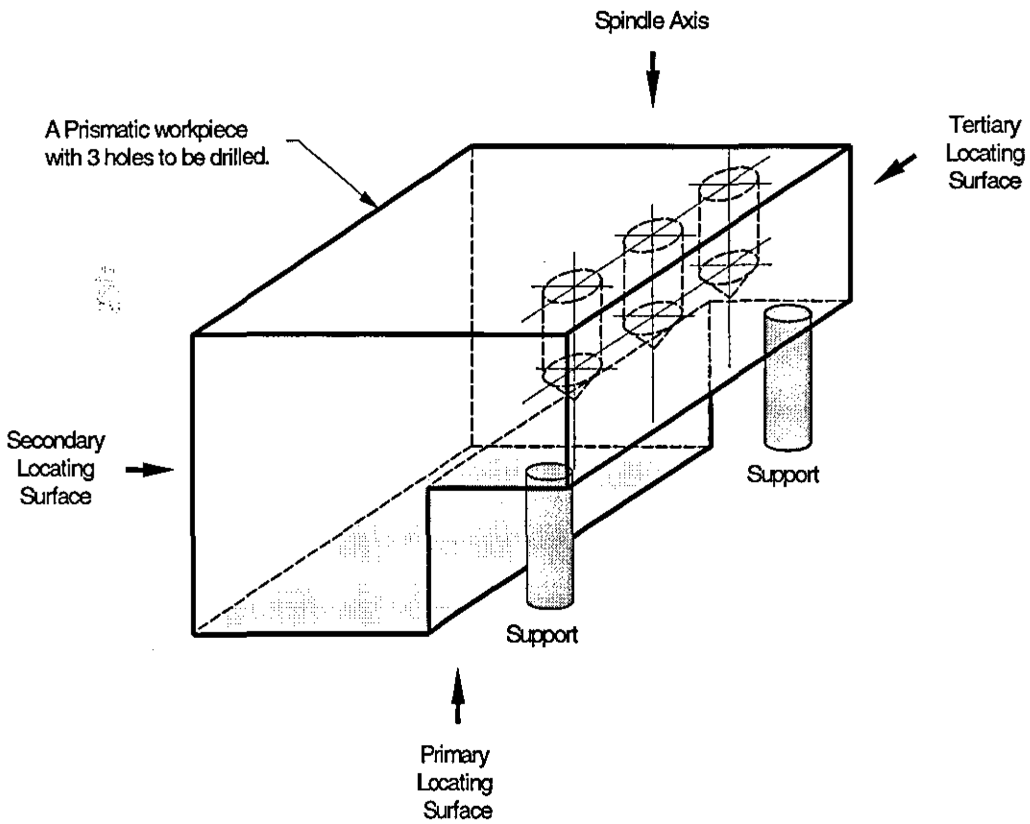


Figure 5.6 – A Prismatic Workpiece with Three Blind Holes Using 3-2-1 Locating Method

5.2.1.1.5.2 The Concentric Locating Method

Concentric location is a process of locating a workpiece from an internal or external diameter and a flat surface. The concentric locating method can be used for locating a workpiece with a hole feature on it. The hole feature should be a reamed hole before it could be used for location in order the accuracy of locating can be achieved. Problems in surfaces to locate are either outside diameter or inside diameter as illustrated in Figure 5.7.

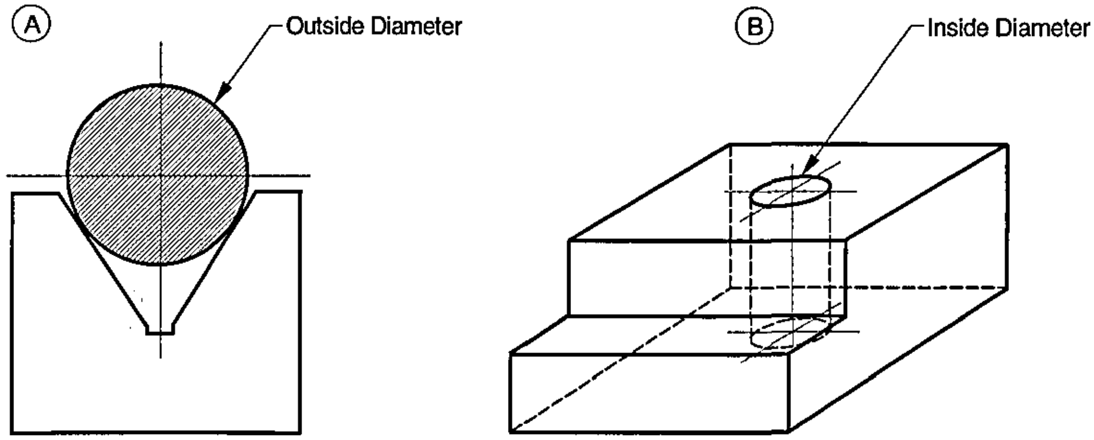


Figure 5.7 – The Concentric Locating Method

Figure 5.7A illustrates an external concentric locating using a vee locator. This locator is used mainly for round or cylindrical workpieces. The vee locator accurately locates and centralises a round workpiece or a workpiece with radiused ends. The normal vee-type locator is 90 degrees for stable and consistent location. The most common type of concentric locating is a locating pin placed on a hole. A further requirement is that the tolerance on the hole must achieve a locational fit with the locating pin. This typically requires a reamed hole. Figure 5.7B shows a prismatic workpiece with a hole that can be used as a concentric locating.

5.2.1.1.5.3 The Radial Locating Method

Radial locating is normally a supplement to concentric locating. With radial locating method, the workpiece is first located concentrically and then a specific point on the workpiece is located to provide a specific relationship to concentric locator. This locating method is used for locating a prismatic workpiece with two hole features. Consider the workpiece shown in Figure 5.8, while concentric locator can be used easily to locate the hole 1, failure to perform radial locating will result locating error for hole 2. Again, the hole tolerance is critical and must affect a locational fit.

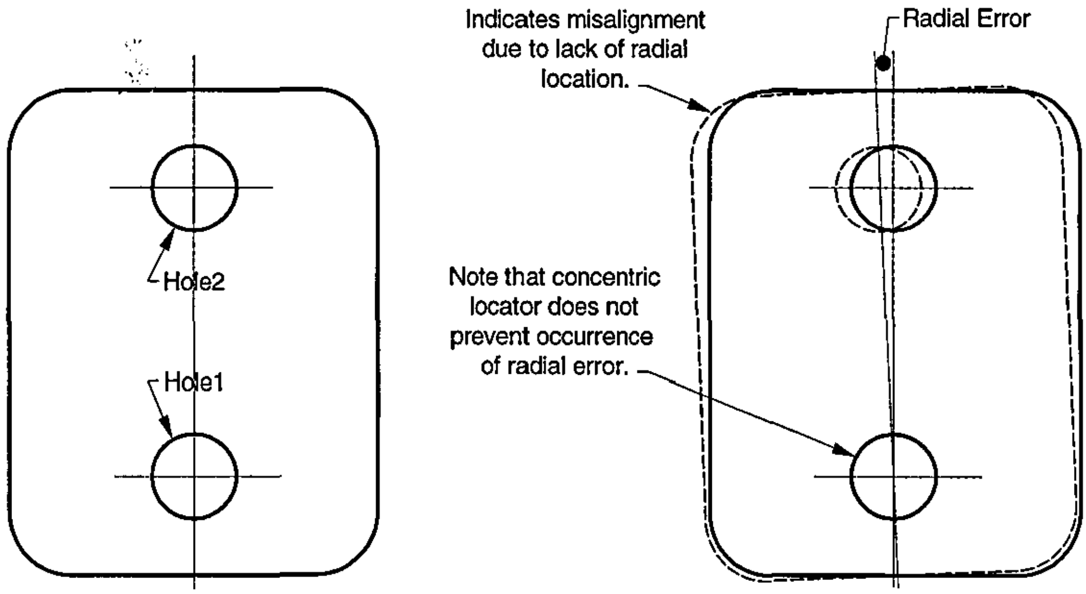


Figure 5.8 – The Radial Locating Method

5.2.1.2 Clamping Process

Clamping is a process of holding firmly a workpiece against the locators and restricting completely the movement of a workpiece during machining operation. By directing the cutting forces towards the locators, the workpiece is forced against solid, fixed locating points and cannot move away from the locators. The type of clamping greatly influences the amount of clamping necessary and also affects the overall deformation that can be inflicted on the general shape of the workpiece [Cecil *et al.*, 1996]. Clamping surfaces must be chosen so that all forces imposed during machining can be reacted to the machine tool bed through the locating surfaces. These are influenced by the following: a) workpiece shape and size, surface finish, strength and stiffness, b) locating surfaces and locators positioning, c) machining force direction and magnitude, and d) clamping methods. The succeeding sub sections discuss each of these factors in order to identify how they influence the clamping process. This leads to the specification of a model of the clamping processes defined in section 5.4.2.2.

5.2.1.2.1 Workpiece Condition for Clamping

The condition of the workpiece to be clamped for machining operations must be considered. This includes the shape, size, surface finish, strength and stiffness. Once the workpiece is located, then it must also be held to prevent movement during the machining operation. Normally, the external surfaces of the workpiece that is opposite to the locating surfaces are used for clamping [Lin *et al.*, 1997]. For simple prismatic workpieces to be clamped on a machine tool, the conventional types of clamping devices are employed. This includes standard clamps such as a vises, strap clamps, screw clamps, edge clamps, swing clamps and toggle clamps. For a rotational work-pieces, standard clamping devices such as arbors, mandrels, collets, and chucks are normally used for holding the workpiece during the machining operations.

For complex shapes and sizes of the workpiece may require contoured clamps to add bosses, lugs, ribs and others, as clamp areas for adequate holding. Magnetic, electro-static or vacuum devices instead of conventional clamps may hold the workpiece. Equalising clamps or clamps with very long or short travel or small but powerful pneumatic or hydraulic clamps may have to be used with workpiece with complex shapes. For a large workpiece, one or two ways of clamping can be used such as a greater number of small clamps or the fewer, larger and stronger clamps. The choice will depend upon which arrangement provides the best holding force for the strength and stiffness of the workpiece. Surface variations are normal in castings and those may dictate the need for equalising clamps to compensate for the surface irregulari-ties. Surface finish of the workpiece may necessitate clamps incorporating soft or resilient faces of plastic, rubber and other like materials to prevent the deformation of the workpieces.

5.2.1.2.2 Locating Surfaces and Locator Positioning

The implication of the locating surfaces in clamping is that, clamping surfaces are opposite to the locating surfaces and clamps are placed on the opposite surface where the locators are positioned. Locating a workpiece from external surfaces is the most common locating method. The bottom or primary locating surface is positioned on the three locators. The two adjacent surfaces usually perpendicular to each other are then used to complete the location. In clamping the 3-2-1 method, six individual locators are used to restrict some degrees of freedom of the workpiece and the complete restriction of the workpiece is done when the clamps are placed opposite to the locators. This is illustrated in Figure 5.9, the clamps are directly opposite to the six locators. Clamping methods are discussed in section 5.2.1.2.4.

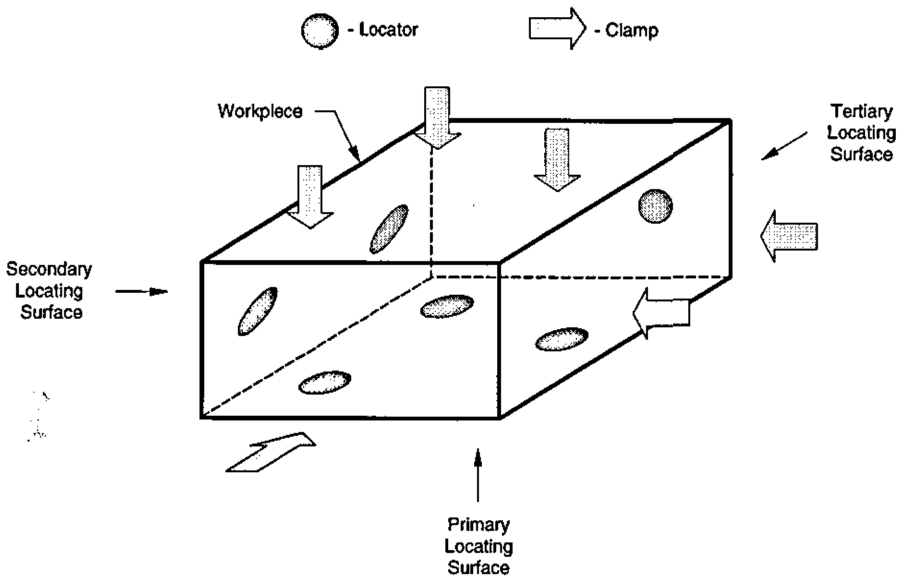


Figure 5.9 – The Clamps are Placed Directly Opposite to the Locators

Locating a workpiece from an internal surface is a good form of location. The primary features used for this form of location are individual holes. Depending on the placement of the locators, either concentric or radial or both locations are accomplished when locating an internal surface. A base plate used to mount the locators also provides a plane location. The two forms of locators used for internal location are locating pins and locating plugs. The only difference between these locators is their size; locating pins are used for smaller holes and locating plugs are used for larger holes.

As shown Figure 5.10, the base plate under the workpiece restricts one degree of freedom. It prevents any axial movement downward, along the negative z-axis. The center pin acting in conjunction with the plate as a concentric locator prevents any axial or radial movement along the x-axis and y-axis. Together, these two locators restrict nine degrees of freedom. The final locator, the pin in the outer hole is the radial locator that restricts two degrees of freedom by arresting the radial movement around the z-axis. Together, the locators restrict eleven degrees of freedom. A clamp will restrict the last degree of freedom in the positive z-axis direction.

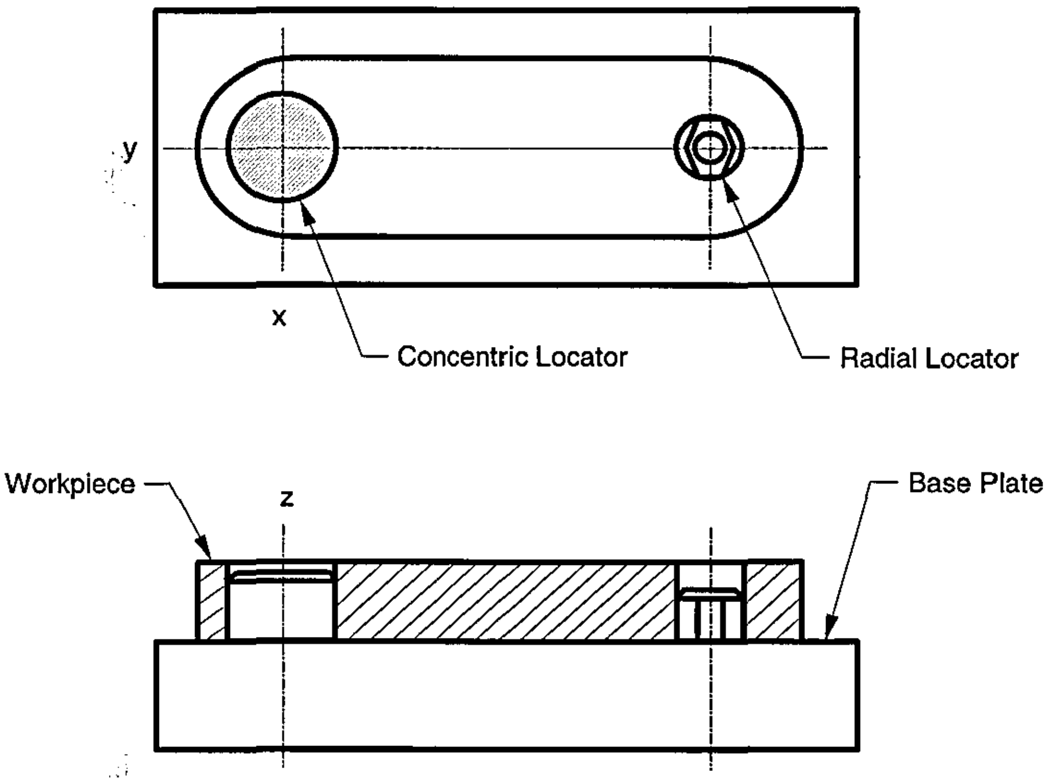


Figure 5.10 – Workpiece Mounted on a Base Plate with Two Locating Pins

5.2.1.2.3 Machining Force Direction and Magnitude

Another important factors to consider in clamping a workpiece are the direction, magnitude of the machining force exerted during the operation. Figures 5.11, the milling forces generated on a workpiece when properly clamped in a vise tend to push the workpiece down and toward the solid jaw. The clamping action of the movable jaw holds the workpiece against the solid jaw and maintains the position of the part during the cut.

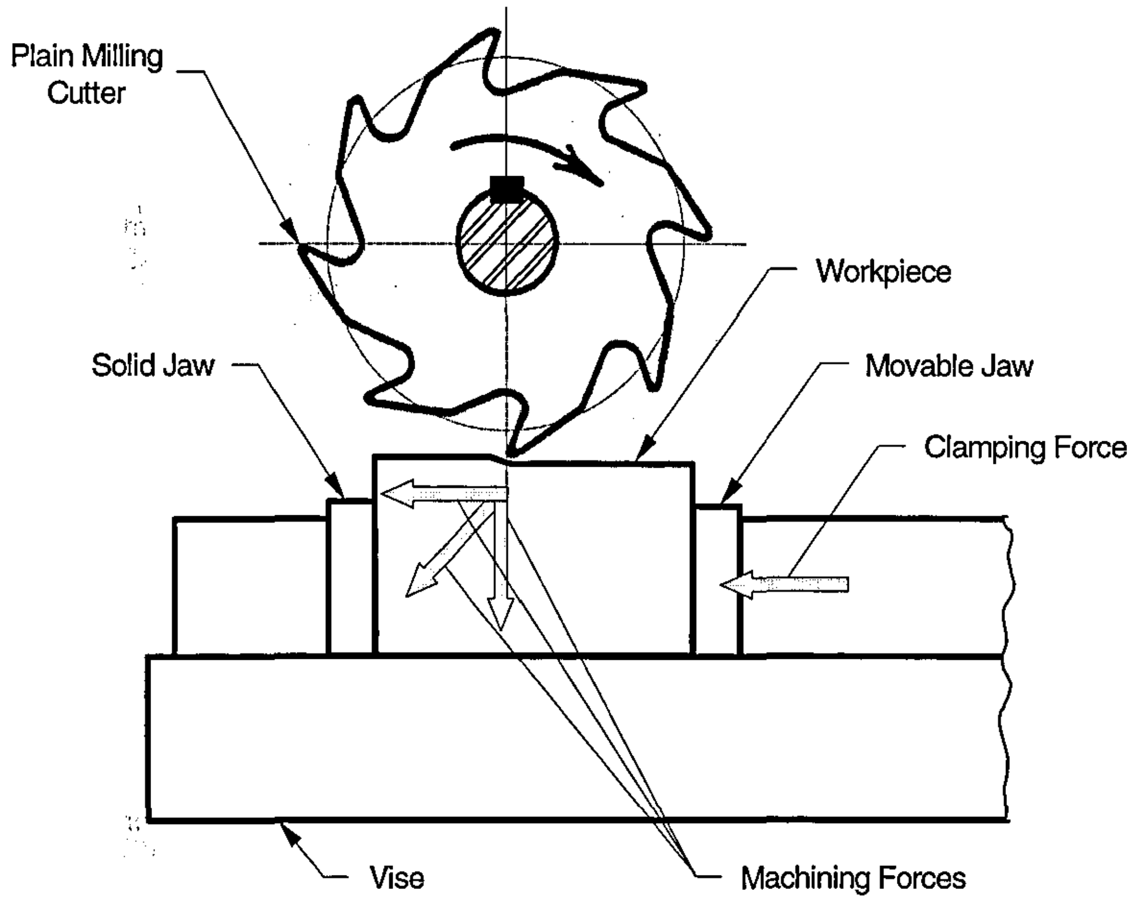


Figure 5.11 – Cutting Forces in a Milling Machine Operation

Another example of cutting forces on a workpiece can be seen in a drilling operation shown in Figure 5.12. The machining forces tend to push the workpiece down onto the locators. An additional machining forces acting radially around the drill axis also forces the workpiece into the locators. The clamps that hold this workpiece are intended only to hold the workpiece against the locators and to maintain its position during the machining cycle. The only real force exerted on the clamps occurs when the drill breaks through the opposite side of the workpiece, the climbing action of the part on the drill. The machining forces acting on a correctly designed workholder actually help hold the workpiece.

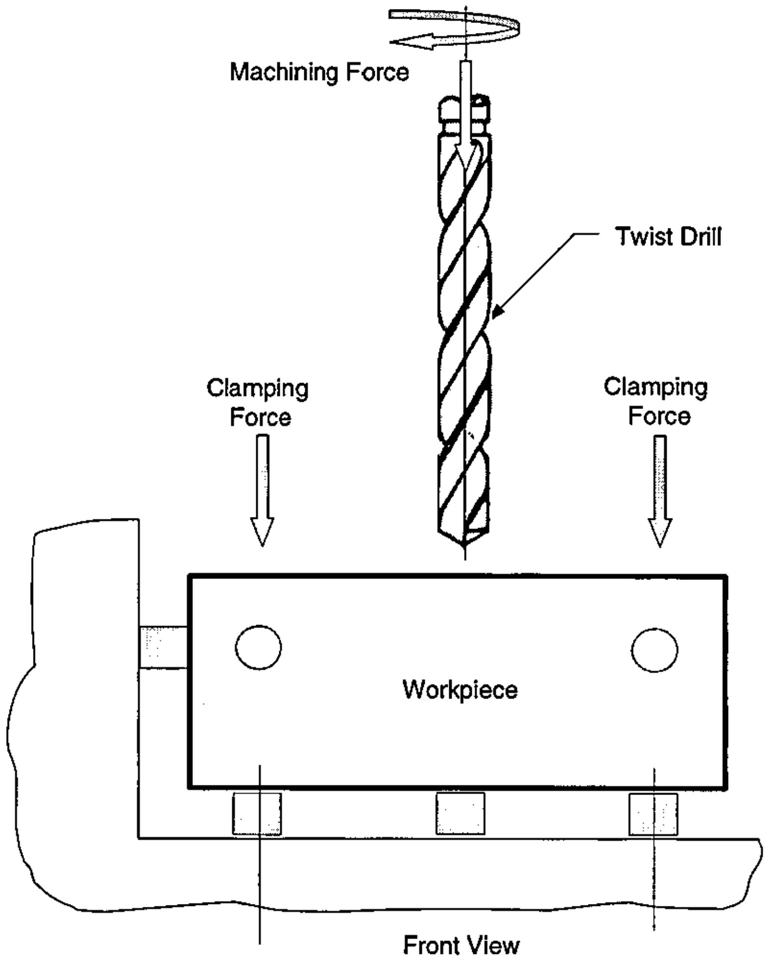


Figure 5.12 – Cutting Forces in a Drilling Operation

5.2.1.2.4 Clamping Methods

When the locating surfaces have been selected, the next task is to select the appropriate clamping surfaces. The surfaces that are opposite to the locating surfaces are all normally considered possible clamping surfaces. Clamping surfaces should have a surface area big enough to support the clamps. The accessibility of the clamping device is a major consideration when selecting the clamping surfaces. When it is positioned, clamp device should not block the path of the cutting tool. The number of clamping surfaces should be reduced to the minimum when appropriate. Clamping process involved applying vertical clamping force in vertical direction on the top surface of the workpiece and applying clamping force in a horizontal direction on the side surface of the workpiece.

The vertical clamping force is applied on the surfaces opposite of the primary locating surfaces, so that the clamping force will oppose and counteract the locating forces. The most rigid area is used as the clamping position to prevent deflection and deformation of the workpiece during the machining process. The best position is therefore the opposite of the three locators, as it will provide the rigidity and support that is required. The horizontal clamping force is applied to the secondary and tertiary locating surfaces, so that the clamping force will oppose and counteract the locating forces. The most rigid area is selected for clamping to avoid deformation and cracking of the workpiece during the machining process. The best position is therefore the opposite of the locators, as it will provide the rigidity and support that is required.

There are different types of clamping methods used for clamping to restrict the movements of the workpiece while it is under going machining process on a machine tool. The top clamping method is used to position onto the area where the primary datum and clamped surface overlaps. The side-clamping method is used to position onto the area where the secondary and tertiary datum [Lin, *et al.,* 1997]. In this research work reported, three types of clamping methods have been modelled; the first is clamping for 3-2-1 method, secondly, clamping for concentric method and the third is clamping for radial method. These clamping methods are discussed in succeeding sections.

5.2.1.2.4.1 Clamping for the 3-2-1 Method

As discussed in the previous sections, it is known that the basic method of locating a surface is by 3-2-1 locating. Once the locating surfaces are selected for this location method, the next step is selected the clamping surfaces. The most rigid area is used as the clamping position to prevent deflection and deformation of the workpiece during machining process. It is usually applied on the surfaces opposite to the locating surfaces as shown in Figure 5.13. The six locators of the 3-2-1 locating restrict the nine degrees of freedom of the workpiece and the three remaining degrees of freedom are restricted with clamps.

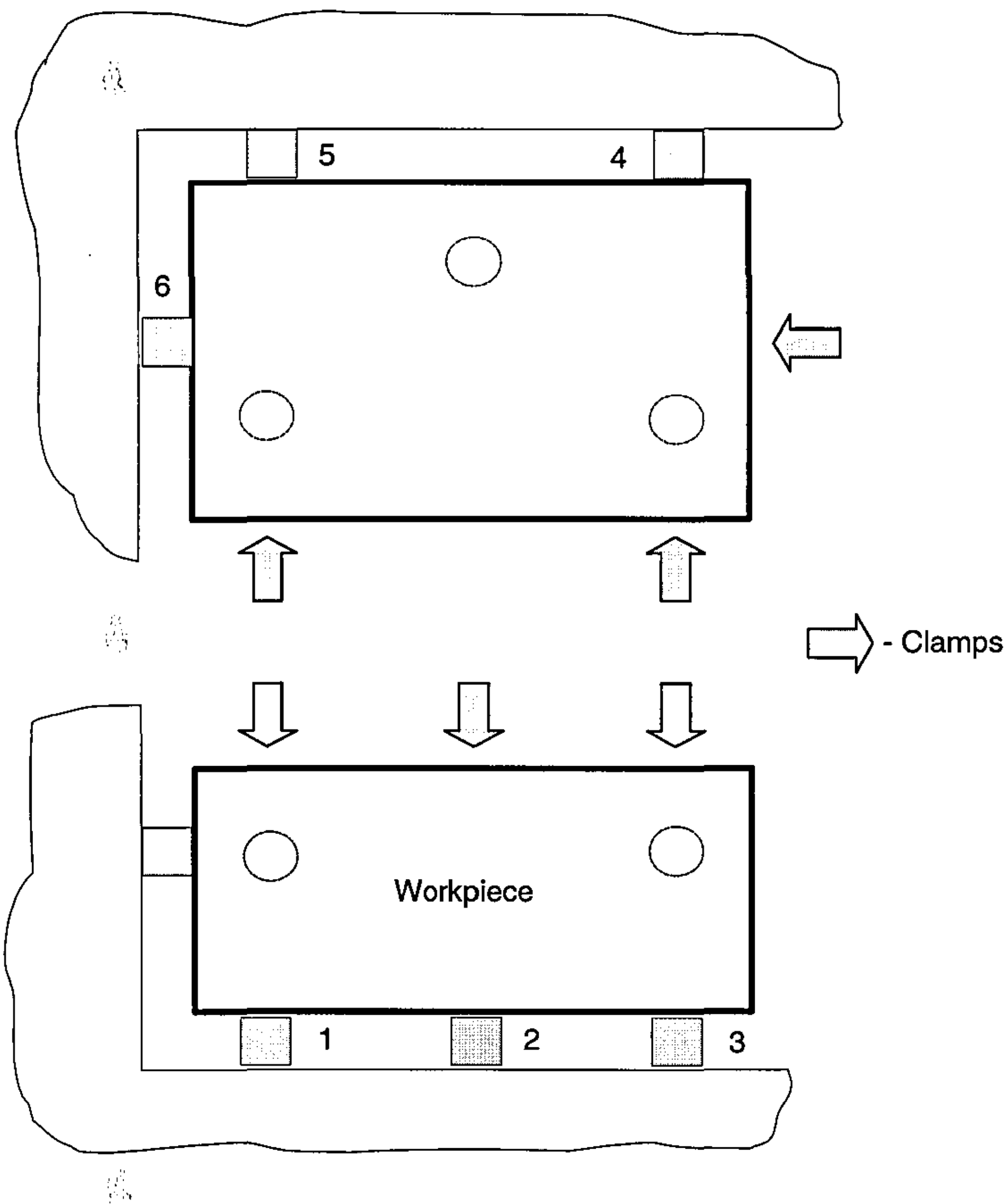


Figure 5.13 – Clamps are Placed on the Surfaces Opposite the Locating Surface

The largest surface opposite to face where the features are placed is generally selected as the primary locating surface in a 3-2-1 locating method, in effect the surface opposite is also selected as the primary clamping surface. Figure 5.14 illustrates this method of selecting the primary clamping surface for a simple prismatic workpiece.

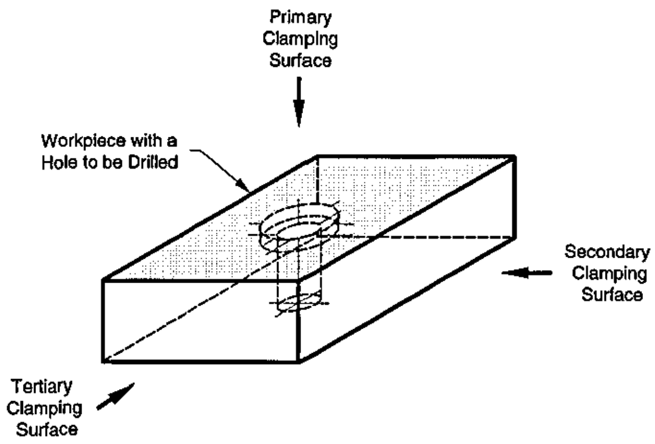


Figure 5.14 – The Clamping for 3-2-1 Method

5.2.1.2.4.2 Clamping for the Concentric Method

The clamping for concentric method needs information about the locating surfaces. As discussed in the previous sections that when a workpiece has a hole feature on it, the concentric locating is used. In the concentric method, the secondary clamping surface and secondary locating surface is on the same surface, which is a hole surface. Figure 5.15 shows the clamping for the concentric method of a workpiece that has a hole, which could be used for locating.

The figure shows that a workpiece has a hole existing that can be used for locating and a second hole is to be drilled at the other end. In order to clamp this workpiece, the locating surfaces are selected and then the clamping surfaces. The primary clamping surface is the top surface and an arrow pointing downward opposite to a locator in the primary locating surface indicates the clamp position. In this case, the secondary clamping surface is a hole surface. It is shown in the figure that a hole surface is used as the secondary locating surface and a locating pin with thread on both ends is used as a concentric locator. The concentric locator that is threaded on both ends can be used to clamp the workpiece together with a plain washer, nut and the base plate. The tertiary clamping surface is selected opposite to the tertiary locating surface in which a clamp as indicated by an arrow is positioned opposite to a locator.

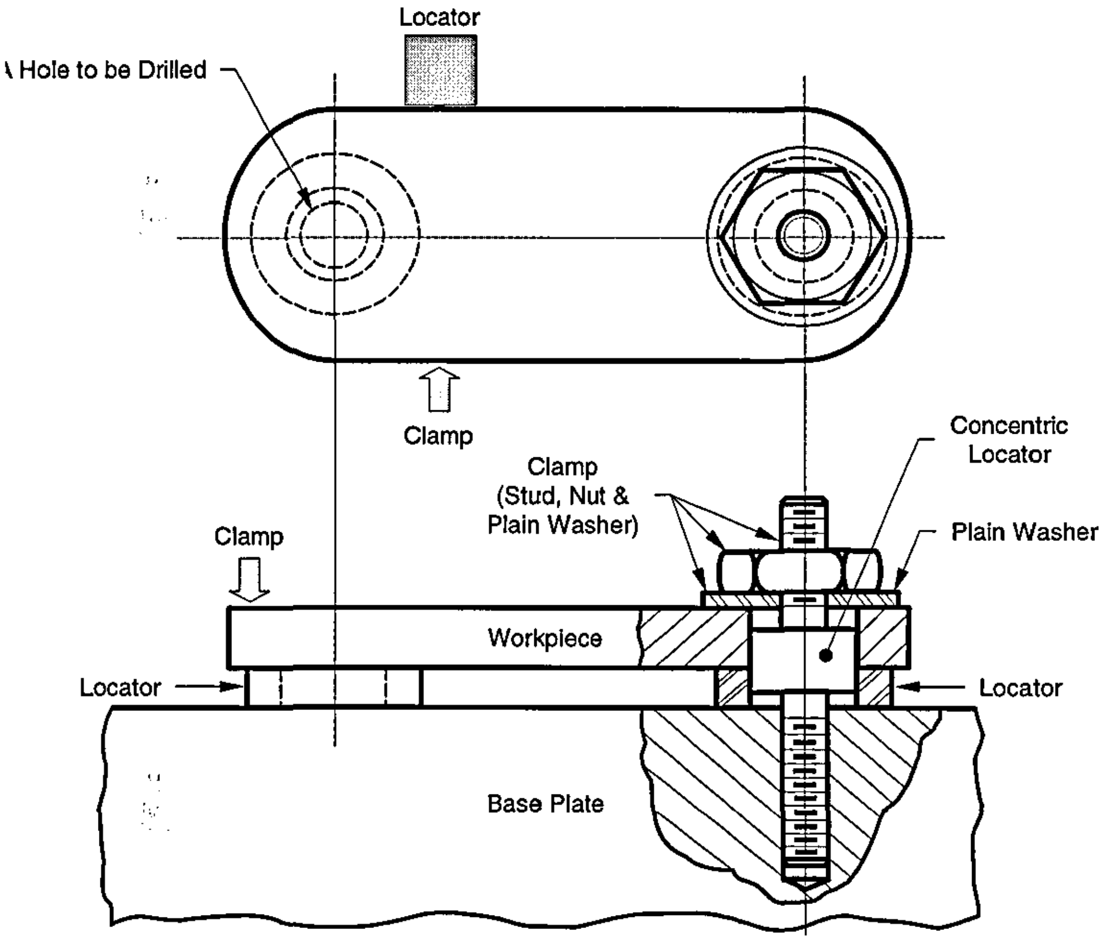


Figure 5.15 – The Clamping for Concentric Method

5.2.1.2.4.1 Clamping for the Radial Method

The clamping for radial method also needs information about the locating surfaces. As described in the previous sections that when a workpiece has two or more hole features on it, the radial locating is used. In radial method, the secondary clamping surface and secondary locating surface is on the same hole surface as well as the tertiary clamping surface and the tertiary locating surface is also on the same hole surface. Refer to Figure 5.16 that described the clamping for radial method of a work-piece that has two or more holes, which could be used for locating.

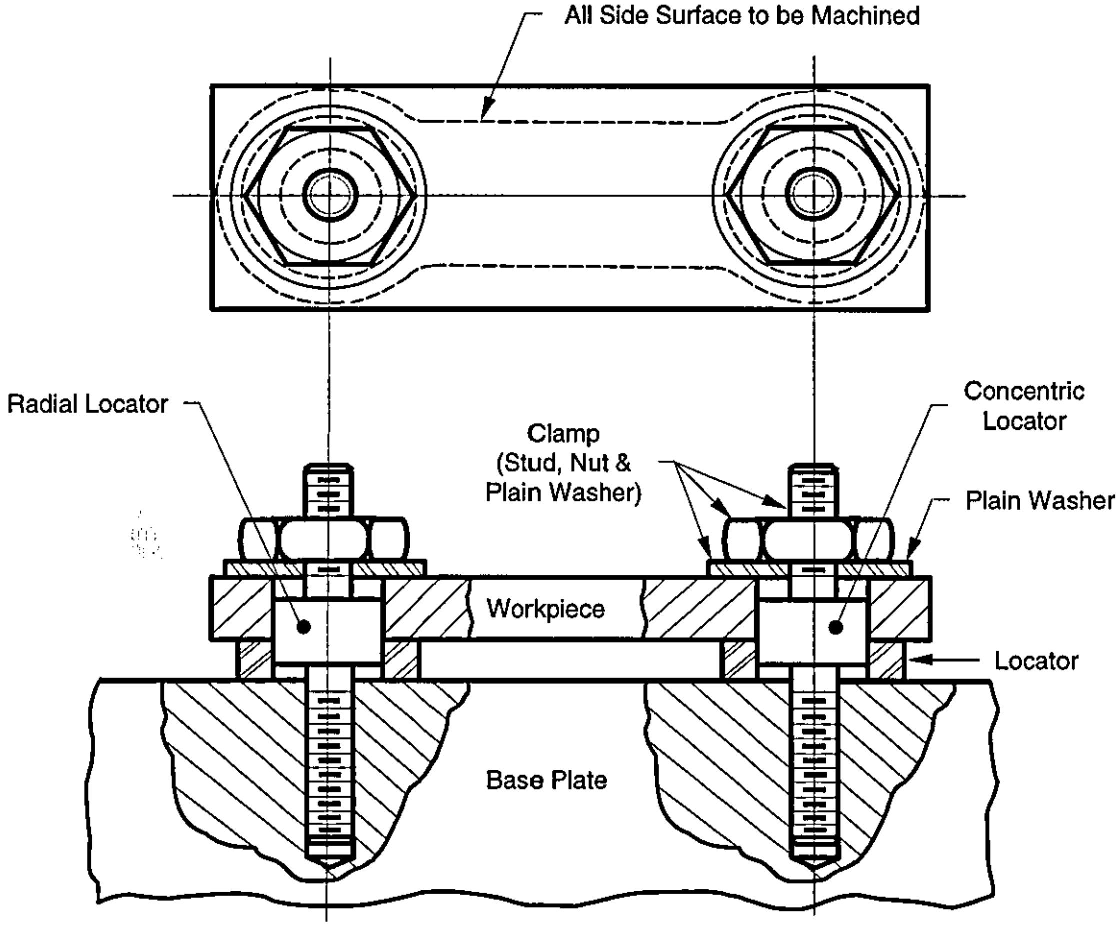


Figure 5.16 – The Clamping for Radial Method

Clamping surfaces are selected once the locating surfaces have been selected, being the surfaces opposite to the locating surfaces. Like the locating process, clamping process has been looked at as one of a sub-process of fixturing process and was used showing that there are three different ways of doing it, being clamping for 3-2-1 method, clamping for concentric method and clamping for radial method. These clamping methods were also applied to selected prismatic workpieces in defining the clamping process in general way and capturing this in an object-oriented database and then, using this fixturing information to support design and manufacture activities that requires fixturing inputs. The representation of clamping process can be found in section 5.4.2.2.

5.2.2 The Fixturing Resources

5.2.2.1 The General Requirements to Select Fixture Elements

As mentioned in Chapter 3, this work utilised modular fixtures to represent the fixturing resources. Selection of fixturing elements for locating a workpiece depends primarily on the function and geometry of the fixture component, the geometry of the workpiece and the degrees of freedom to be limited. Modular fixtures comprise standard components that can be easily assembled and disassembled. Among the manufacturers of modular fixtures are Bluco Tecknik, Carr Lane, Qu-Co, Venlic, Halder and others. In this research work the Halder Modular Jig and Fixture Systems; Product Catalogue (1994) of fixture elements has been used.

The workpiece geometry to be considered for primary locating includes plane, cylinder, sphere and irregular surface. Thus, a fixture element can be determined according to the shape of the locating surface on the workpiece and the specific dimension of the fixture element to the workpiece surface [Fuh *et al.*, 1993]. The same principles can be also applied to secondary and tertiary locating elements. However, according to the 3-2-1 locating principle, only two locating points are needed for secondary locating surface and one locating point for tertiary locating surface. A locator with a cylindrical surface might be considered for secondary or tertiary locating if the workpiece has holes perpendicular to the primary locating surface.

In every locating and clamping point generated there should be suitable fixture elements will be selected from the modular fixture kit which must in turn satisfies the various factors affecting it (Nee *et al.*, 1995).

- The type of locator is influenced by:

  1. The accuracy of workpiece blank.
  2. The amount of free space around the point.
  3. The surface finish required.
  4. The magnitude of the machining forces.

- The type of clamp is influenced by:

1. The shape and size of the workpiece.
2. The surface finish required.
3. The size and position of the machining feature.
4. The applied clamping forces.
5. The clamping method.

- The type of mounting plate is influenced by:

1. The shape and size of workpiece.
2. The machining envelope.
3. The machining forces applied.
4. The cutting tools access.

5.2.2.2 Classification of Basic Modular Fixturing Elements

To complete the fixture planning process, it is necessary to classify fixturing elements. In this research, the author adopted the work of Chao-Hwa Chang (1992) in which fixturing elements are classified according to the functions and dimensions. Table 1 illustrates a tentative classification of commonly used locating and clamping components based on their functions and the degrees of freedom of the workpiece limited by them. The dimension factor is not included in this table, but it can be easily introduced on the basis of the fixturing elements available.

Fixturing Element	Function	Degrees of Freedom	Form of part surface in contact
Rest Buttons:			
Flat	Locating	1	- Plane or convex surface
Radius	Locating	1	- Convex or concave surfaces with radius of curvature greater then that of the rest button at contact point
Conical	Locating	1	- Concave surface
Vee	Locating	4	- External cylindrical surface
		2	- External spherical surface
Edge Bar	Locating	2	- Plane or line on a surface

Locating Pin	Locating	4	- Internal cylinder surface or round hole
V-block	Locating	4	- External cylindrical surface - External spherical surface
Edge Clamp	Clamping	Maintaining contact of part with locating element in one axis.	- Plane or convex surface
Clamp with point contact	Clamping	Maintaining contact of part with locating element in one axis.	- Plane or contoured surface
Vise with Flat Jaws	Locating and clamping	5 (assuming that the slideway of the vise can be used to locate the part)	- Plane
Vise with V-Jaws	Locating and clamping	3	- External cylinder surface
Chucks:			
3 jaws	Locating and clamping	4	- External or internal cylindrical surface
collet	Locating and clamping	4	- External cylindrical surface
4 jaws	Locating and clamping	5	- Irregular surface
Expanding mandrel with shoulder	Locating and clamping	5	- Internal cylindrical surface
Plate	Mounting and locating	3	- Plane
Tooling Block	Mounting and locating	3	- Plane
Angle Plate	Mounting and locating	3	- Plane

Table 1 – The Classification of Basic Modular Fixturing Elements
[Adapted from Chao-Hwa Chang, 1992]

With the help of Table 2, the fixturing elements for locating can be selected by considering the form of the part surface to be supported, the dimensional ratio of part surface to the surface of the fixturing elements and the degrees of freedom to be limited [Chao-Hwa Chang, 1992].

Form of the part surface to be supported	Fixturing Elements *Dimension of part surface or dimension of contact surface of fixture element is less than or close to one.	*Dimension of part surface or dimension of contact surface of fixture element is far greater than one.	Degrees of Freedom
Plane	- Base plate for milling machine - Face plate for lathe - Angle plate - Vise with flat jaws (without using its slideway for locating)	- Three locating buttons, two locating pins and one locating pin.	3
External Cylindrical Surface	- V-block - 3-jaw or collet chuck	- Two V-blocks - 3-jaw chuck + supporting center or one V-block + supporting center	4 4 5
Internal Cylindrical Surface	- Locating pin, 3-jaw chuck or mandrel	 - 3-jaw chuck + supporting center or stop	4 5
Irregular Surface	- 4-jaw chuck	 - 4-jaw chuck + supporting center or stop - Three locating buttons	5 6 3 or more depending on the shape of the surface
Sphere	- V-block or 3-jaw chuck - Ring of fixture element with internal conical locating surface	 - Three locating buttons	3 3 3

Table 2 – The Determination of the Locating Components According to the Shape of Part Surface [Adapted from Chao-Hwa Chang, 1992]

This section has discussed the general requirement in order to select the fixturing elements and the factors that influenced it. The later part of this section presented the classification of commonly used fixturing elements for locating and clamping.

The next section discusses the activity modelling of fixturing information.

5.3 Activity Modelling of Fixturing Information

5.3.1 Importance of the Activity Model

In order to achieve an environment that will enable integration to support product life cycle activities, the product and manufacturing data must be accurately planned to aid the data representation in the models that must provide the data integrity [Ham & Lu 1988 and Klein 1990]. The planning for these data structure is dependent on the understanding of the data requirements and information flows between the product life cycle activities, which are going to use the data structure. Therefore, an accurately planned manufacturing information model depends on a clear and a common understanding of the function, which is going to be integrated through its use [Al-Ashaab 1994].

5.3.2 Activity Modelling of Use Fixturing Information

The IDEF0 activity-modelling tool has been used in order to explore the structure and content of the fixturing information model to support design and manufacture activities. Refer to Appendix A for the description of this modelling tool. It is important that first to have a clear view of *"Use Fixturing Information"* activity and the information flows within these activities. "*Use Fixturing Information*" as shown in Figure 5.17 is an activity that utilised fixturing information to support different points in the design and manufacture applications. The activity has two inputs, which are *"Product Data"* and "*Manufacturing Data*". The *"Design Knowledge"*, *"Process Knowledge"* and *"Fixturing Knowledge"* controls this activity. This activity is performed *by "Design Personnel"*, which has shown as a mechanism for this activity. The resulting output in this activity are "*Design Advice*", "*Possible Process Plan*" and *"Fixture Plan"* for a particular workpiece.

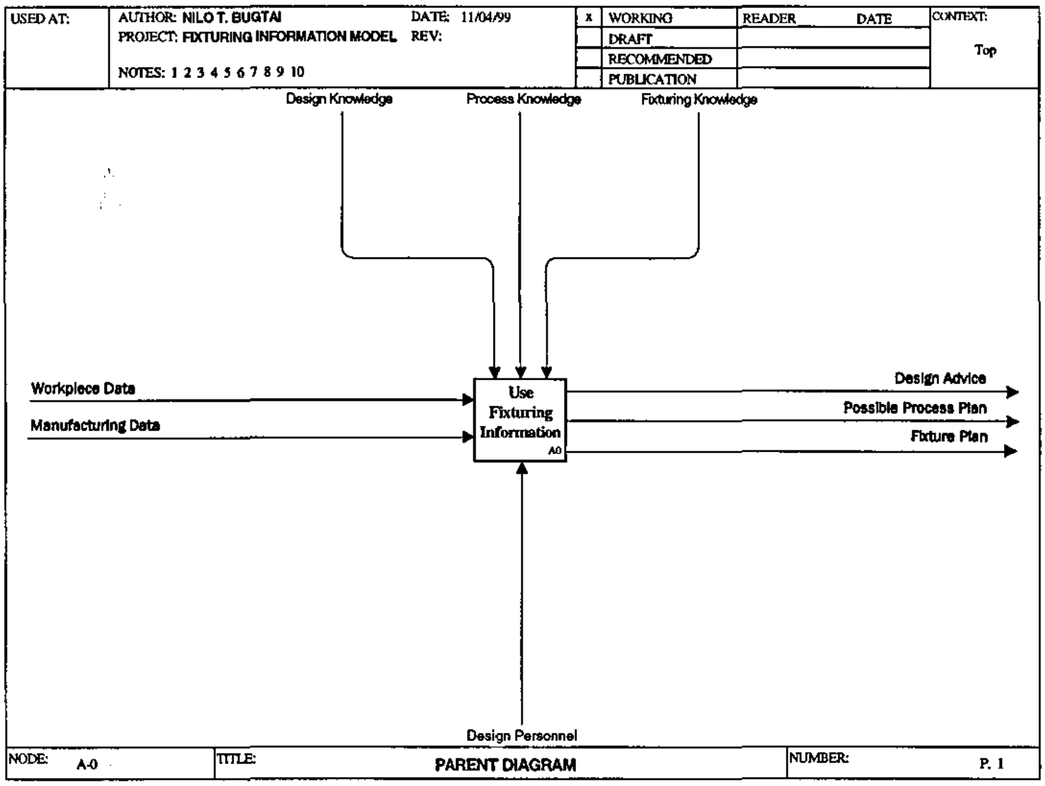


Figure 5.17 – The Parent Diagram for Use Fixturing Information Activity

The resulting top level IDEF0 model of *"Use Fixturing Information"* is shown in Figure 5.18. This illustrates an apparent sequential view that captures the activities of *"Support Product Design"*, *"Support Process Planning"* and *"Support Fixture Planning"*. The support product design activity has an output of a design advice, while the support process planning activity has an output of a possible process plan and the support fixture planning activity has an output of a fixture plan.

It is only when the data requirements of the activities are broken down into some detail that the activities that can be performed concurrently begin to become apparent. The first activity *"Support Product Design"* is illustrated in Figure 5.19, *"Support Process Planning"* activity in Figure 5.20 and *"Support Fixture Planning"* activity in Figure 5.21. Each activity is discussed in terms of information requirements in the following sub-sections.

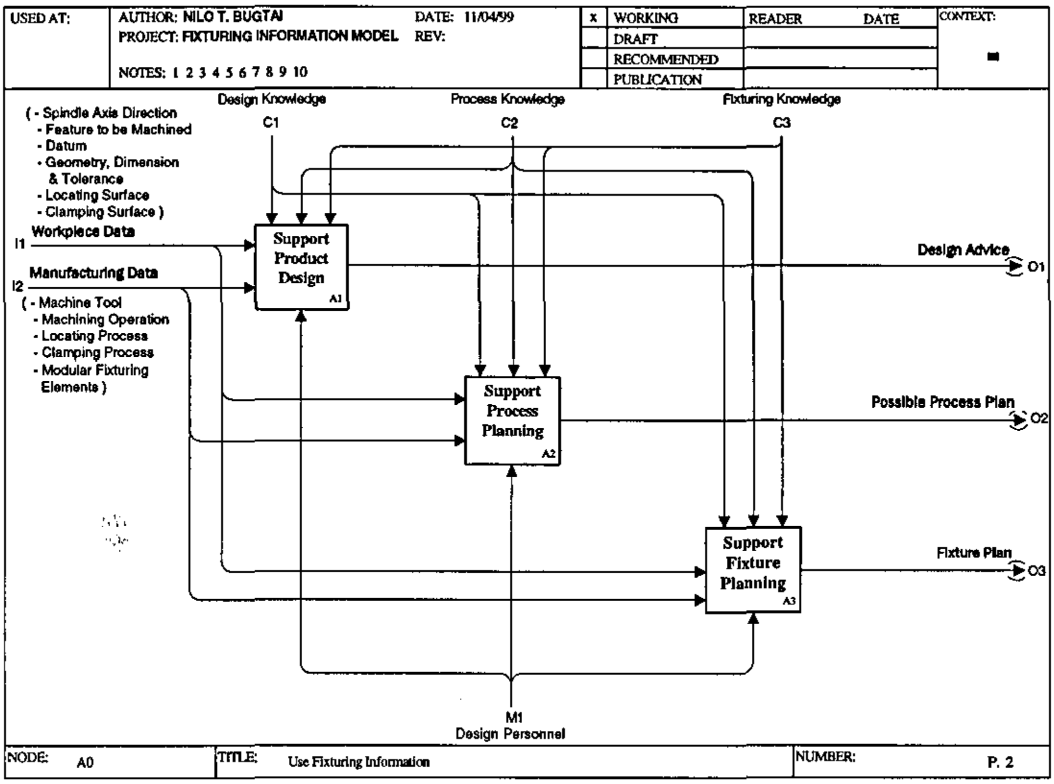


Figure 5.18 – The Use Fixturing Information Activities

5.3.2.1 Support Product Design

"Support Product Design" is an activity that identifies locating surfaces and identifies clamping surfaces. The decomposition of *"Support Product Design"* activity is illustrated into two sub-activities as illustrated in Figure 5.19. The figure shows the two information inputs, which are the workpiece data and manufacturing data and controlled by three forms of common information, which are the design knowledge, process knowledge and fixturing knowledge. The two sub-activities have one mechanism to carry out these activities, which are the design personnel and the outputs of these two sub-activities is the possible fixturing methods to be used and the suggested changes to workpiece. The suggested change to workpiece is only a suggestion where a designer could accept or not. It involves the modifications of the design of the product such as adding a hole feature or reaming a drilled hole.

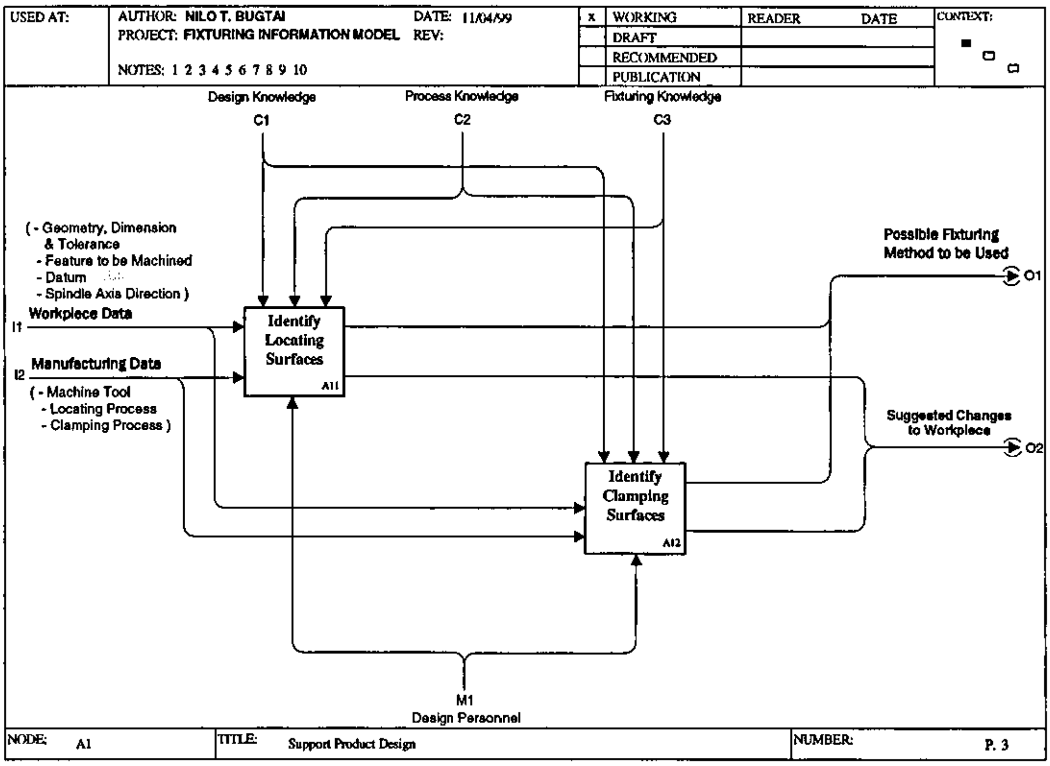


Figure 5.19 – The Support Product Design Activities

5.3.2.2 Support Process Planning

"Support Process Planning" is an activity that evaluates the locating surfaces and evaluates the clamping surfaces. The decomposition of *"Support Process Planning"* into two sub-activities is illustrated in Figure 5.20. The figure shows there are two information inputs, which are workpiece data and manufacturing data. The controls are the three common information to these sub-activities, which are design knowledge, process knowledge and fixturing knowledge. The two sub-activities have one common mechanism to carry out the activities, which are the design personnel. The outputs of these two sub-activities are the possible fixture plan, possible to select different machine tool and the possible fixturing methods to be used.

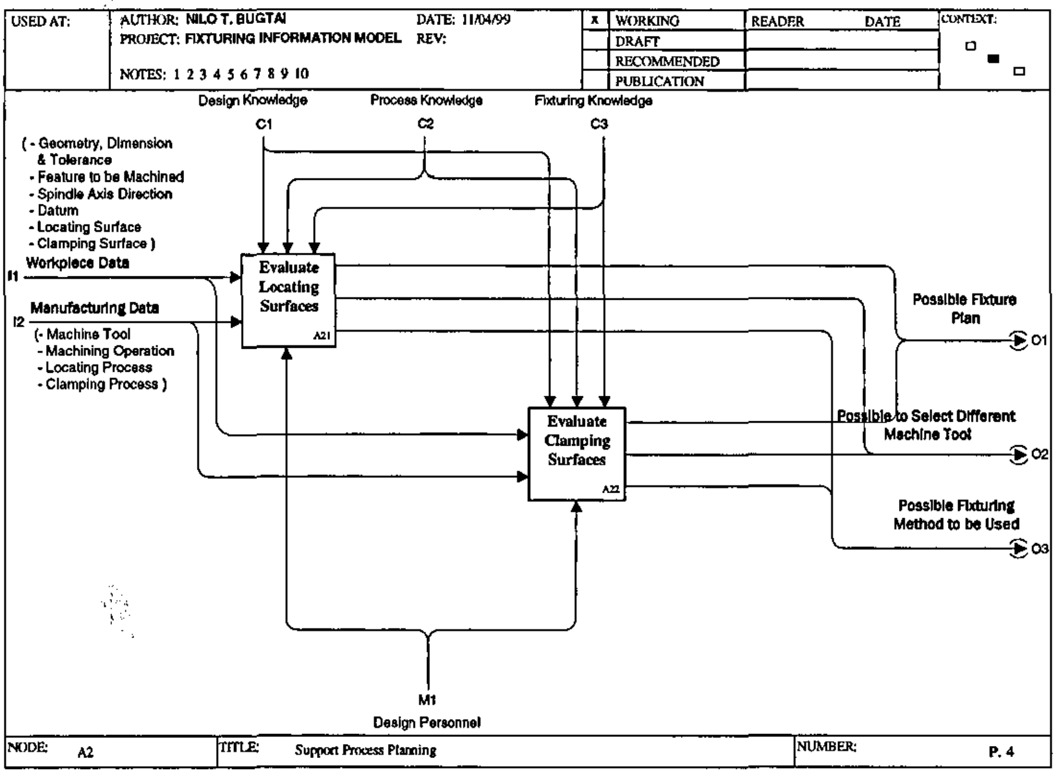


Figure 5.20 – The Support Process Planning Activities

5.3.2.3 Support Fixture Planning

"Support Fixture Planning" is an activity that selects the locating surfaces, selects the clamping surfaces and selects the fixturing elements. The decomposition of *"Support Fixture Planning"* into three sub-activities is illustrated in Figure 5.21. The figure shows there are two information inputs, which are process plan and resources. The controls are the three common information to these sub-activities, which are design knowledge, process knowledge and fixturing knowledge. The three sub-activities have one common mechanism to carry out the activities, which are the design personnel. The outputs of these three sub-activities are the locating surfaces, clamping surfaces and the fixturing elements to be used.

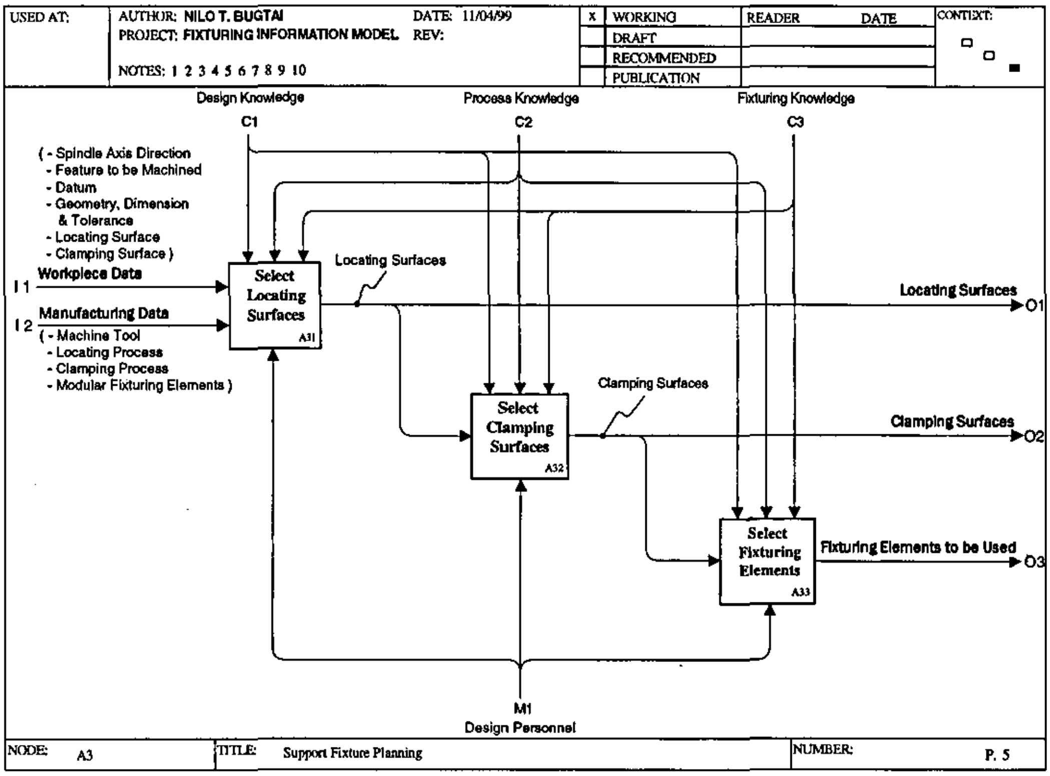


Figure 5.21 – The Support Fixture Planning Activities

5.3.3 Outcome of Activity Modelling

The IDFEO activity models presented and discussed in the previous sections have provided the author with an initial view of the relationships between fixturing information and how it might support the product design activity, the process planning activity and the fixture planning activity. The activity model shows that there is a need of fully detailed design before considering anything useful in terms of fixturing inputs. Also, the activity shows the need to identify and evaluate the possible locating surfaces and clamping surfaces before considering anything on fixture planning.

The information flows identified from the activity model provided a basis from which to gain an understanding of the activities needed in a support environment. Thus, it starts to provide the relationships between potentially the ways in which fixturing inputs that could be put into product design and process planning and the general view of the kind of information requirements for each of these stages. This provided the basis for the exploration of the information structure using UML's class and activity diagrams as discussed in the succeeding sections.

5.4 The Representation of the Fixturing Information Model

5.4.1 The General Structure of the Manufacturing Model

The fixturing information is presented within the manufacturing model structure using the Unified Modelling Language - UML class diagram. This class structure of the manufacturing model is shown in Figure 5.22 in which the concern of this work is being highlighted in the figure. The MOSES manufacturing model framework has as a core element that "describes" the facility (Facility) class. The facility (Facility) class "has" manufacturing resources (ManufacturingResources) class and "has" manufacturing processes (ManufacturingProcesses) class. The relation "performs" describes the capabilities of the manufacturing resources in terms of the manufacturing processes that they can carry out. The machining processes (MachiningProcess) class and fixturing process (FixturingProcess) class are the sub-classes of manufacturing processes class. The workholding (Workholding) class, machine tool (MachineTool) class and cutting tool (CuttingTool) class are the sub-classes of manufacturing resources class. The relation "requires" describes the capabilities of fixturing process, which is to locate and hold the workpiece before the machining process can be performed. The fixturing process "has" workholding tool relation, this means that in order that the fixturing process to perform, it needs the workholding tools to locate and clamp the workpiece. The workholding tool (WorkholdingTool) class is used in the figure to show that there are different types of workholding tools and the modular fixturing elements is sub-type of flexible fixture which is a sub-type of a workholding tools.

The classes that have been highlighted are the fixturing process (FIXTURING_PROCESS) class, which have two sub-classes, the locating process (LOCATING_PROCESS) class and the clamping process (CLAMPING_PROCESS) class. Also classes being highlighted are the modular fixturing elements

(MODULAR_FIXTURING_ELEMENTS) class. The plate (PLATE) class, locating pin (LOCATING_PIN) class, screwed rest button (SCREWED_REST_BUTTON) class, clamp element (CLAMP_ELEMENT) class, down hold clamp (DOWN_HOLD_CLAMP) class and the centering bolt (CENTERING_BOLT) class inherit the attributes from the modular fixturing elements (MODULAR_FIXTURING_ELEMENTS) class. The figure shows the classes that were adapted from Molina's (1995) generic manufacturing model structure using UML class diagram and has been modified in order to fit the fixturing information.

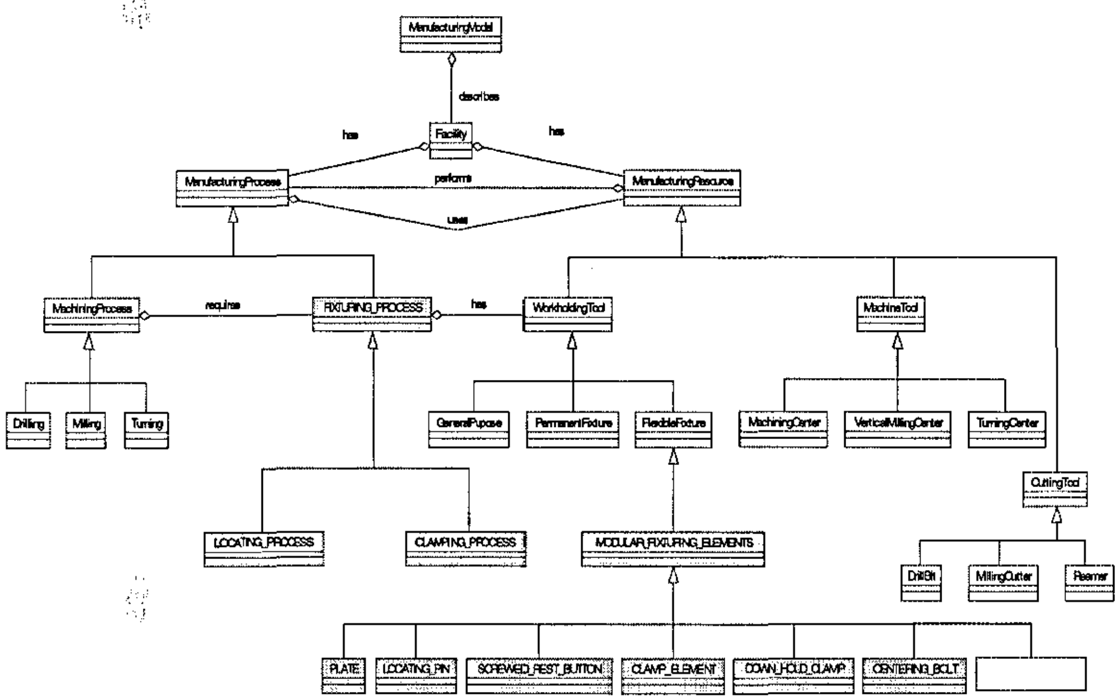


Figure 5.22 – The MOSES Manufacturing Model Structure in UML Class Diagram with the Fixturing Information

5.4.2 The Representation of Fixturing Process

The explorations of the fixturing information requirements were discussed in section 5.3. The classifications of this information, the problems, how the problem has been dealt and the solutions were presented. The two classifications were fixturing process, which consist two sub-processes, being the locating and clamping process and the fixturing resources of which modular fixture has been used.

Figure 5.23 shows the UML class structure of fixturing process (FIXTURING_PROCESS). The figure illustrates that locating process (LOCATING_PROCESS) class and clamping process (CLAMPING_PROCESS) class inherit from the fixturing process FIXTURING_PROCESS) class. This means that fixturing process composed of two sub-processes being the locating process and the clamping process. The figure also shows that 3-2-1 locating (3-2-1_LOCATING) class, concentric locating (CONCENTRIC_LOCATING) class and radial locating (RADIAL_LOCATING) class inherit from the locating process (LOCATING_PROCESS) class. This means that locating process have different ways of locating being the 3-2-1 method, concentric method and radial method.

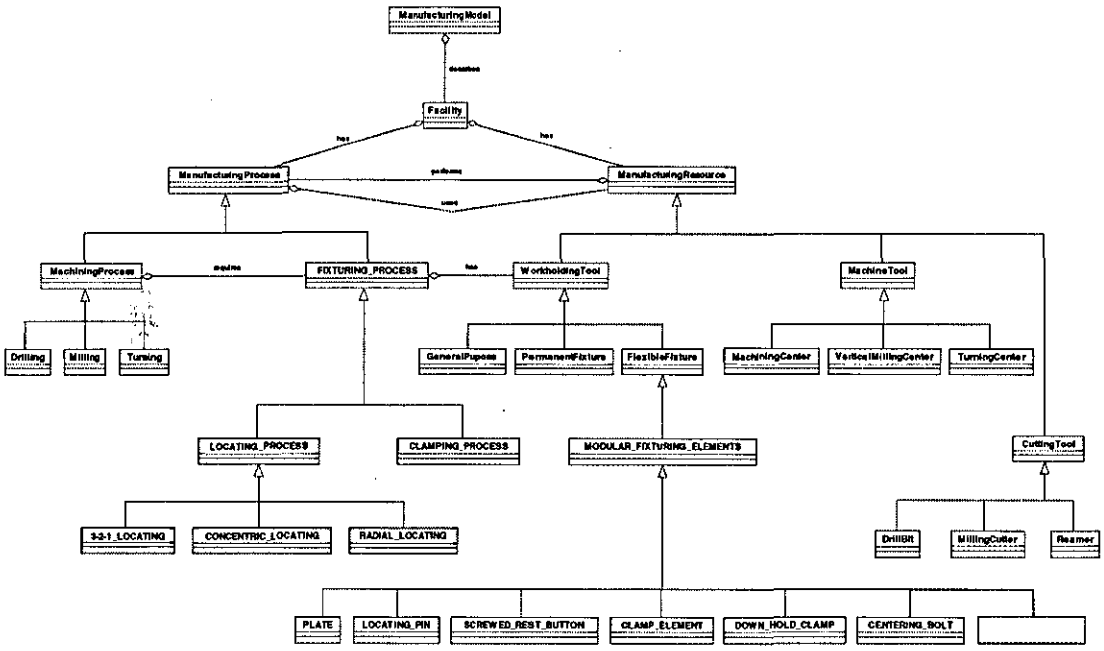


Figure 5.23 – Locating Process Data Structure in UML Class Diagram

5.4.2.1 Workpiece Information Needed to Enable the Locating Process Methods

Fixturing information requirements were discussed in section 5.3. From that three major pieces of information related to the workpiece are needed for input to the locating process. These are the workpiece geometry, the machining feature and the spindle axis direction of the machine tool as shown in Figure 5.24. While the workpiece definition and representation is discussed in section 5.5, this figure provides the general illustration of the inputs to the locating process in the next sections. The relationships between the surfaces are of particular significance as they provide an important input to making decision on fixturing.

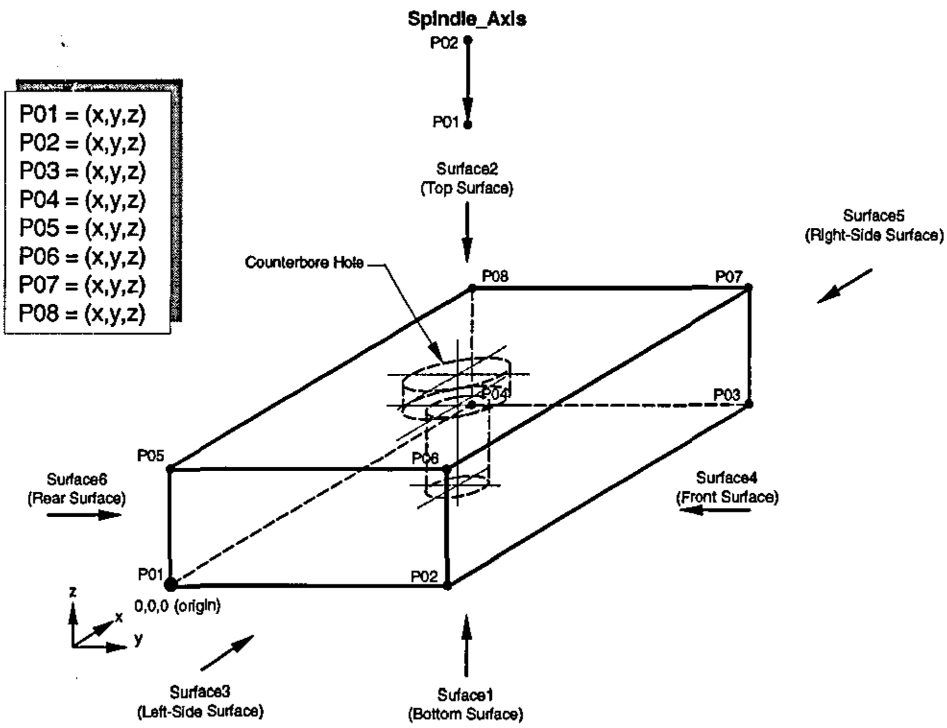


Figure 5.24 – Example of a Prismatic Workpiece as Depicted in the Product Model

5.4.2.2 The Representation of the Locating Process

5.4.2.2.1 The Representation of the Locating Process for 3-2-1 Method

The UML activity diagrams have been used as a method of capturing the locating process. Figure 5.25 illustrates the UML activity diagram of the selection of the primary locating surface for the 3-2-1 location method contained in the manufacturing model. The first step is to initialise the selection process for primary locating surface. The second step is to get the workpiece locating surfaces information from the product model and then, the next step is to orient the workpiece so that the features to be machined are in alignment with the spindle axis. After the workpiece has been properly oriented, the largest surface opposite to the face on which the features are placed has been identified as the primary locating surface. The last step is to name primary locating surface, which in this example the name given to this surface is a bottom surface and the name given to the surface opposite of primary locating surface is a top surface.

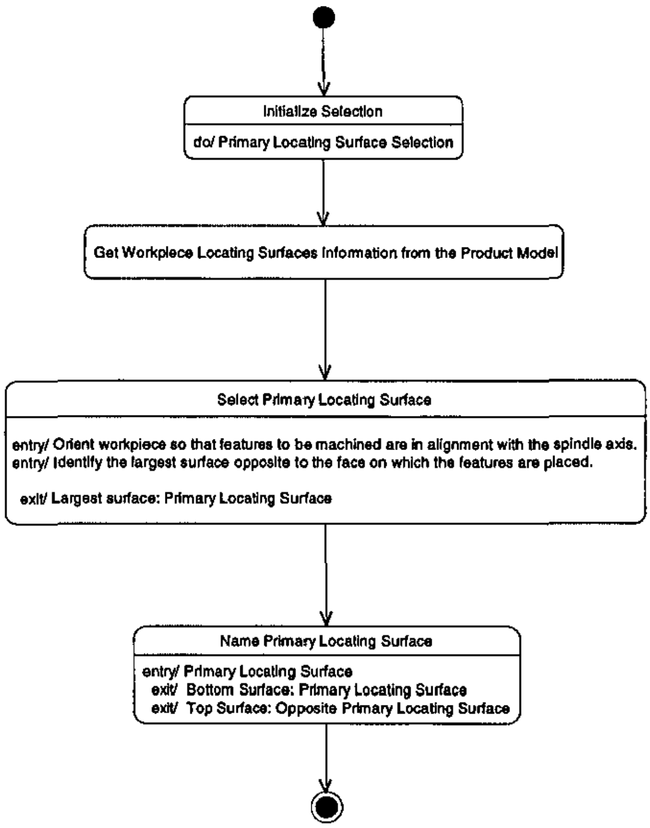


Figure 5.25 – Primary Locating Surface Selection for 3-2-1 Locating in UML Activity Diagram

The representation in selecting the secondary locating surface is described in Figure 5.26. The first step is to initialise the selection process for the secondary locating surface. Then, the next step is to identify the largest surfaces that are perpendicular to primary locating surface. This process may result in two surfaces especially for rectangular shaped workpieces and with these two surfaces either can be selected as the secondary locating surface. To select from the two the surfaces, is the surface nearest to the specified origin of the workpiece. The last step is to name the secondary locating surface, which in this example the name given to this surface is a rear surface and the name given to the surface opposite of secondary locating surface is a front surface.

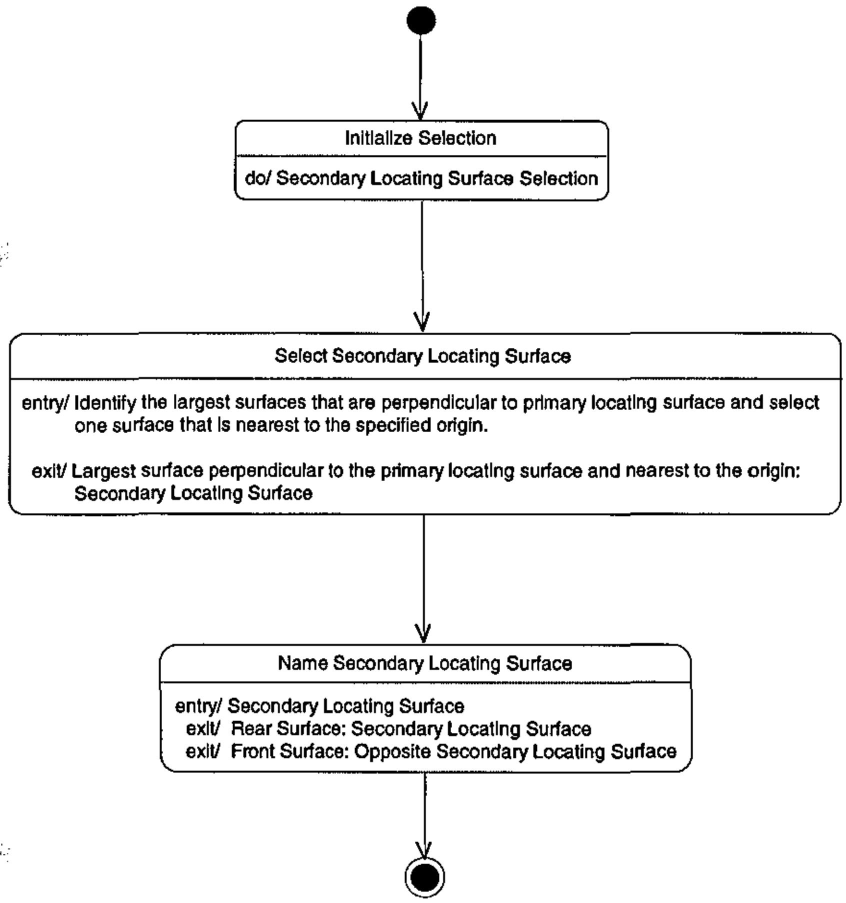


Figure 5.26 – Secondary Locating Surface Selection for 3-2-1 Locating

Figure 5.27 illustrates the activity diagram for the selection of tertiary locating surface. The first step is to initialise the selection process for tertiary locating surface. Then, the next step is to identify the surfaces that are perpendicular to primary and secondary locating surfaces. For rectangular shape workpiece, this process will result in two surfaces and either of these two surfaces can be selected as the tertiary locating surface. To select from these two the surfaces, is the surface farthest from the specified origin of the workpiece. The last step is to name the tertiary locating surface, which in this example the name given to this surface is a right-side surface and the name given to the surface opposite of tertiary locating surface is a left-side surface.

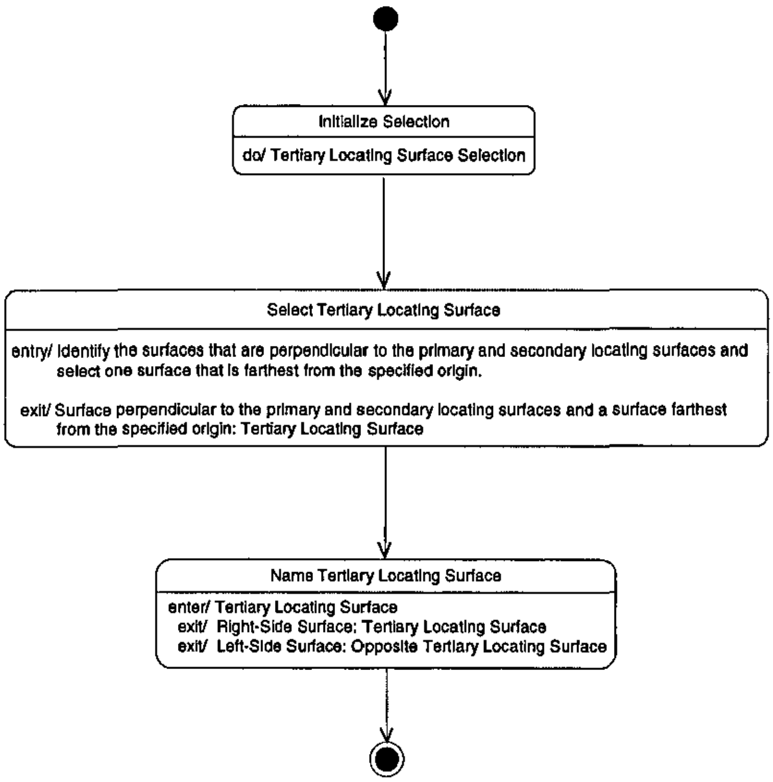


Figure 5.27 – Tertiary Locating Surface Selection for 3-2-1 Locating

5.4.2.2.2 The Representation of the Locating Process for Concentric Method

Figure 5.28 illustrates the UML activity diagram of the selection of the primary locating surface for the concentric locating method contained in the manufacturing model. The first step is to initialise the selection process for primary locating surface. The second step is to get the workpiece locating surfaces information from the product model. Then, the next step is to orient the workpiece so that the features to be machined are in alignment with the spindle axis and identify the largest surface opposite to the face on which the features are placed. After the workpiece has been properly oriented, the largest surface opposite to the face on which the features are placed has been identified as the primary locating surface. The last step is to name primary locating surface, which in this example the name given to this surface is a bottom surface and the name given to the surface opposite of primary locating surface is a top surface.

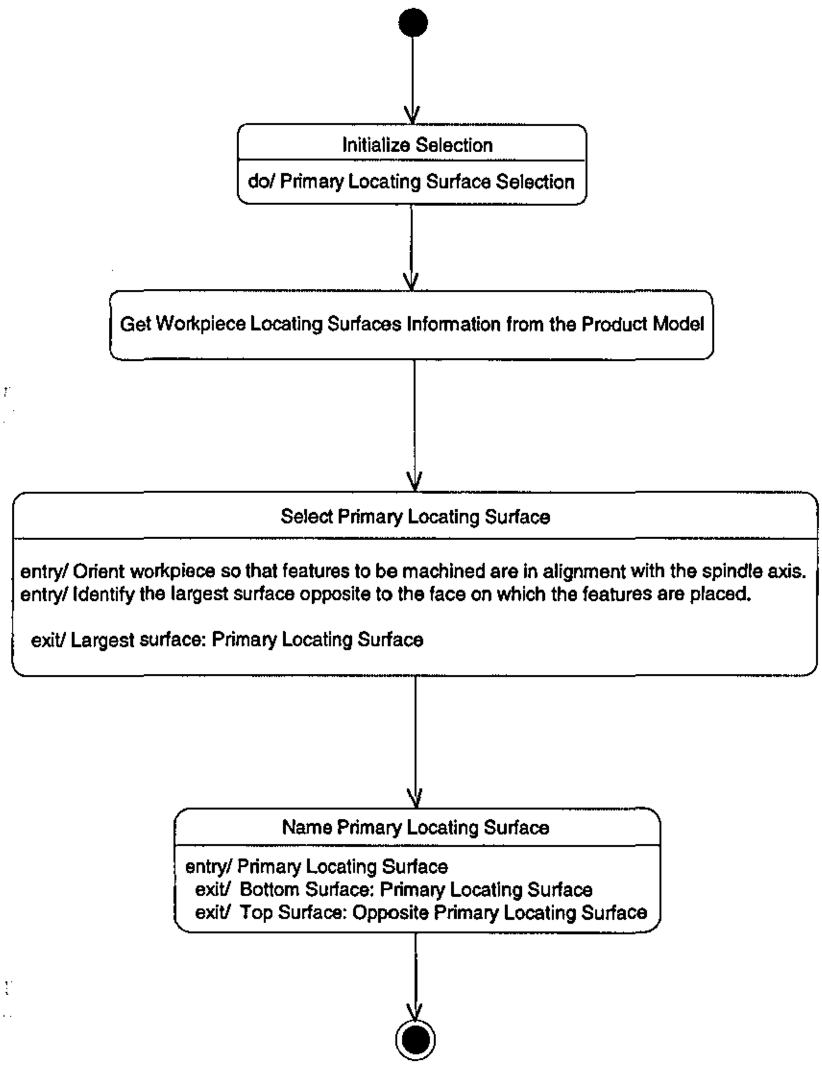


Figure 5.28 – Primary Locating Surface Selection for Concentric Method in UML Activity Diagram

The representation in selecting the secondary locating surface is described Figure 5.29. The first step is to initialise the selection process for secondary locating surface. Then, the next step is to identify a hole surface that can be used for locating and whose axis is perpendicular to the primary locating surface. The last step is to name the secondary locating surface, which in this example the name given to this surface is a hole surface.

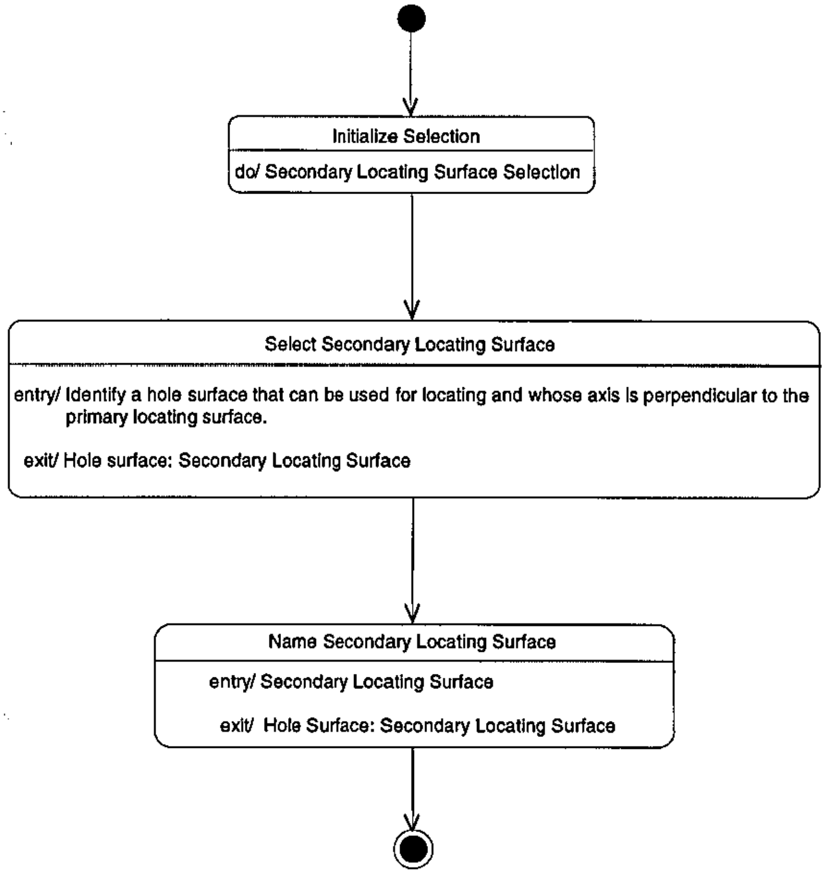


Figure 5.29 – Secondary Locating Surface Selection for Concentric Method

Figure 5.30 illustrates the activity diagram for the selection of tertiary locating surface. The first step is to initialise the selection process for tertiary locating surface. Then, the next step is to identify the surfaces that are perpendicular to primary locating surfaces. For rectangular shape workpiece, this process will result in two surfaces and one of these two surfaces can be selected as the tertiary locating surface. To select tertiary locating surface is the surface furthest from the specified origin. The last step is to name the tertiary locating surface, which in this example the name given to this surface is a rear surface and the name given to the surface opposite of tertiary locating surface is a front surface.

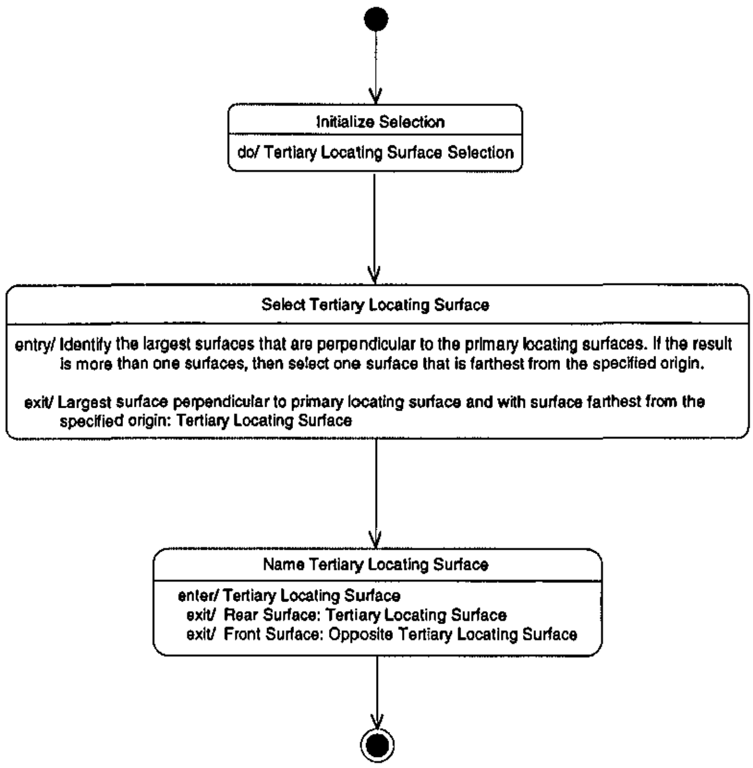


Figure 5.30 – Tertiary Locating Surface Selection for Concentric Method

5.4.2.2.3 The Representation of the Locating Process for Radial Method

Figure 5.31 illustrates the UML activity diagram of the selection of the primary locating surface for the radial location method contained in the manufacturing model. The first step is to initialise the selection process for primary locating surface. The second step is to get the workpiece locating surfaces information from the product model. Then, the next step is to orient the workpiece so that the features to be machined are in alignment with the spindle axis and identify the largest surface opposite to the face on which the features are placed. After the workpiece has been properly oriented, the largest surface opposite to the face on which the feature to be machined is placed has been identified as the primary locating surface. The last step is to name primary locating surface, which in this example the name given to this surface is a bottom surface and the name given to the surface opposite of primary locating surface is a top surface.

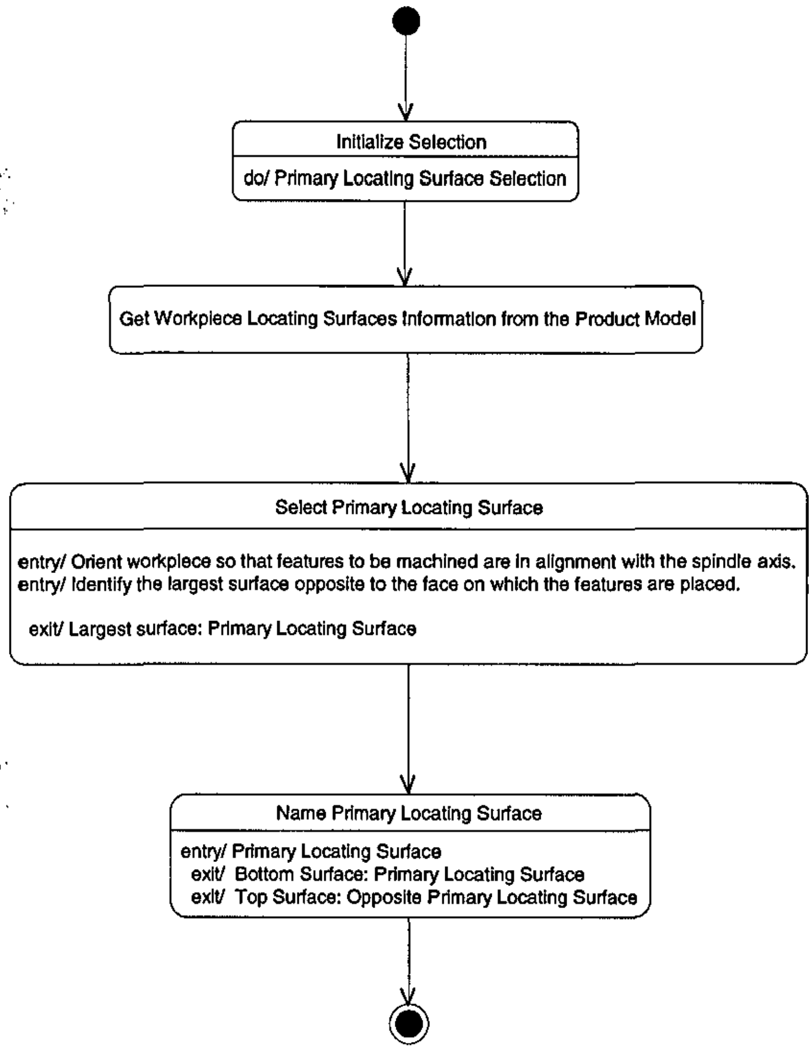


Figure 5.31 – Primary Locating Surface Selection for Radial Method in UML Activity Diagram

The representation in selecting the secondary locating surface is described Figure 5.32. The first step is to initialise the selection process for secondary locating surface. Then, the next step is to identify a hole surface that can be used for locating and whose axis is perpendicular to the primary locating surface. The last step is to name the secondary locating surface, which in this example the name given to this surface is a hole surface #1.

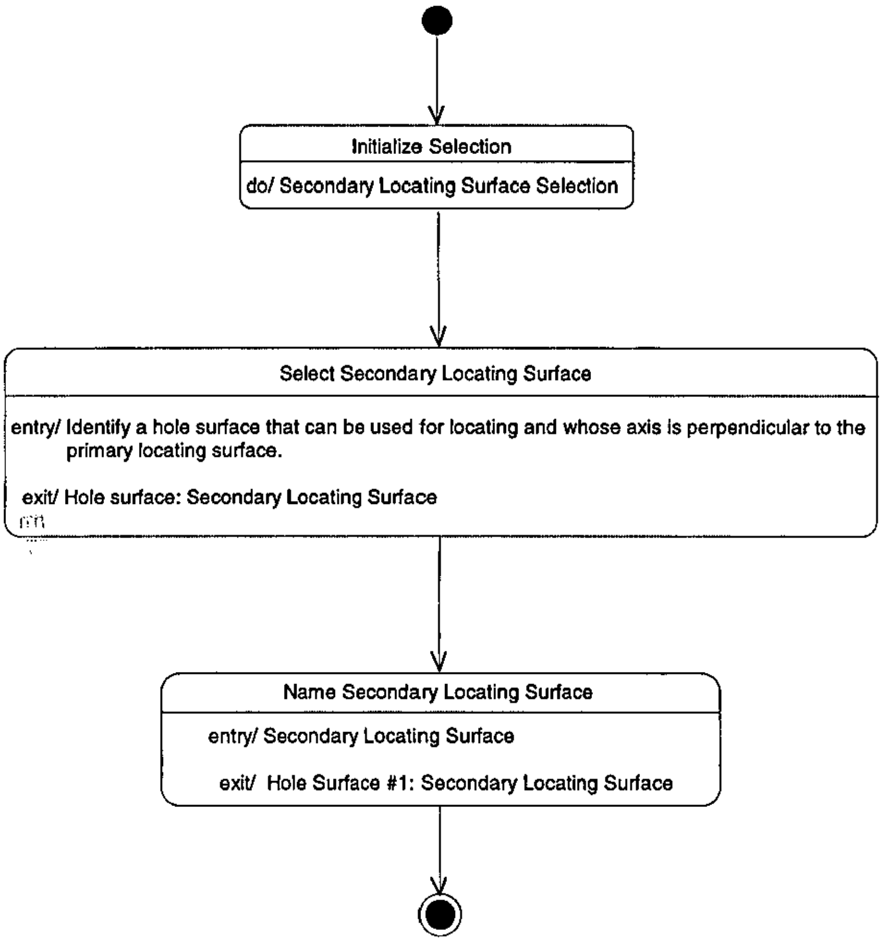


Figure 5.32 – Secondary Locating Surface Selection for Radial Method

The representation in selecting the tertiary locating surface is described Figure 5.33. The first step is to initialise the selection process for tertiary locating surface. Then, the next step is to identify another hole surface that can be used for locating and whose axis is perpendicular to the primary locating surface. The last step is to name the tertiary locating surface, which in this example the name given to this surface is a hole surface #2.

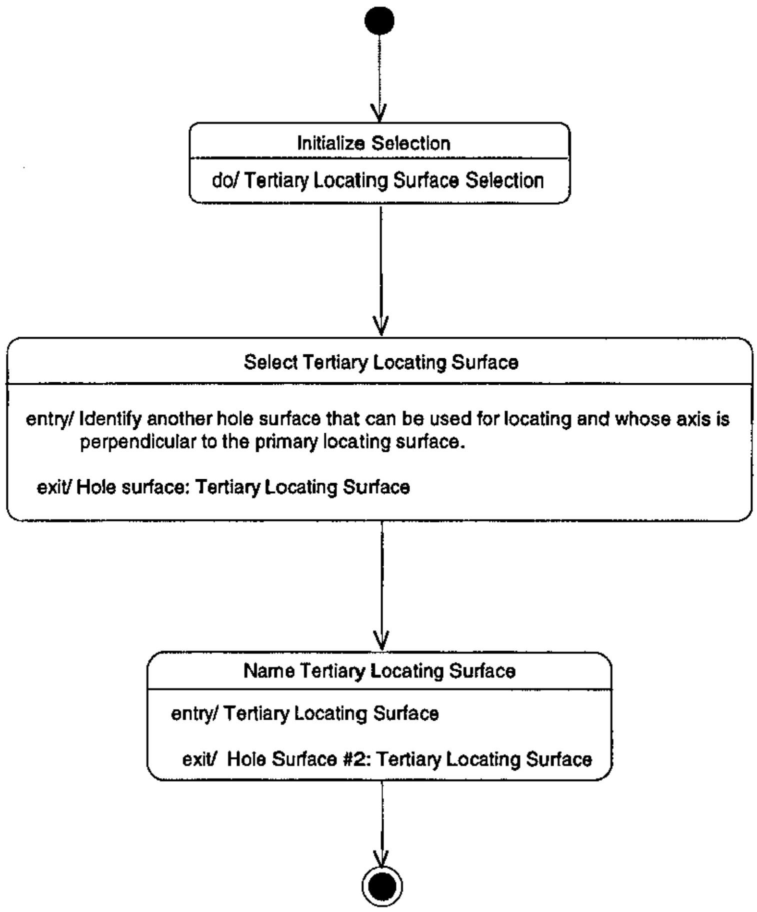


Figure 5-33 – Tertiary Locating Surface Selection for Radial Method

These methods for selecting locating surfaces on a simple workpiece can also applied to complex workpieces, because the process is the same. The difference lies in the selection of the type of locators where for an irregular surface need adjustable locators and supports to accommodate the uneven surfaces of the workpiece.

Depending on the complexity of the workpiece, e.g., for a small complicated shaped workpieces the tool engineer may use to locate the whole piece material using the same process. Then, machined the shapes or the profiles of the workpiece from the material being fixtured in the machine tool and cut the individual workpieces that has been machined from the material.

5.4.2.3 Workpiece Information Needed to Enable the Clamping Process

The clamping process can be achieved after the workpiece locating surfaces have been identified. The clamping process needs the information of the surfaces where the clamps could be placed. In this case the clamping surfaces are generally the surfaces opposite to the locating surfaces.

5.4.2.4 The Representation of the Clamping Process

Figure 5.34 illustrates how the clamping process has been represented using the UML class diagram. In the figure, 3-2-1 clamping (3-2-1_CLAMPING) class, concentric clamping (CONCENTRIC_CLAMPING) class and radial clamping (RADIAL_CLAMPING) class inherit from the clamping process (CLAMPING_PROCESS) class. This means that clamping process have three different methods of clamping being the 3-2-1 clamping method, concentric clamping method and radial clamping method.

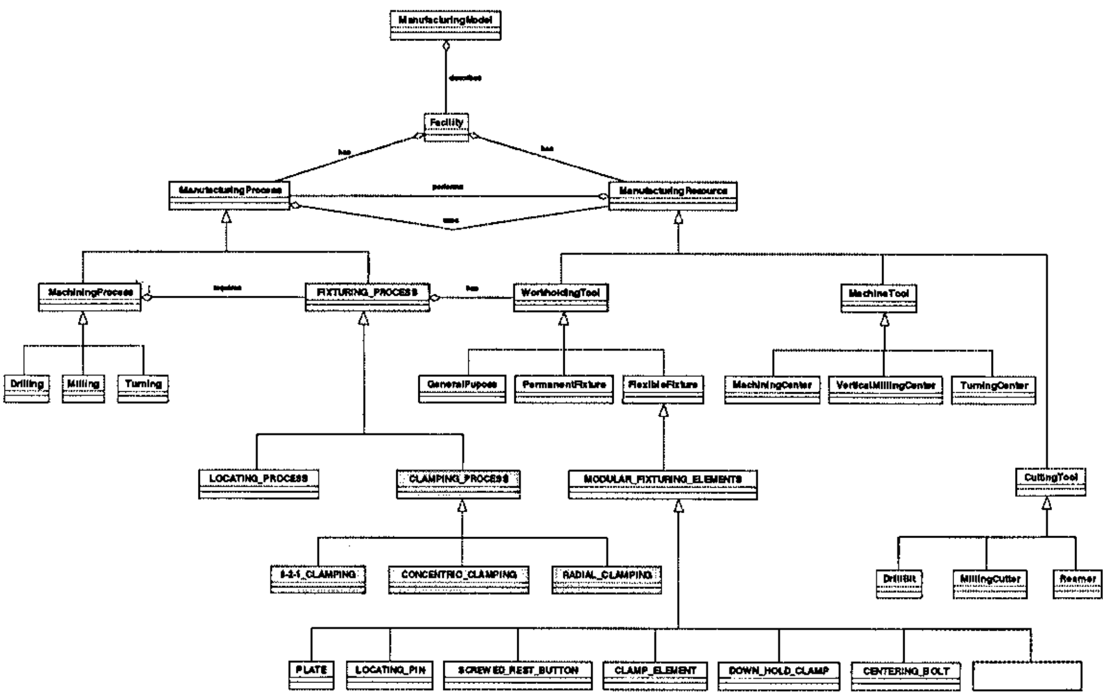


Figure 5.28 – Clamping Process Data Structure in UML Class Diagram

5.4.2.4.1 The Representation of the Clamping Process for 3-2-1 Method

The UML activity diagrams have been used as a method of capturing the clamping methods. In this case the clamping surfaces are generally the surfaces opposite to the locating surfaces, therefore the clamping process needs to know the primary locating surface, secondary locating surface and tertiary locating surface. Figure 5.35 illustrates the UML activity diagram of the selection of the primary clamping surface for the 3-2-1 clamping method contained in the manufacturing model. The first step for selecting the primary clamping surface is to initialise the selection process for primary clamping surface. The second step is to get the workpiece clamping surfaces information from the product model. Then, the next step is to identify the surface opposite to the primary locating surface. The last step is to name the primary clamping surface, which in this example is the name given to this surface is a top surface and the name given to the surface opposite of primary clamping surface is a bottom surface. The activity diagrams provide the basis from which object-oriented methods can be defined to represent the 3-2-1 clamping method.

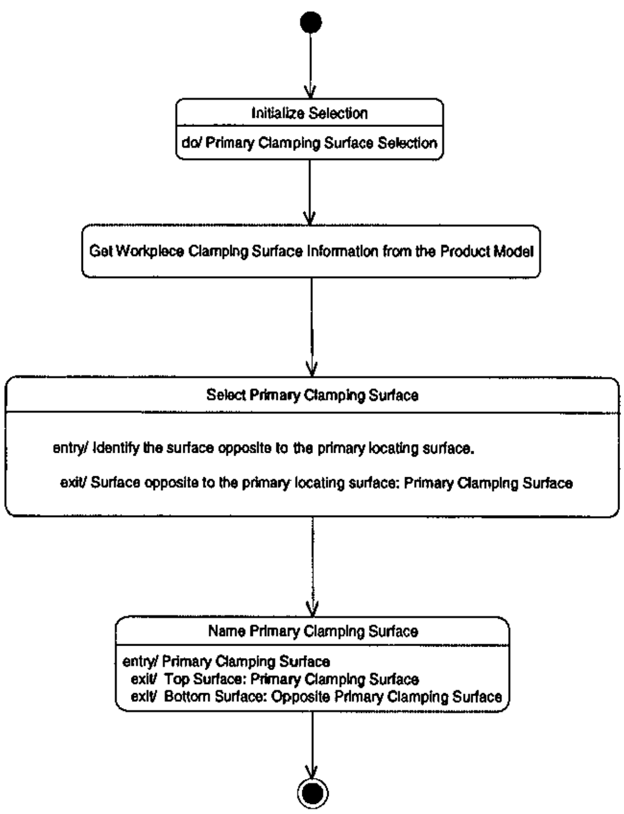


Figure 5.35 – Primary Clamping Surface Selection for 3-2-1 Clamping in UML Activity Diagram

The representation in selecting the secondary clamping surface is described in Figure 5.36. The first step for selecting the secondary clamping surfaces is to initialise the selection process for secondary clamping surface. Then, the next step is to identify the surface that is opposite secondary locating surface. The last step is to name the secondary clamping surface, which in this example the name given to this surface is a front surface and the name given to the surface opposite of secondary clamping surface is a rear surface.

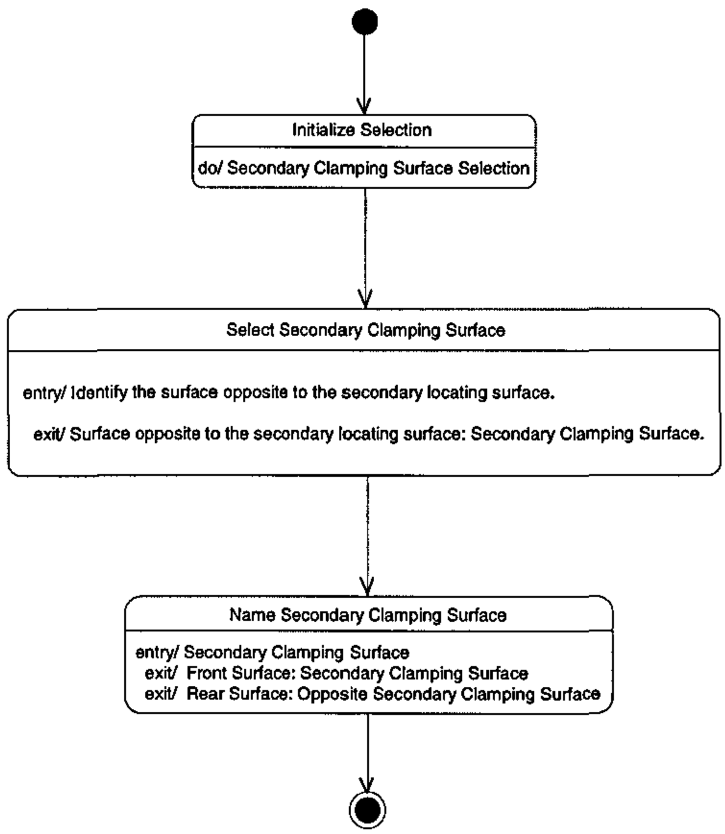


Figure 5.36– Secondary Clamping Surface Selection for 3-2-1 Clamping

Figure 5.37 illustrates the activity diagram for the selection of tertiary clamping surface. In the first step for selecting the tertiary clamping surface is initialise the selection process for tertiary clamping surface. Then the next step is to identify the surface that is opposite to tertiary locating surface. The last step is to name the tertiary clamping surface, which in this example the name given to this surface is a left-side surface and the name given to the surface opposite of tertiary clamping surface is a right-side surface.

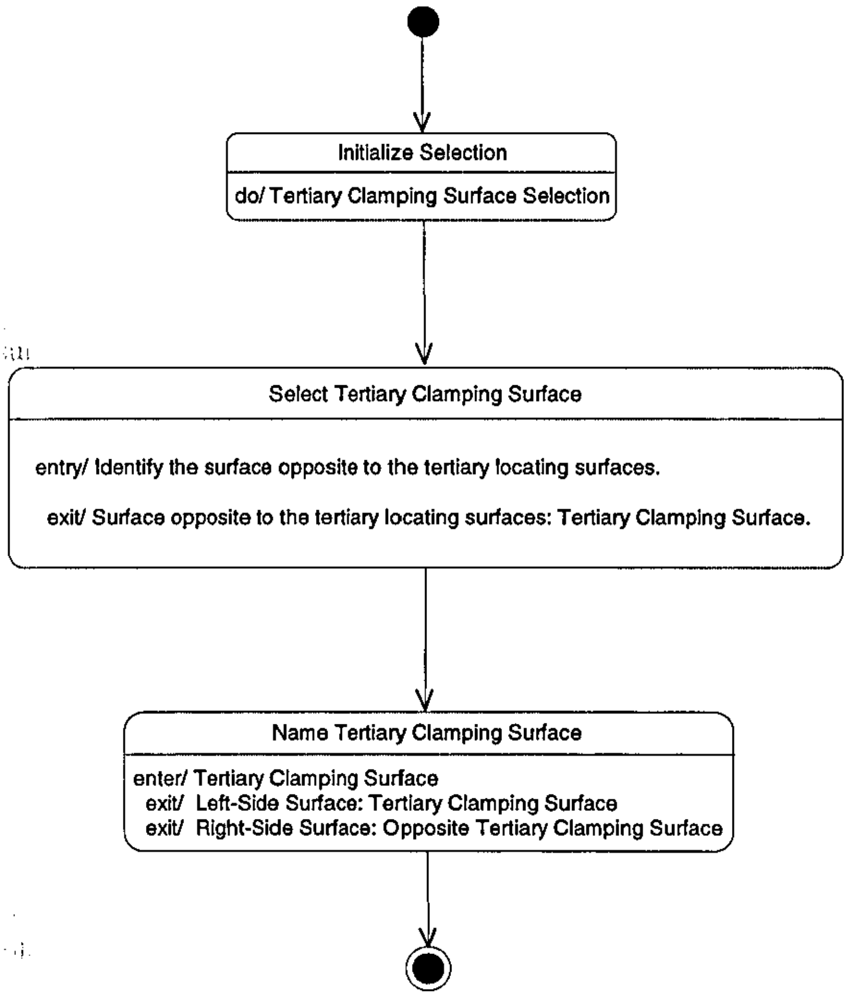


Figure 5.37 – Tertiary Clamping Surface Selection for 3-2-1 Clamping

5.4.2.4.2 The Representation of the Clamping Process for Concentric Method

Figure 5.38 illustrates the UML activity diagram of the selection of the primary clamping surface for the concentric clamping method contained in the manufacturing model. The first step for selecting the primary clamping surface is to initialise the selection process for primary clamping surface. Then, the next step is to identify the surface opposite to the primary locating surface. The last step is to name primary clamping surface, which in this example the name given to this surface is a top surface and the name given to the surface opposite of primary clamping surface is a bottom surface.

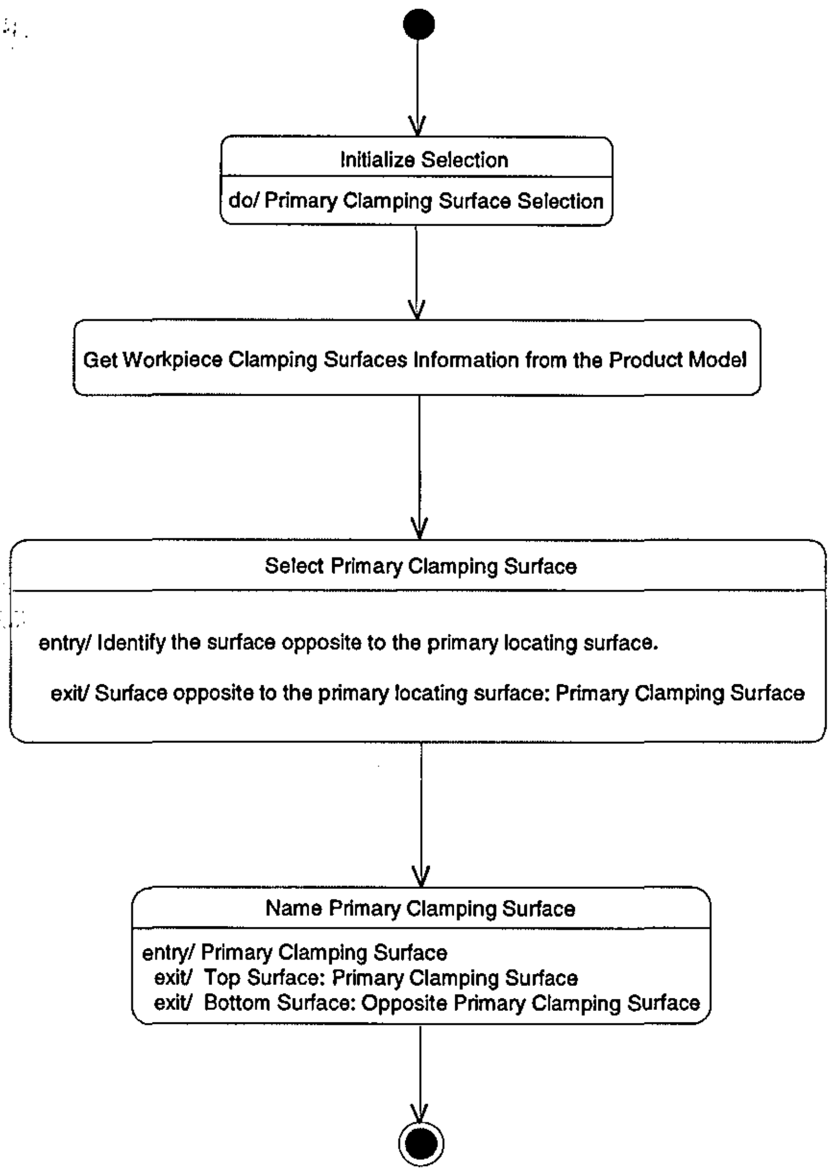


Figure 5.38 – Primary Clamping Surface Selection for Concentric Method in UML Activity Diagram

The representation in selecting the secondary clamping surface is described Figure 5.39. The first step is to initialise the selection process for secondary clamping surface. Then, the next step is to identify a hole surface that can be used for secondary locating surface. The last step is to name the secondary clamping surface, which in this example the name given to this surface is a hole surface.

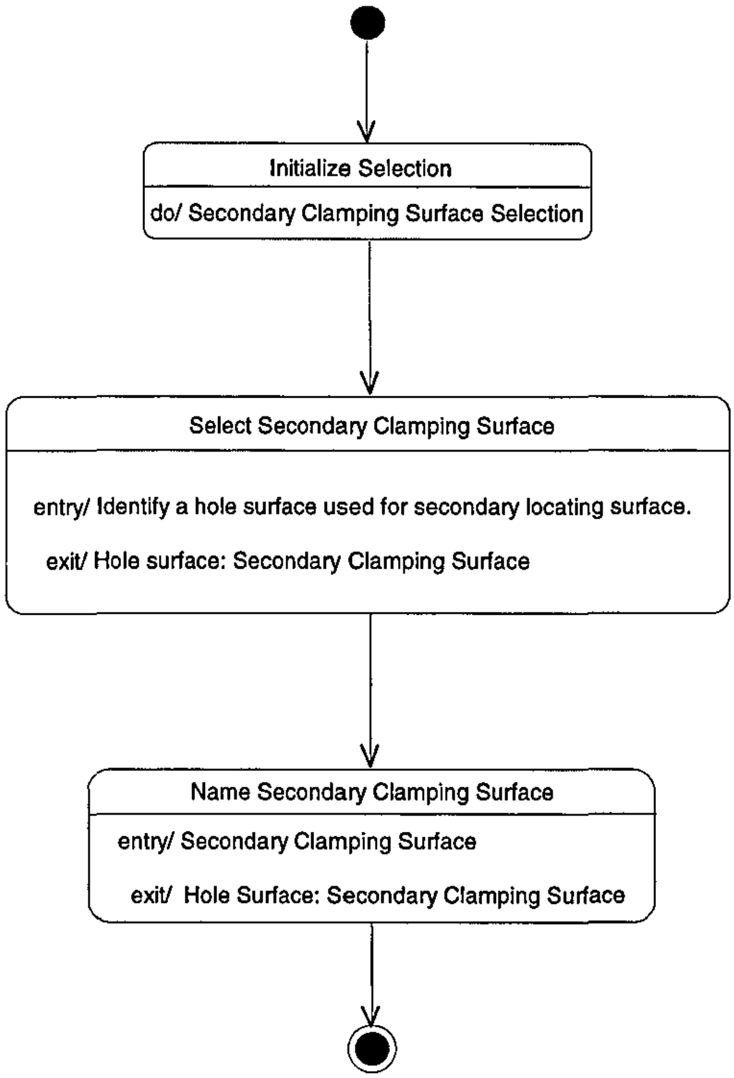


Figure 5.39 – Secondary Clamping Surface Selection for Concentric Method

Figure 5.40 illustrates the activity diagram for the selection of tertiary clamping surface. The first step is to initialise the selection process for tertiary clamping surface. Then, the next step is to identify the surface opposite to the tertiary locating surface. The last step is to name the tertiary clamping surface, which in this example the name given to this surface is a front surface and the name given to the surface opposite of tertiary locating surface is a rear surface.

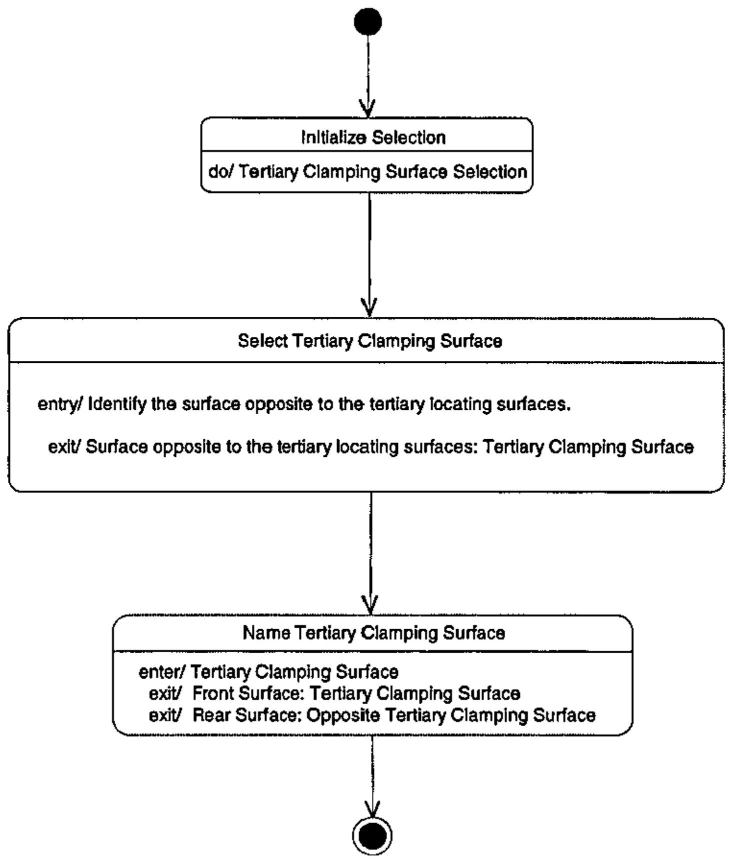


Figure 5.40 – Tertiary Clamping Surface Selection for Concentric Method

5.4.2.4.3 The Representation of the Clamping Process for Radial Method

Figure 5.41 illustrates the UML activity diagram of the selection of the primary clamping surface for the radial clamping method contained in the manufacturing model. The first step for selecting the primary clamping surface is to initialise the selection process for primary clamping surface. The second step is to get the work-piece clamping surfaces information from the product model. Then, the next step is to identify the surface opposite to the primary locating surface. The last step is to name primary clamping surface, which in this example the name given to this surface is a top surface and the name given to the surface opposite of primary clamping surface is a bottom surface. The activity diagrams provide the basis from which object-oriented methods can be defined to represent the radial clamping method.

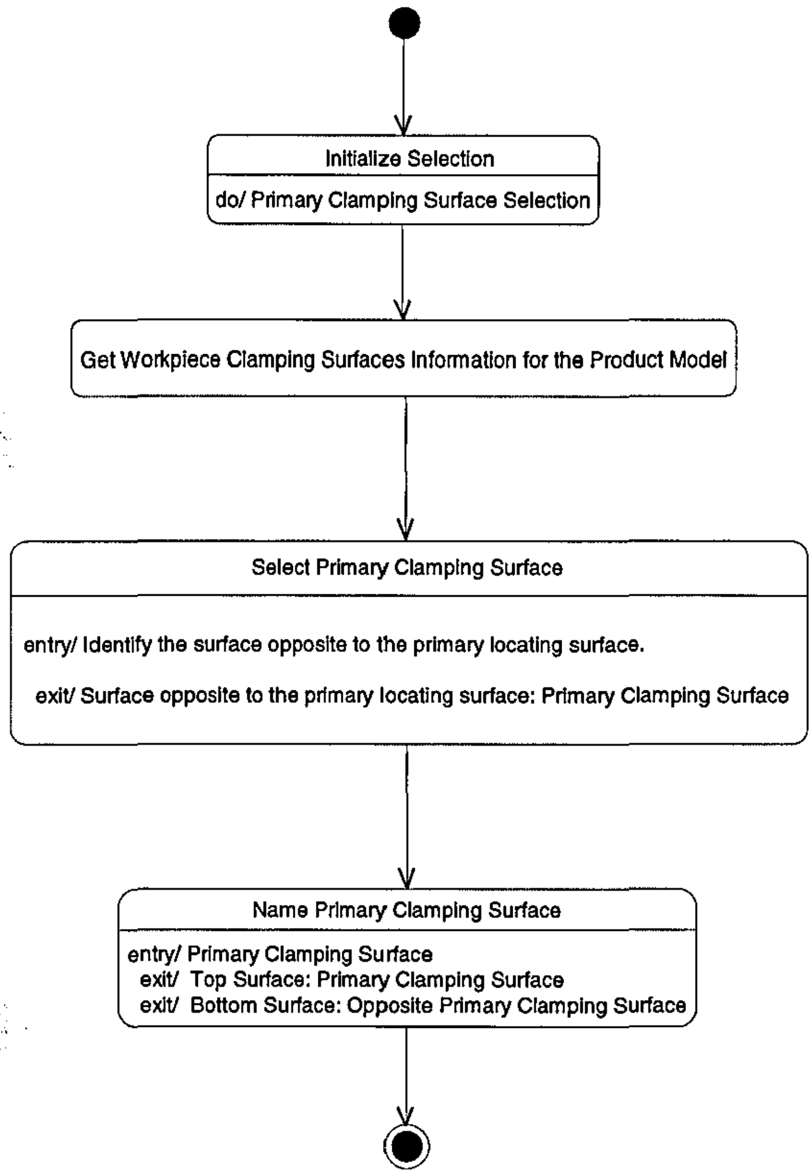


Figure 5.41 – Primary Clamping Surface Selection for Radial Method in UML Activity Diagram

The representation in selecting the secondary clamping surface is described Figure 5.42. The first step is to initialise the selection process for secondary clamping surface. Then, the next step is to identify a hole surface that has been used for secondary locating surface. The last step is to name the secondary clamping surface, which in this example the name given to this surface is a hole surface #1.

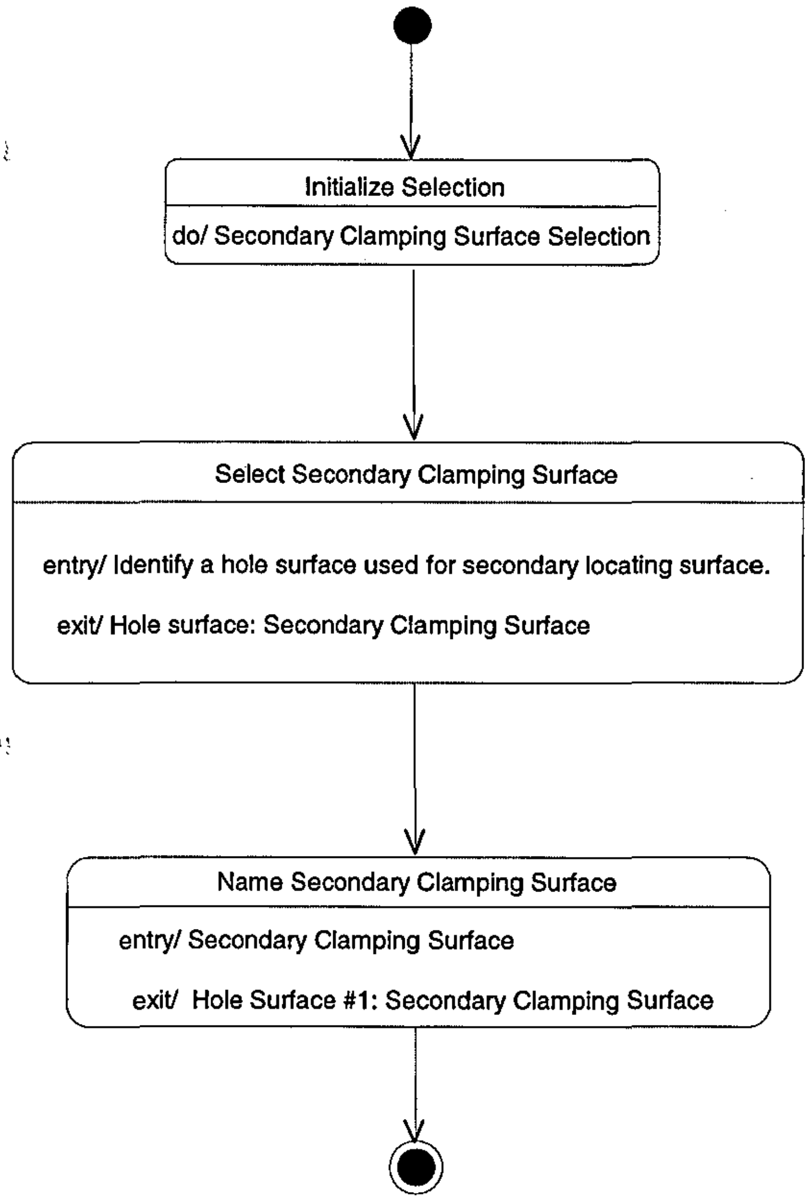


Figure 5.42 – Secondary Clamping Surface Selection for Radial Method

The representation in selecting the tertiary clamping surface is described Figure 5.43. The first step is to initialise the selection process for tertiary clamping surface. Then, the next step is to identify a hole surface that has been used for tertiary locating surface. The last step is to name the tertiary claming surface, which in this example the name given to this surface is a hole surface #2.

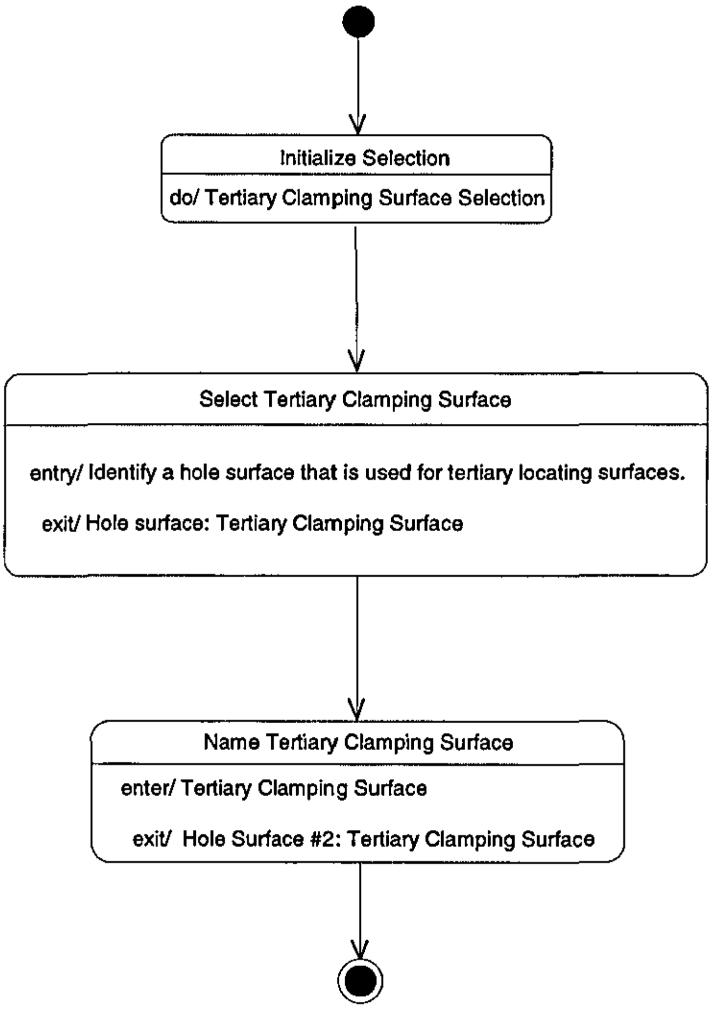


Figure 5.43– Tertiary Clamping Surface Selection for Radial Method

These methods for selecting clamping surfaces on a simple workpiece can also applied to complex workpieces, because the process is similar. The difference lies when the clamping surfaces are not able to accommodate the clamps. In this case, the clamping surfaces may not be the surfaces opposite to the locating surfaces, because of the complex shape of these surfaces the clamps are inadequate in holding the workpiece. Depending on the complexity of the workpiece, special type of clamps may be utilised to hold complex shaped workpieces.

5.4.3 The Representation of the Fixturing Resources

5.4.3.1 Fixturing Elements Data Structure

The representation of the fixturing resources is captured using the UML class diagram as shown in Figure 5.44. The figure shows fixturing elements data structure of the manufacturing model extending the modular fixturing (MODULAR_FIXTURING_ELEMENTS) class to different fixturing elements. As mentioned in the previous section that this work focuses on the modular fixturing elements as the fixturing resources to aid the representation of the fixturing process.

The figure illustrates that plate (PLATE) class, locating pin (LOCATING_PIN) class, screwed rest button (SCREWED_REST_BUTTON) class, clamp element (CLAMP_ELEMENT) class, down hold clamp (DOWN_HOLD_CLAMP) class and centering bolt (CENTERING_BOLT) class inherits from the modular fixturing elements (MODULAR_FIXTURING_ELEMENTS) class. The dotted box represent the other modular fixturing elements which are not included in the list, but the six listed below are there in order to illustrate this research work. The UML class diagrams provide the basis from which object-oriented methods can be defined to represent the modular fixture elements. The details of these classes have been described in the succeeding sections.

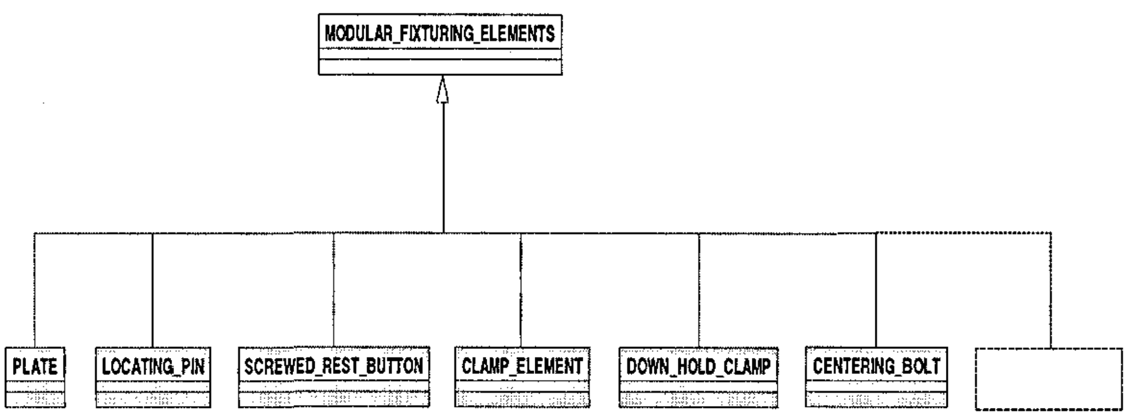


Figure 5.44 – Fixturing Elements Data Structure in UML Class Diagram

5.4.3.2 Representing the Fixturing Elements

There are several companies that are presently supplying modular fixturing elements and one of these, is Halder Modular Jig and Fixture Systems (1994). The author has used these fixturing elements from this company and selected some basic fixturing elements in order to be used in the implementation of the fixturing system that is being explored in this research work. The selected basic fixturing elements are discussed in the succeeding sections.

5.4.3.2.1 Representing Plates

The plates or general called base plate are used for locating and mounting a workpiece on the machine tool while in operation. The plate comes in different types and in various sizes and normally has holes on it. Figure 5.45 shows that the plate (PLATE) class inherits from the modular fixturing elements (MODULAR_FIXTURING_ELEMENTS) class. The rectangular plate with chamfer (RECTANGULAR_PLATE_WITH_CHAMFER) class and the rectangular plate (RECTANGULAR_PLATE) class are the two types of plates that inherit the plate (PLATE) class. The figure highlights the attributes that represent the specifications of the plates and this information contributes in locating element selection for locating process.

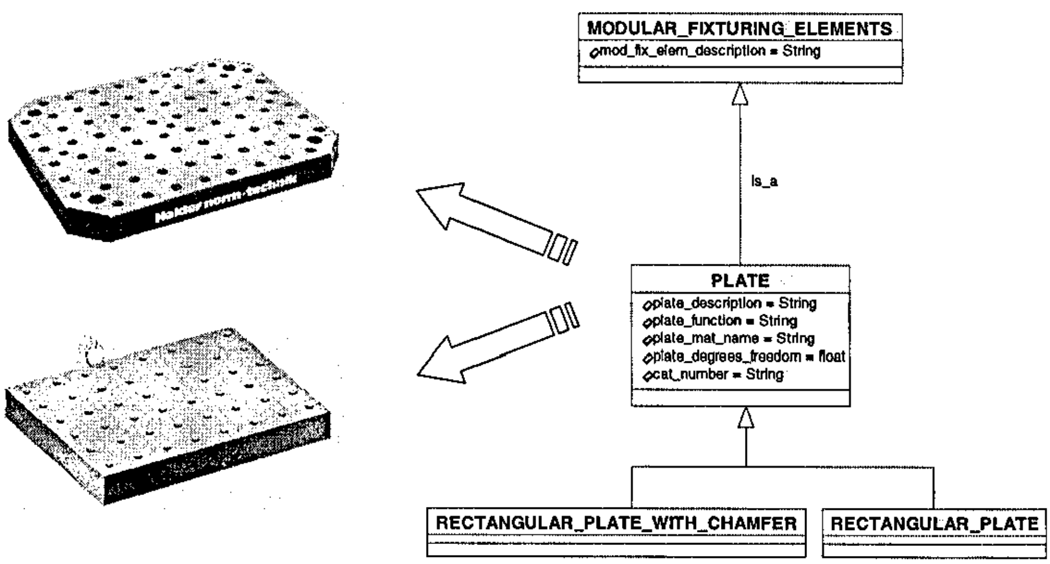


Figure 5.45 – The Representation of Plates

5.4.3.2.2 Representing Locating Pins

The locating pins are fixturing element use for location. The types and sizes vary depending from the design of the manufacturers. Locating pins can be used in different locating surfaces of the workpiece. Figure 5.46 shows that the locating pin (LOCATING_PIN) class inherits from the modular fixturing elements (MODULAR_FIXTURING_ELEMENTS) class. The double ended locating pin (DOUBLE_ENDED_LOCATING_PIN) class and the single ended locating (SINGLE_ENDED_LOCATING_PIN) class are the two types of locating pins that inherit the locating pin (LOCATING_PIN) class. The figure highlights the attributes that represent the specifications of the locating pins and this information contributes in locating element selection for locating process.

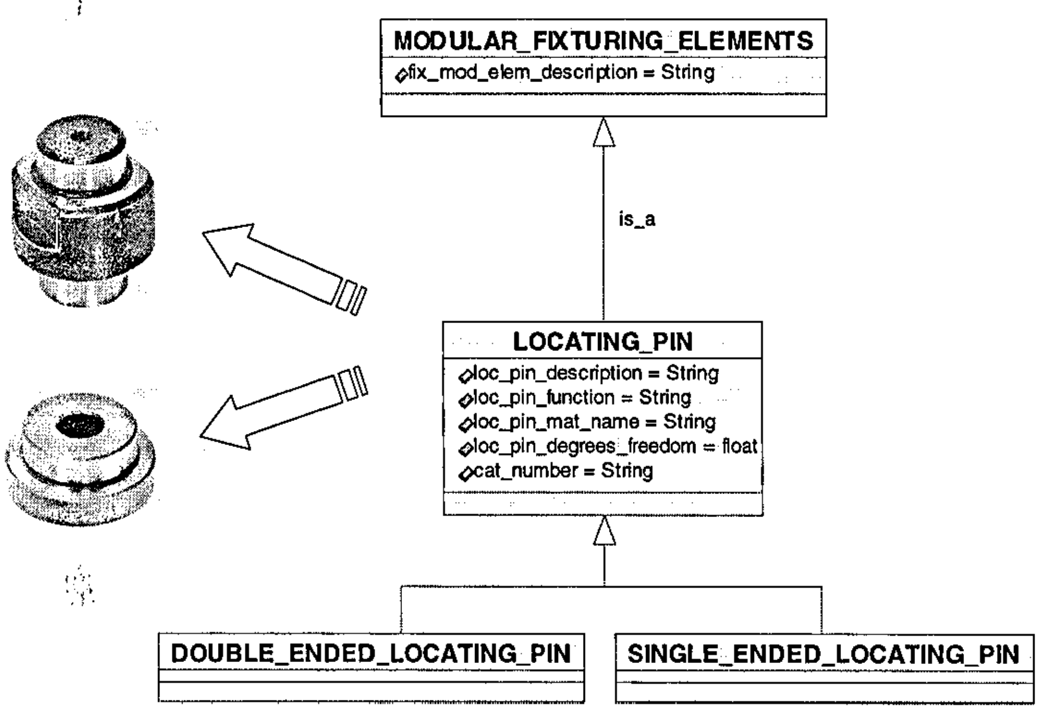


Figure 5.46 – The Representation of Locating Pins

5.4.3.2.3 Representing Screwed Rest Buttons

The screwed rest buttons are fixturing element use for location. The types and sizes vary depending from the design of the manufacturers. Figure 5.47 shows that the screwed rest button (SCREWED_REST_BUTTON) class inherits from the modular fixturing elements (MODULAR_FIXTURING_ELEMENTS) class. The male thread screwed rest button (MALE_THREAD_SCREWED_REST_BUTTON) class and the female thread screwed rest button (FEMALE_THREAD_SCREWED_REST_BUTTON) class are the two types of screwed rest buttons that inherit the screwed rest button (SCREWED_REST_BUTTON) class. The figure highlights the attributes that represent the specifications of the screwed rest buttons and this information contributes in locating element selection for locating process.

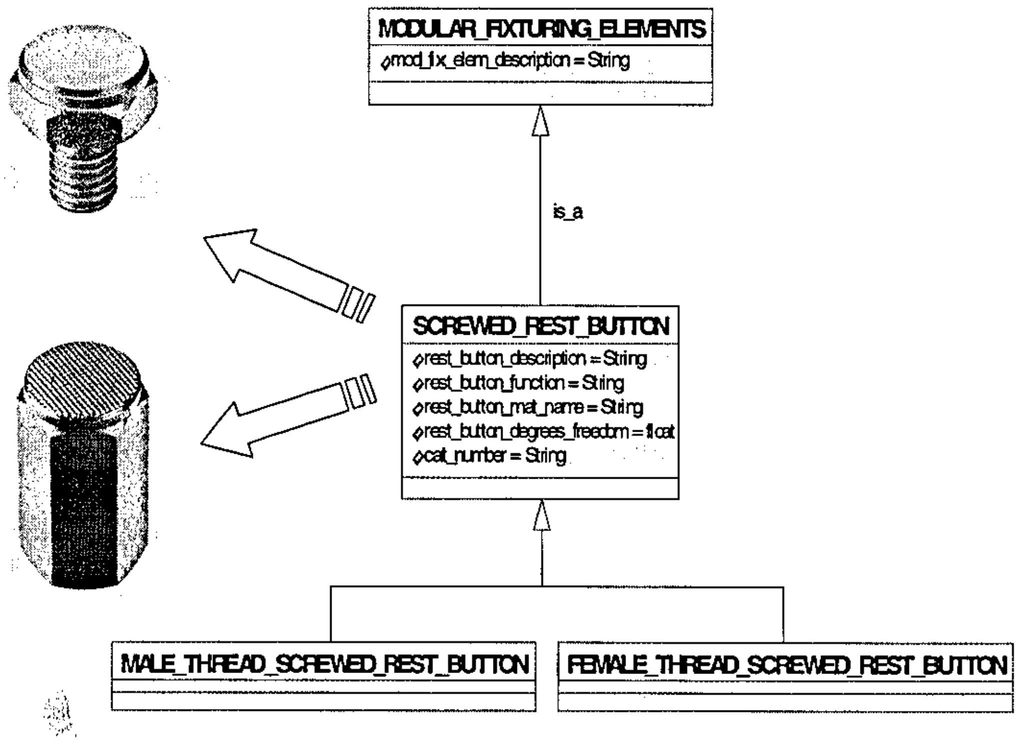


Figure 5.47 – The Representation of Screwed Rest Buttons

5.4.3.2.4 Representing Clamp Elements

The clamp elements are fixturing element use for clamping. This type of clamp comprises of different components that are assembled and normally placed on top of the base plate to clamp simple workpieces. The types and sizes vary depending from the design of the manufacturers. Figure 5.48 shows that the clamp element (CLAMP_ELEMENT) class inherits from the modular fixturing elements (MODULAR_FIXTURING_ELEMENTS) class. The figure highlights the attributes that represent the specifications of the clamp elements and this information contributes in clamp selection for clamping process.

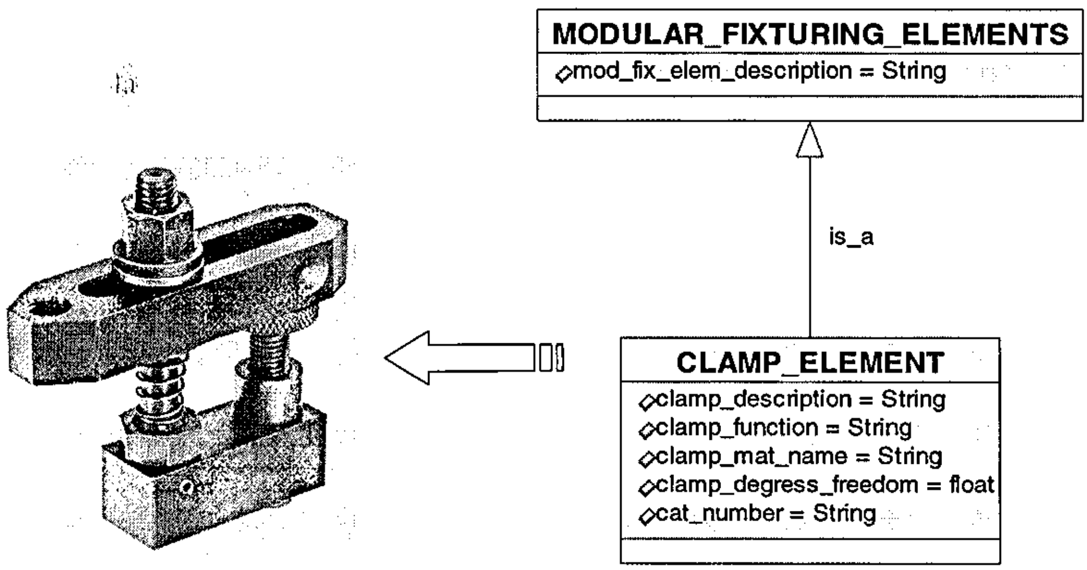


Figure 5.48 – The Representation of Clamp Elements

5.4.3.2.5 Representing Down Hold Clamp

The down hold clamps are fixturing element use for clamping. This type of clamp comprises of different components that are assembled and normally placed on top of the base plate to clamp simple workpieces. The sizes and types vary depending from the design of the manufacturers. Figure 5.49 show that the down hold clamp (DOWN_HOLD_CLAMP) class inherits from the modular fixturing elements (MODULAR_FIXTURING_ELEMENTS) class. The figure highlights the attributes that represent the specifications of the down hold clamps and this information contributes in clamp selection for clamping process.

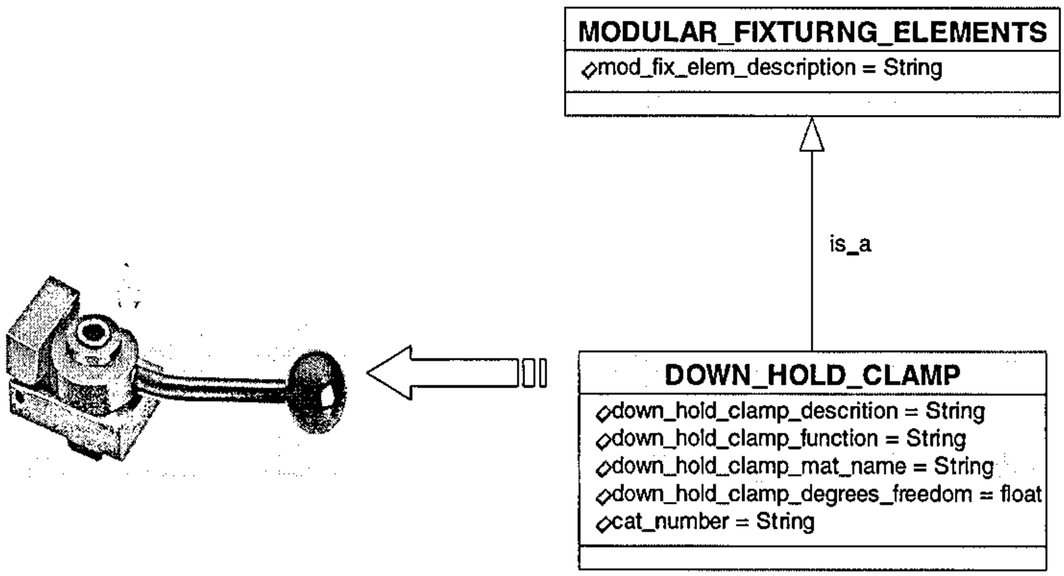


Figure 5.49 – The Representation of Down Hold Clamps

5.4.3.2.6 Representing Centering Bolts

The centering bolts are fixturing element use for concentric and radial locating methods. The types and sizes vary depending from the design of the manufacturers. Figure 5.50 shows that the centering bolt (CENTERING_BOLT) class inherits from the modular fixturing elements (MODULAR_FIXTURING_ELEMENTS) class. The centering bolt with step (CENTERING_BOLT_WITH_STEP) class and the plain centering bolt (PLAIN_CENTERING_BOLT) class are the two types of centering bolts that inherit the centering bolt (CENTERING_BOLT) class. The figure highlights the attributes that represent the specifications of the centering bolts and this information contributes in locating element selection for locating process.

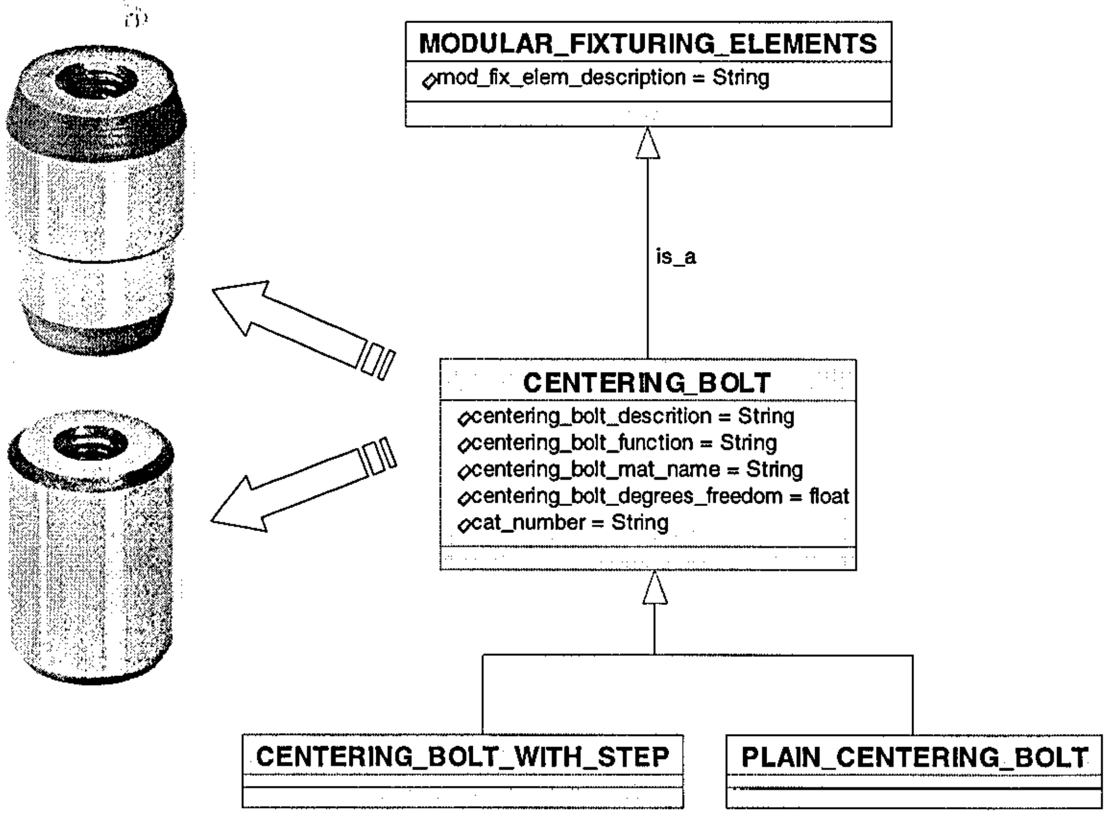


Figure 5.50 – The Representation of Centering Bolts

This section has presented the basic modular fixturing elements that will be used in the implementation of the fixturing system that is being explored in this work. The information that is related to the types and sizes of these modular fixturing elements can be found in Appendix C.

5.5 Product Data Model

5.5.1 The General Structure of the Product Model

A product model can be considered a computer representation of a product, which holds a complete depiction of the information concerning a product. The product model therefore becomes a source and repository for information to be shared between the users and software components of the CAE system. In considering the fixturing process in terms of product data model, there were two problems being addressed; what product information should be stored in the product model and what should be the structure of this product information? As stated earlier the work reported in this thesis does not aim to contribute to product modelling research, but in order to illustrate the research ideas of the author on the use of fixturing information, a product information representation has been defined.

The product information requirements for fixturing has been defined by extending the general data structures previously defined from the works of Borja (1997) and Young & Bell (1992) to include fixturing information. The general product data structure is shown in Figure 5.51. The figure illustrates the workpiece is a product that has specification and definition. The information of the workpiece that is needed in fixturing has been highlighted in the figure.

The product model that contains the information about the product needs to be there in order to exploring the use of information models to support decision-making in design and manufacture activities. This section discusses the general data structure of a product model, which has a class workpiece (Workpiece) using the UML class diagram.

The figure presents the class structure of a workpiece and the relationships to other classes defined by the author. In the class structure, workpiece (Workpiece) class aggregates to a specification (Specification) class with multiplicity of one to many and also aggregates to a (Definition) class with a multiplicity of one to many. The focus in this class diagram, which has been highlighted in the figure, is the fixturing information from the workpiece.

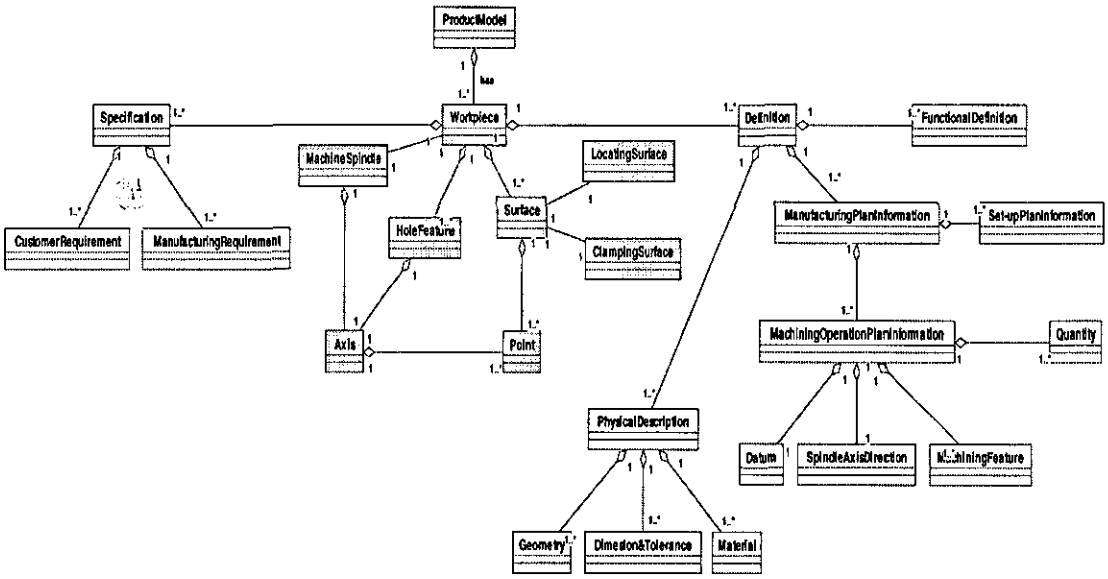


Figure 5.5.1 – The General Structure of the Product Model in UML Class Diagram [Extended from Borja, 1997]

Figure 5.51 illustrates the physical description (PhysicalDescription) class, manufacturing plan information (ManufacturingPlanInformation) class and functional definition (FunctionalDefinition) class aggregates from definition (Definition) class with one to many multiplicities for both classes. From these classes, the manufacturing plan information (ManufacturingPlanInformation) class has the machining operation plan information (MachiningOperationPlanInformation) class of the workpiece that contained the information needed to plan for the manufacture of the workpiece.

The significant information related in order to illustrate the process of selecting locating and clamping surfaces of a workpiece is discussed in the next section. These information are highlighted in Figure 5.51 and the details of these class diagrams can be found in the next section.

5.5.2 The Representation of the Product Data Model of a Workpiece

The UML class diagram provides the basis from which the product data can be represented in an object-oriented method. Figure 5.52 shows the structure of the product data model of a workpiece in UML class diagram. The highlighted classes are the information directly related to the surfaces of the workpiece, which is important in the selection of the locating and clamping surfaces and the other to classes are related to the machine tool. The author's work in the product model is to supplement the manufacturing model in order that the assessment of the research ideas will be successful. This product model captured only the information needed to support-decision that is relevant to fixturing.

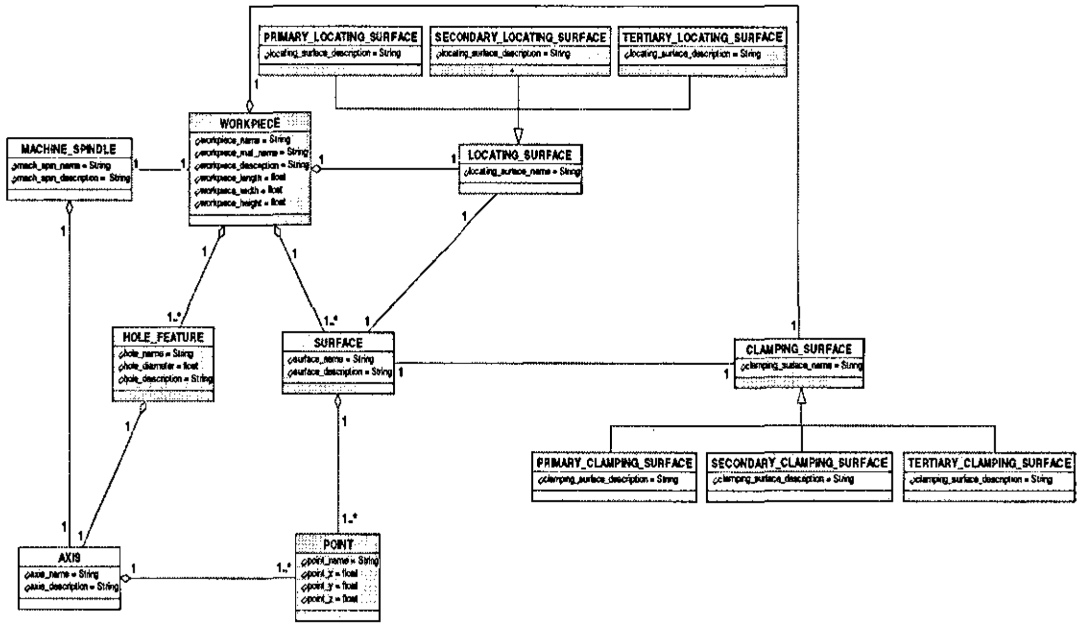


Figure 5.52 – The Structure of the Product Data Model in UML Class Diagram

The product model has a workpiece (WORKPIECE) class, which is associated with machine spindle (MACHINE_SPINDLE). The machine spindle is important because it will determine what kind of orientation the workpiece is to be set-up. Workpiece class has a hole-feature (HOLE_FEATURE) class; it has surface (SURFACE) class that is associated with locating surface (LOCATING_SURFACE) class and clamping surface (CLAMPING_SURFACE) class. The surface is important because it is where the definition of the points of the each surfaces in the workpiece. The machine spindle has axis (AXIS) class, which has point (POINT) class. The point is the one will defined the position of the axis as well as in the surfaces. Workpiece has locating surface (LOCATING_SURFACE) class and clamping surface (CLAMPING_SURFACE) class, which is associated with surface (SURFACE) class. Primary locating surface (PRIMARY_LOCATING_SURFACE) class, secondary locating surface (SECONDARY_LOCATING_SURFACE) class and tertiary locating surface (TERTIARY_LOCATING_SURFACE) class inherits from locating surface (LOCATING_SURFACE) class. Primary clamping surface (PRIMARY_CLAMPING_SURFACE) class, secondary clamping surface (SECONDARY_CLAMPING_SURFACE) class and tertiary clamping surface (TERTIARY_CLAMPING_SURFACE) class inherits from clamping surface (CLAMPING_SURFACE) class. These are the classes that the author has used in order to develop the experimental system to test the research concept of this work.

5.6 Summary

This chapter has defined the general information structure to capture the fixturing information of fixturing processes and fixturing resources in the manufacturing model in conjunction with a product model to support the design and manufacture applications. These information structures are the results of the exploration of the issues of this research. The information structure resulted from a general evaluation of fixturing in terms of the processes and resources involved. Then, it was followed by the formal modelling of design and manufacture activities using the IDEF0 to provide an understanding of how fixturing information be used to have a useful support for these activities.

The general information structure that is illustrated in Figure 5.22, led to the definition of data structures for fixturing processes and fixturing resources, which have been represented using UML class diagram. Fixturing methods have been represented using UML activity diagram. The information concerning the product data has been also represented using UML class diagrams.

The use of this fixturing information models is discussed in the next chapter.

Chapter 6

UTILISING FIXTURING INFORMATION MODELS TO SUPPORT DESIGN AND MANUFACTURE APPLICATIONS

6.1 Introduction

This chapter presents the research work done by the author to explore how the fixturing information models can be utilised through an application environment to provide support for product design, process planning and fixture planning stage in the design and manufacture activities. Section 6.2 discusses the utilisation of the information models to support product design, section 6.3 discusses the utilisation the information models to support process planning and section 6.4 discusses the utilisation of the information models to support fixture planning. Section 6.5 discusses the fixturing information sharing across the applications.

To ensure effective data support to be achieved between the applications which require fixturing information, then fixturing information representation captured in the manufacturing model and in the product model that is presented in Chapter 5, must support any application that requires fixturing information inputs. The work of this thesis has addressed fixture planning, process planning and product design for fixturing. These applications have enabled the author to explore how modelling of fixturing information can be utilised to support a range of design and manufacture applications.

6.2 Support Product Design

The product design is broadly concerned with the design of products and their component parts, this aspect of work considers and assumes that they can be viewed as workpieces. The support product design application for fixturing is concerned with ensuring that a workpiece can be located and held easily. It provides advice to the designer of possible fixturing methods to be used combined with suggestions for changes to the design of the workpiece. This application is supported by the fixturing information captured in the manufacturing model and product model.

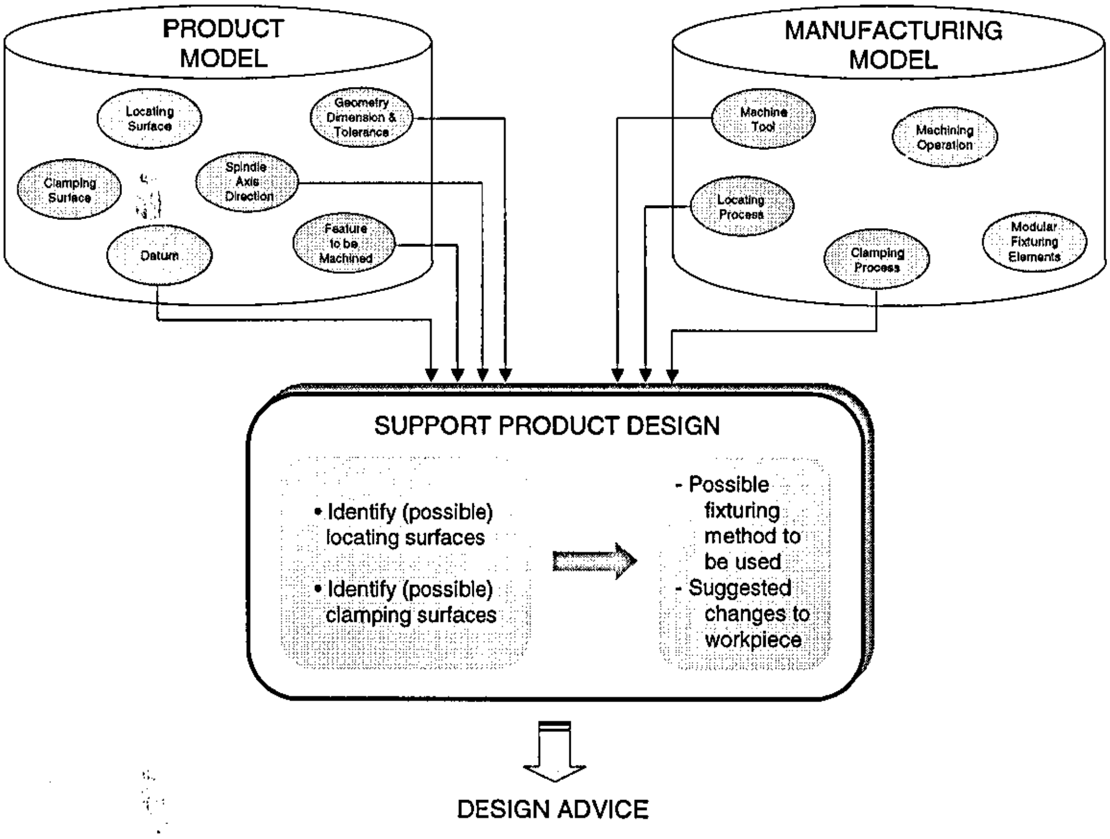


Figure 6.1 – Support Product Design Activities

Figure 6.1 illustrates that the support product design application has two main activities, one being to identify possible locating surfaces and the second to identify possible clamping surfaces. These activities require inputs of workpiece information stored in the product model, in particular these are geometry, dimensions/tolerances, feature to be machined and spindle axis direction, because this is the information needed in order to illustrate how the application is able to do the activities. From the manufacturing model the information of the machine tool, locating process and clamping process are needed in these activities.

To illustrate the details on how the applications utilise the information, the author used the UML activity diagram and this method is described in Appendix B. The locating process, which is discussed in section 5.2.1.1 and clamping process, which is discussed in section 5.2.1.2, are used for the exploration of this application. These fixturing processes have three methods, one being the radial, the second the concentric and third the 3-2-1 and the preferred priority is assumed in that order. This is because to have a decreasing complexity in dealing with the three fixturing methods. The radial method is complex because of the two holes which must be align accurately with its tolerances, the concentric with one hole is less complex than radial and the 3-2-1 that uses only plane surfaces.

Figure 6.2 shows the interactions of the information models and the activity diagram that represents the support product design application. The first activity is "Check the applicability of Radial Method" and extracts information from the product model and information from the manufacturing model and evaluates the applicability of the radial method. The decision point "Can this method be used?" is answered by the support product design application based on the output from the first activity. The breakdown of the activity is shown in Figure 6.3.

If the radial method can be used, the system then through the "Consider radial method" activity identifies the locating and clamping features to be used. However, if the decision point response is negative the system will have on to consider the concentric method. The activity sequence is repeated for the concentric method. Once again if the decision point response is negative the system will have on to consider the 3-2-1 method. The detail's representations for "Check the Applicability of Concentric Method and "Check the Applicability of 3-2-1 Method are shown in Figure 6.5 and Figure 6.7 respectively.

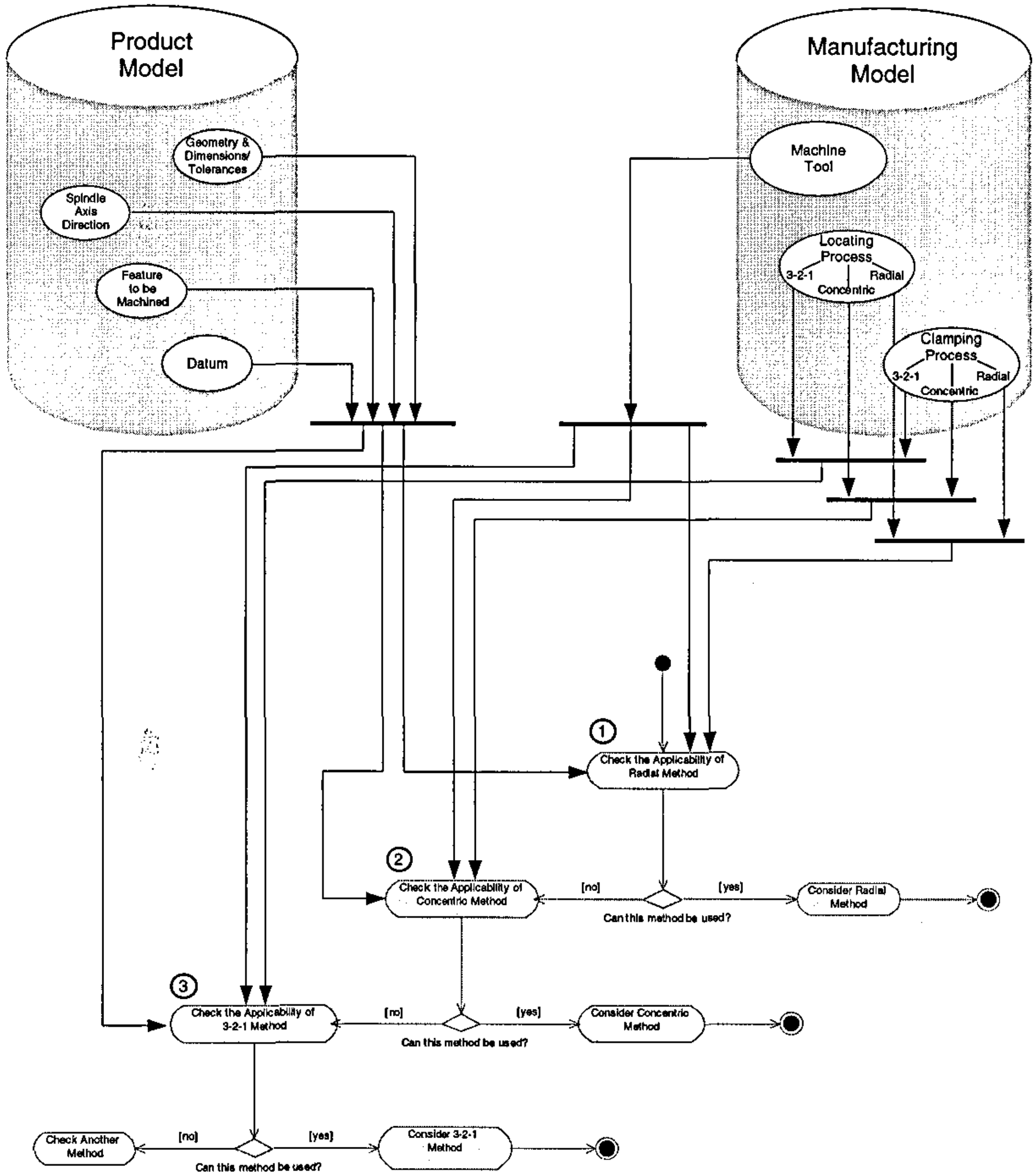


Figure 6.2 – Support Product Design Activities in UML Activity Diagram

The discussions above refer to the high level activity diagram of support product design application and shows that the application is able to use the information in the models. The next paragraphs will present the breakdown of the numbered activities 1, 2 & 3 respectively from Figure 6.2.

Figure 6.3 shows the "Check the Applicability of Radial Method" activity diagram. From the diagram, the first activity is the "Start" of the checking and then, the second activity is to "Identify two hole surfaces needed for the radial method" and this information is drawn from the manufacturing model. It is followed by the third activity "Identify two hole surfaces available on the workpiece" and this information is drawn from the product model.

The first decision point "Is there a hole which can be used for location?" and if the response is "yes", it will go to the second decision point "Is there another hole which can be used for location?" If the second decision point response is "yes" then the applicability of radial method is confirmed and it goes to the fifth activity "Use radial method". If the response of the first decision point is "no", it goes to the third decision point "Can a new hole be created and used for location?", which the user provides the answer to this particular decision point and if the response is "yes", it goes to the fourth decision point "Are there two holes which can be used for location?", if the answer is "yes", it goes to the fourth activity "Update database for the accepted changes to workpiece", then followed by the "Use radial method" activity. If the response to the second and fourth decision points are "no" the arrows of the decision point will join of the arrow in the first decision point "no" response. If the response of the third decision point is "no", then it goes to the last activity "Method cannot be used".

The responses of the decision points on the activity diagrams are provided by the support product design application based on the output of the third activity, which is "Identify hole surfaces available on the workpiece". The activity diagram of "Check the Applicability of Radial Method" shows that it has two main outputs; one being the "Use radial method" and second is the "Update database for the accepted changes to workpiece".

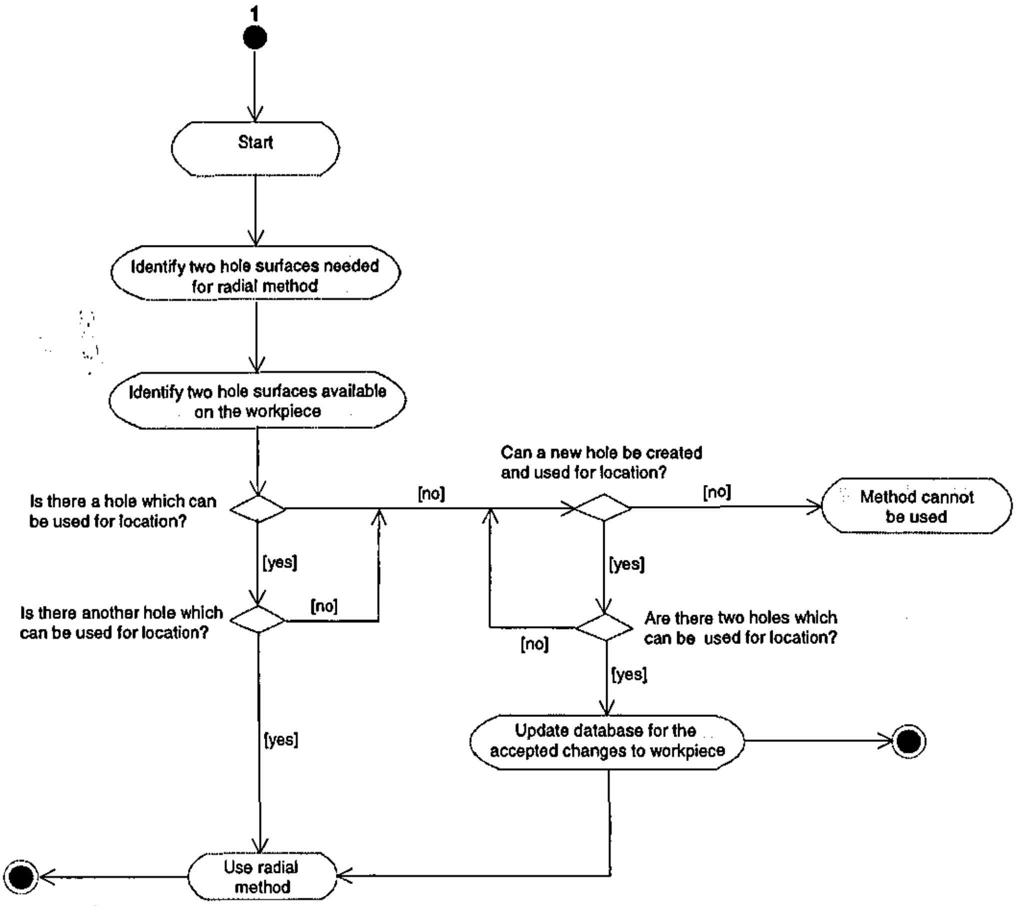


Figure 6.3 – Check the Applicability of Radial Method in UML Activity Diagram for Support Product Design Application

To demonstrate this method described above, a prismatic workpiece has been used to show how this application utilises the fixturing information stored in the models. The workpiece example in Figure 6.4 has three variations; at (A) two holes are reamed and therefore can be used for location. Following the activity diagram in Figure 6.3, the radial method is applied because it has two reamed holes that can be used for location and satisfies the requirement for this method. The variations on a workpiece at (B) and (C) in the figure suggested changes to workpiece in order that the radial method can be applied. At (B) suggests reaming the hole and at (C) suggests creating a new hole on a workpiece.

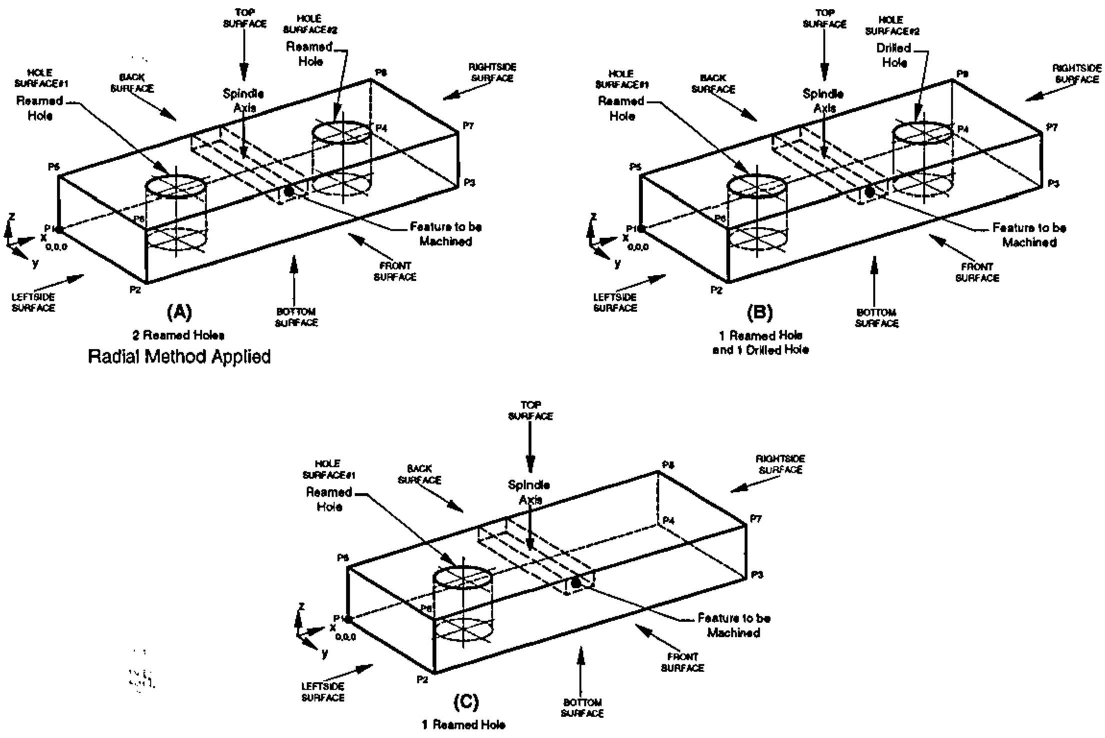


Figure 6.4 – Sample Variations on a Workpiece for the Applicability of Radial Method

Figure 6.5 shows the details of the "Check the Applicability of Concentric Method" activity diagram for support product design application. From the diagram, the first activity is the "Start" of the checking and then, the second activity is to "Identify two hole surfaces needed for the concentric method" and this information is drawn from the manufacturing model. It is followed by the third activity "Identify two hole surfaces available on the workpiece" and this information is drawn from the product model.

The first decision point "Is there a hole which can be used for location?" and if the response is "yes", then the applicability of the concentric method is confirmed and it goes to the fifth activity "Use concentric method". If the response of the decision point is "no", it goes to the second decision point "Can a new hole be created and used for location?", which the user provides the answer to this decision point and if the response is "yes", it goes to the fourth activity "Update database for the accepted changes to workpiece", then followed by the "Use concentric method" activity. If the response of the second decision point is "no", then it goes to the last activity "Method cannot be used".

The responses of the decision points on the activity diagrams are provided by the support product design application based on the output of the third activity, which is "Identify a hole surface available on the workpiece". The activity diagram of "Check the Applicability of Concentric Method" shows that it has two main outputs; one being the "Use radial method" and second is the "Update database for the accepted changes to workpiece".

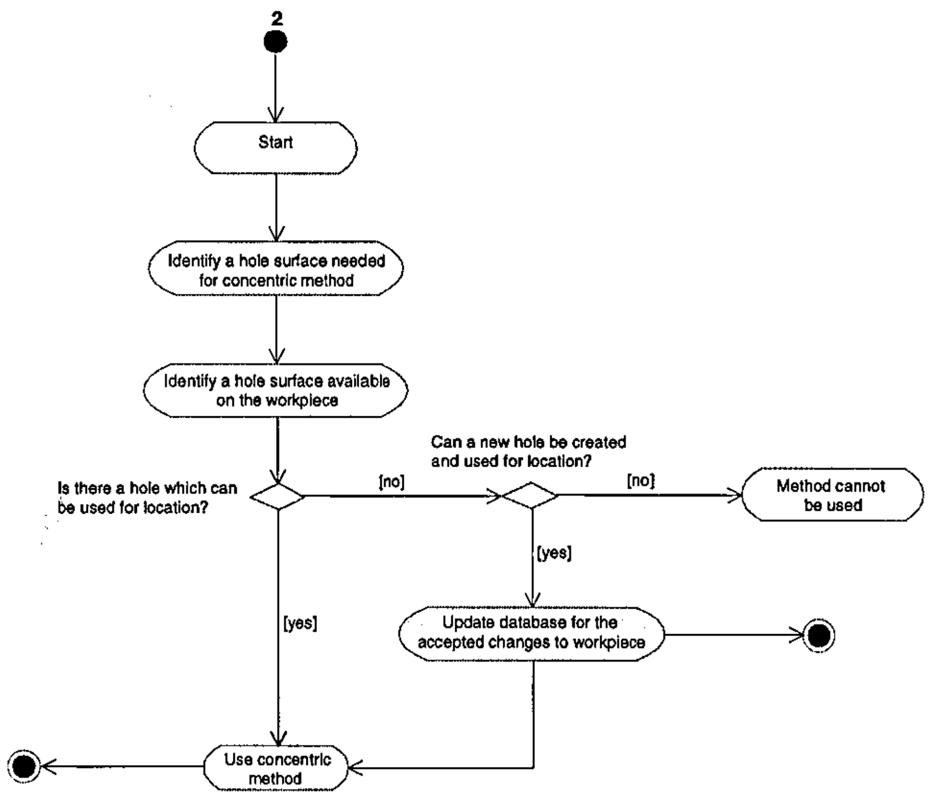


Figure 6.5 – Check the Applicability of Concentric Method in UML Activity Diagram for Support Product Design Application

To illustrate this method, a prismatic workpiece has been used to show how this application utilised the fixturing information stored in the models. The workpiece example in Figure 6.6 has two variations, (A) a hole that is reamed and therefore can be used for location. Following the activity diagram in Figure 6.5, the concentric method is applied because it has a reamed hole that can be used for location and satisfies the requirement for this method. At (B) the hole is not reamed and suggests for changes to workpiece to ream the hole or to create a new hole in order the concentric method can be applied.

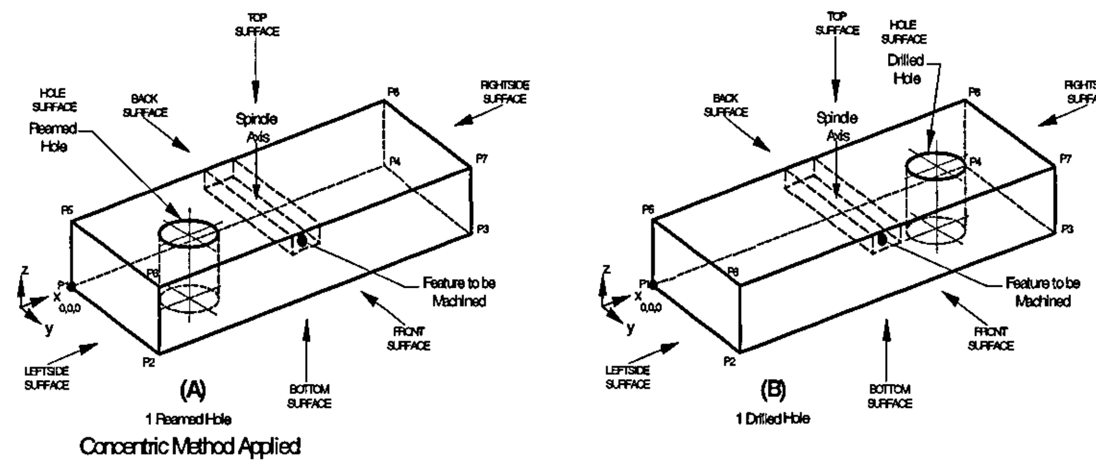


Figure 6.6 – Sample Variations of a Workpiece for the Applicability of Concentric Method

Figure 6.7 shows the "Check the Applicability of 3-2-1 Method" activity diagram. From the diagram, the first activity is the "Start" of the checking and then, the second activity is to "Identify plane surfaces needed for the 3-2-1 method" and this information is drawn from the manufacturing model. It is followed by the third activity "Identify plane surfaces available on the workpiece" and this information is drawn from the product model.

The decision point "Is there plane surfaces which can be used for location?" and if the response is "yes" then the applicability of the 3-2-1 method is confirmed and it goes to the fourth activity "Use 3-2-1 method". If the response of the decision point is "no", it goes to the last activity "Method cannot be used". The response of the decision point on the activity diagram is provided by the support product design application based on the output of the third activity, which is "Identify plane surfaces available on the workpiece". The activity diagram of "Check the Applicability of 3-2-1 Method" shows that it has one main output the "Use radial method" activity.

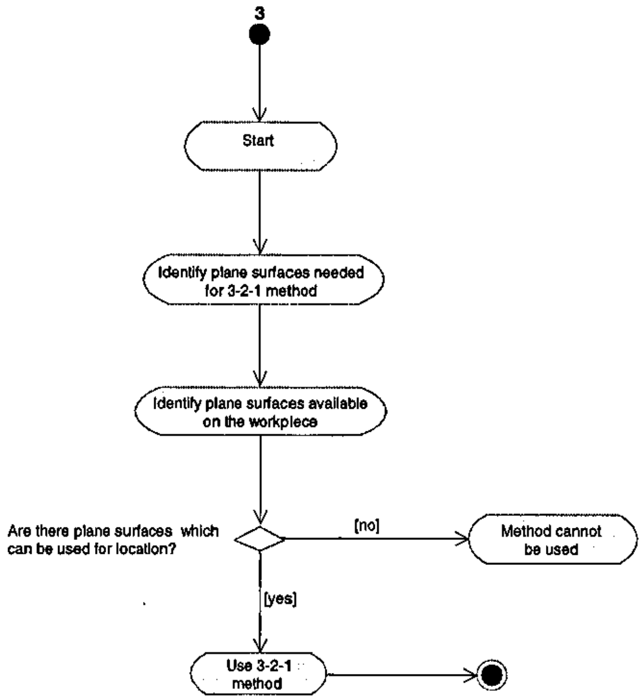


Figure 6.7 – Check the Applicability of 3-2-1 Method in UML Activity Diagram for Support Product Design Application

To illustrate this method described above, a prismatic workpiece has been used to show how this application utilised the fixturing information stored in the models. The workpiece example in Figure 6.8 has no hole surface that can be used for location, but it uses plane surfaces and following the activity diagram in Figure 6.7, the 3-2-1 fixturing method is applied.

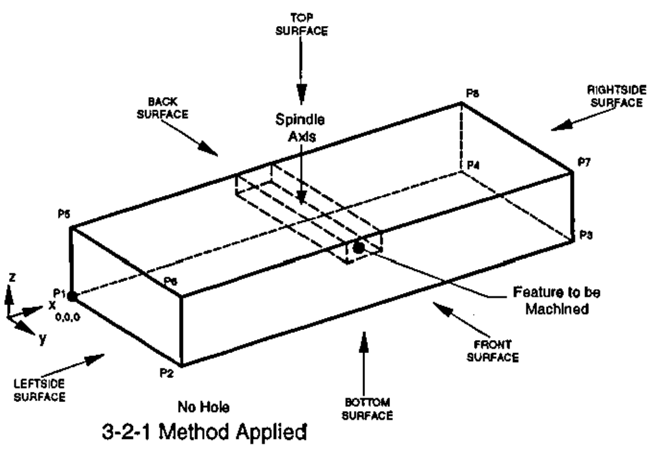


Figure 6.8 – Workpiece for the Applicability of 3-2-1 Method

6.3 Support Process Planning

The support process planning application is concerned with the evaluation of the locating and clamping surfaces in order to have a possible process plan in the early stage of design and manufacture activities. It provides advice to the designer for possible fixturing methods to be used, possible fixture plan and possible select a different machine tool. The support process planning activity could be used after the support product design activity by identifying the possible locating and clamping surfaces and this is why it also gives the advice about the possible fixturing method. This application is supported by the fixturing information captured in the manufacturing model and product model.

Figure 6.9 shows that the support process planning application has two main activities, one being to evaluate locating surfaces and second to evaluate clamping surfaces. The term evaluates in this context means that the surfaces to be used as locating are assessed whether the surface is machined finish where the locators can be placed accurately and is not on the path of the cutter. The surfaces to be used for clamping are assessed whether the surface has the area for placing the clamps that will not collide with cutting tool.

These activities require inputs of workpiece information stored in the product model; in particular these are geometry, dimensions/tolerances, feature to be machined, datum and spindle axis direction, locating surfaces and clamping surfaces, because these are the information needed in order to illustrate how the application is able to do the activities. From the manufacturing model the information of the machine tool, machining operation, locating process and clamping process are needed in these activities.

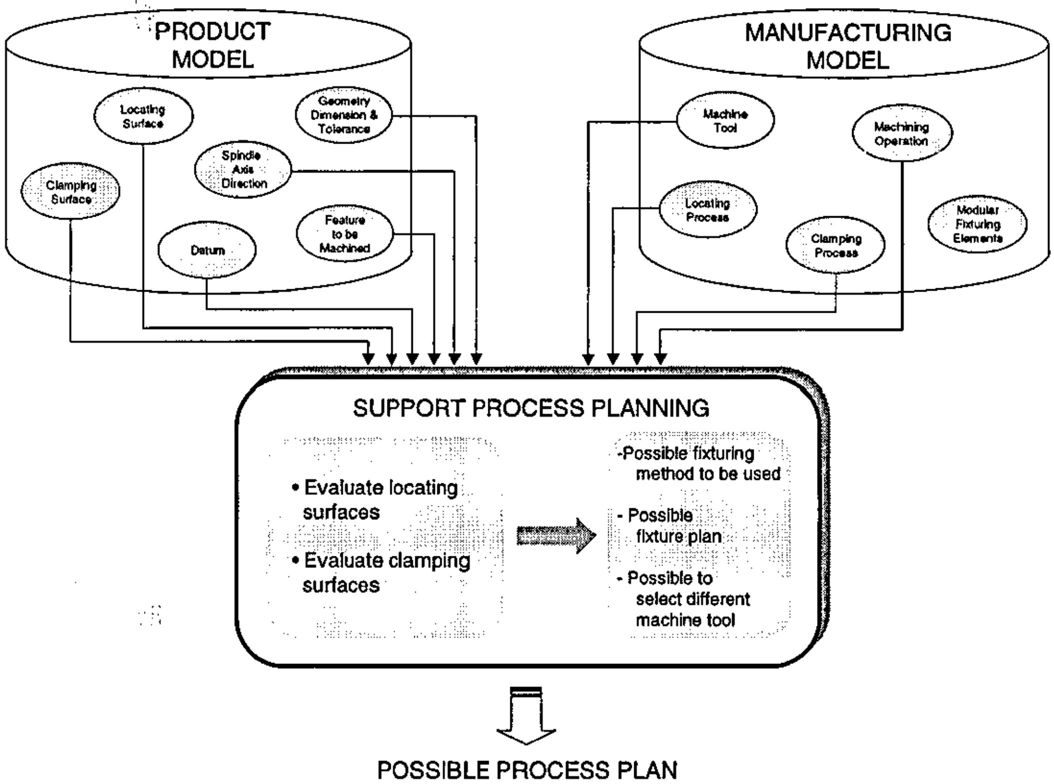


Figure 6.9 – Support Process Planning Activities

Figure 6.10 shows the interactions of the information models and the activity diagram that represents the support process planning application. The first activity is "Check the applicability of Radial Method" and extracts information from the product model and information from the manufacturing model and evaluates the applicability of the radial method. The decision point "Can this method be used?" is answered by the support process planning application based on the output from the first activity. The breakdown of the activity is shown in Figure 6.11.

If the radial method can be used, the system then through the "Consider radial method" activity identifies the locating and clamping features to be used. However, if the decision point response is negative the system will have on to consider the concentric method. The activity sequence is repeated for the concentric method. Once again if the decision point response is negative the system will have on to consider the 3-2-1 method. The detail's representations for "Check the Applicability of Concentric Method and "Check the Applicability of 3-2-1 Method are shown in Figure 6.12 and Figure 6.13 respectively.

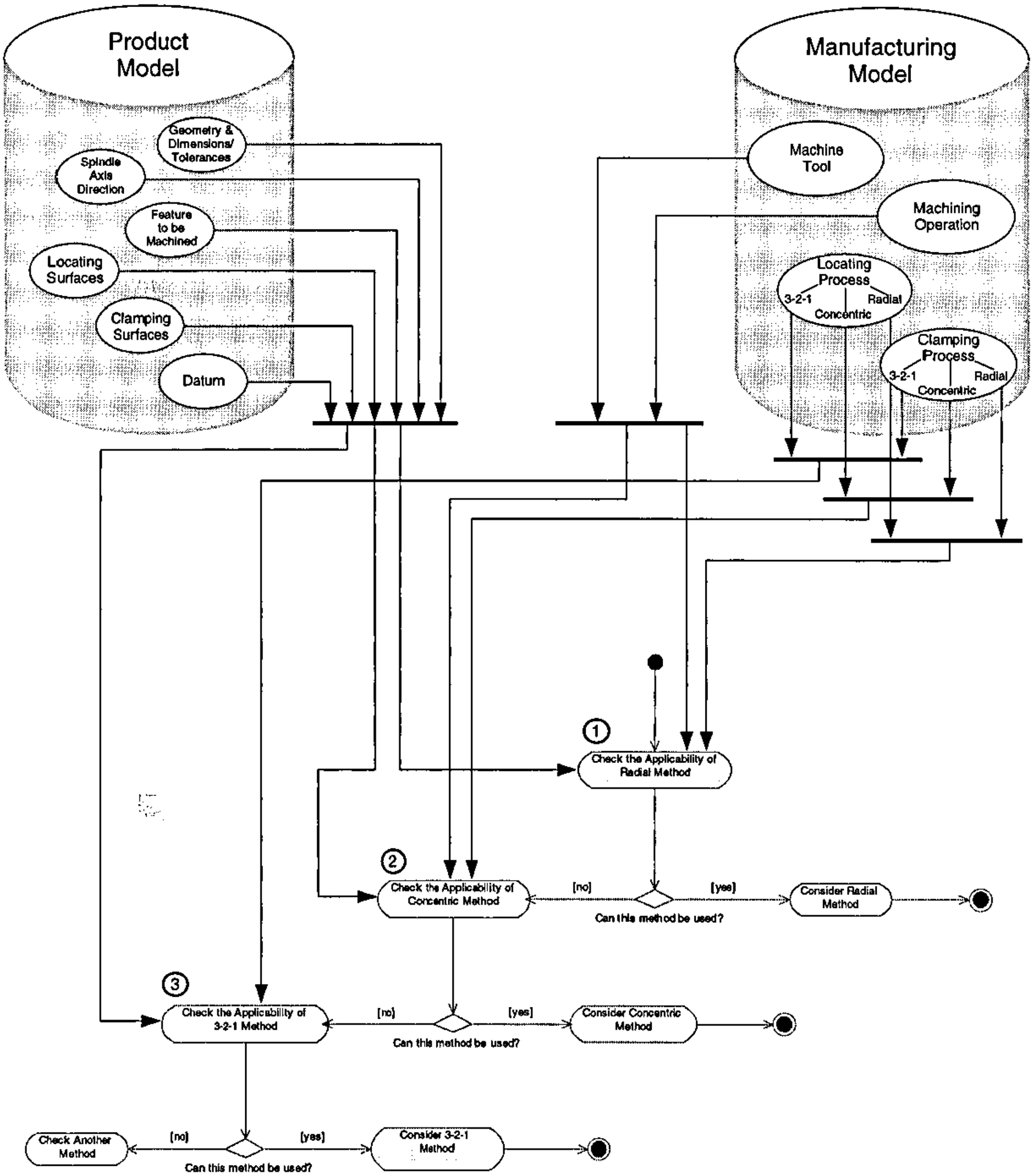


Figure 6.10 – Support Process Planning Activities in UML Activity Diagram

The discussions above refer to the high level activity diagram of support product design application and shows that the application is able to use the information in the models. The next paragraphs will present the breakdown of the numbered activities 1, 2 & 3 respectively from Figure 6.10.

Figure 6.11 shows the details of the "Check the Applicability of Radial Method" activity diagram for support process planning application. The activity sequence from the support product design application for the radial method is repeated until it reached the "Use radial method" activity where a decision point "Do you want to evaluate locating and clamping surfaces", which the user provides the answer to this particular decision point and if the answer is "yes" it goes to the "Evaluate locating surfaces" activity and then followed by "Evaluate clamping surfaces" activity. If the answer is "no" it will "Exit" and back to the main window. Then another decision point, "Can all evaluated locating and clamping surfaces be used", which the support process planning application provides the answer and if the response is "yes" it will give advice for a "Possible fixture plan and if the answer is "no" it will give advice for a "Possible to select different machine tool". The activity diagram of "Check the Applicability of Radial Method" for support process planning application shows that it has three main outputs; one being the "Use radial method" and second is the "Possible fixture plan" and third is the Possible to select different machine tool".

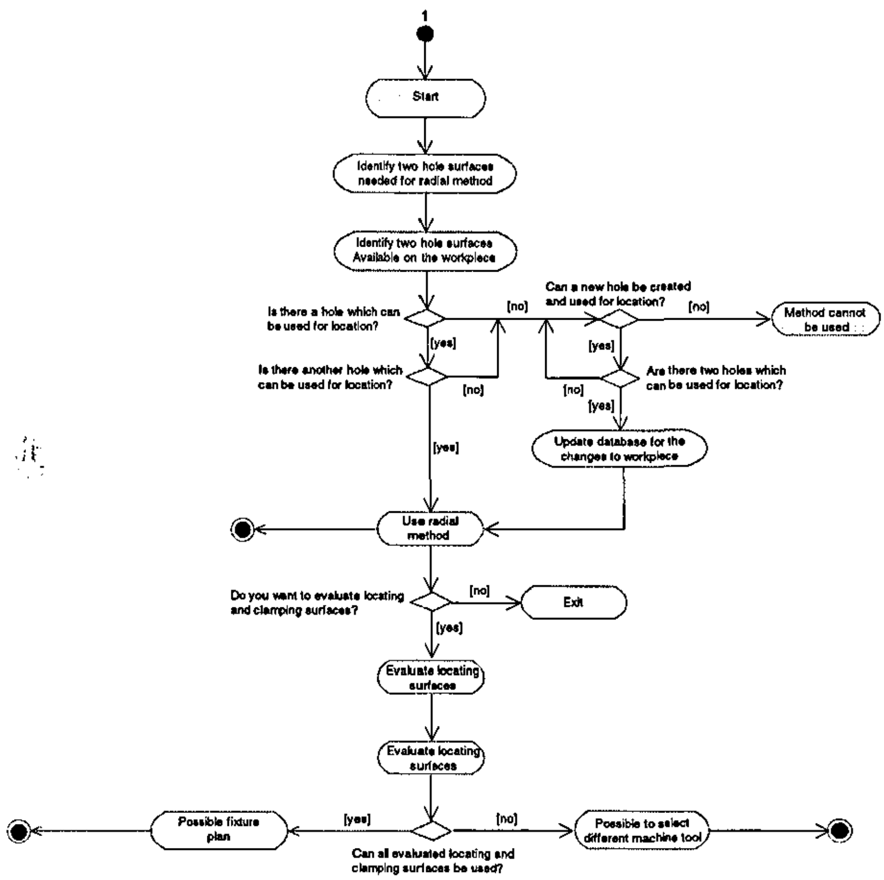


Figure 6.11 – Check the Applicability of Radial Method in UML Activity Diagram for Support Process Planning Application

To demonstrate this method, a prismatic workpiece has been used to show how this application utilised the fixturing information stored in the models. This support process planning will use the same prismatic workpiece example found in Figure 6.4. The three variations on a workpiece at (A) two holes are reamed can be used for location and following the activity diagram in Figure 6.11, the radial method is applied. The variations on a workpiece at (B) and (C) suggest changes to workpiece in order radial method can be applied. If the evaluated locating and clamping surfaces can be used the support planning application will give advice to the user for a possible fixture plan and if the evaluated locating and clamping surfaces cannot be used, the application will advice to the user for a possible to select different machine tool.

Figure 6.12 shows the details of the "Check the Applicability of Concentric Method" activity diagram for support process planning application. The activity sequence from the support product design application for the concentric method is repeated until it reached the "Use concentric method" activity where a decision point "Do you want to evaluate locating and clamping surfaces", which the user provides the answer to this particular decision point and if the answer is "yes" it goes to the "Evaluate locating surfaces" activity and then followed by "Evaluate clamping surfaces" activity. If the answer is "no" it will "Exit" and back to the main window. Then another decision point, "Can all evaluated locating and clamping surfaces be used", which the support process planning application provides the answer and if the response is "yes" it will give advice for a "Possible fixture plan" and if the answer is "no" it will give advice for a "Possible to select different machine tool". The activity diagram of "Check the Applicability of Concentric Method" for support process planning application shows that it has three main outputs; one being the "Use concentric method" and second is the "Possible fixture plan" and third is the "Possible to select different machine tool".

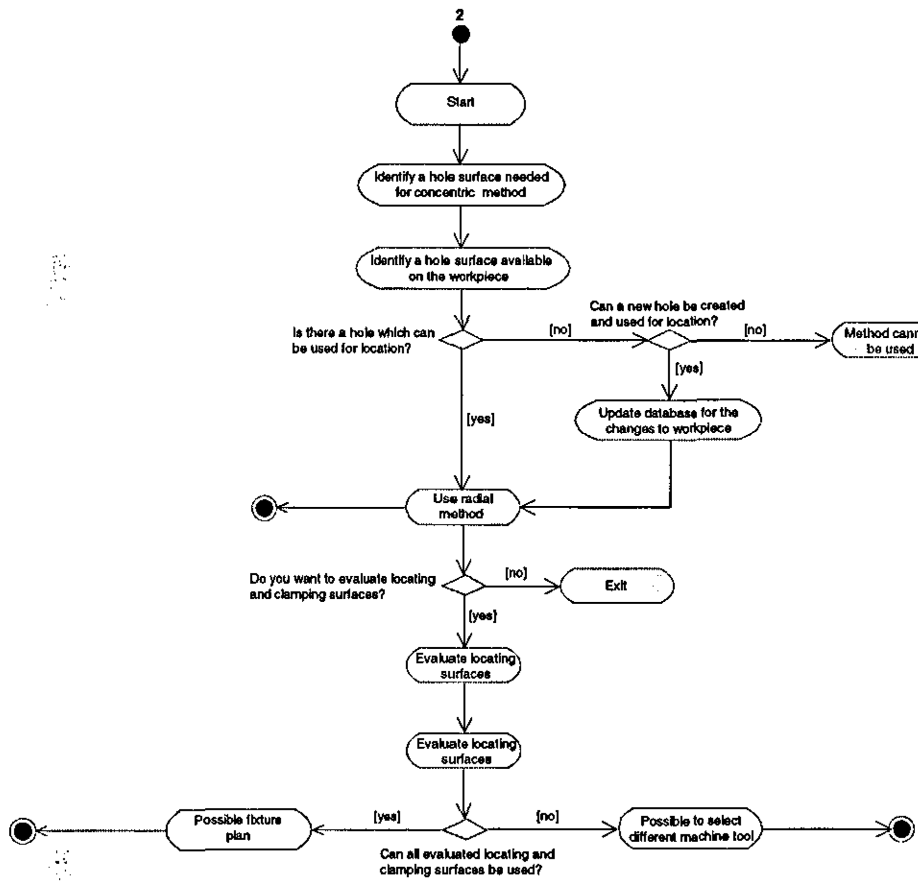


Figure 6.12 – Check the Applicability of Concentric Method in UML Activity Diagram for Support Process Planning Application

To illustrate this method, a prismatic workpiece has been used to show how this application utilised the fixturing information stored in the models. This support process planning will use the same workpiece example found in Figure 6.6. The two variations on a workpiece at (A) one hole is reamed can be used for location and following the activity diagram in Figure 6.12, the concentric method is applied. The variation on a workpiece at (B) suggests changes to workpiece in order concentric method can be applied. If the evaluated locating and clamping surfaces can be used the support planning application will give advice to the user for a possible fixture plan and if the evaluated locating and clamping surfaces cannot be used, the application will advice to the user for a possible to select different machine tool.

Figure 6.13 shows the details of the "Check the Applicability of 3-2-1 Method" activity diagram for support process planning application. The activity sequence from the support product design application for the 3-2-1 method is repeated until it reached the "Use 3-2-1 method" activity where a decision point "Do you want to evaluate locating and clamping surfaces", which the user provides the answer to this particular decision point and if the answer is "yes" it goes to the "Evaluate locating surfaces" activity and then followed by "Evaluate clamping surfaces" activity. If the answer is "no" it will "Exit" and back to the main window. Then another decision point, "Can all evaluated locating and clamping surfaces be used", which the support process planning application provides the answer and if the response is "yes" it will give advice for a "Possible fixture plan" and if the answer is "no" it will give advice for a "Possible to select different machine tool". The activity diagram of "Check the Applicability of 3-2-1 Method" for support process planning application shows that it has three main outputs; one being the "Use 3-2-1 method" and second is the "Possible fixture plan" and third is the "Possible to select different machine tool".

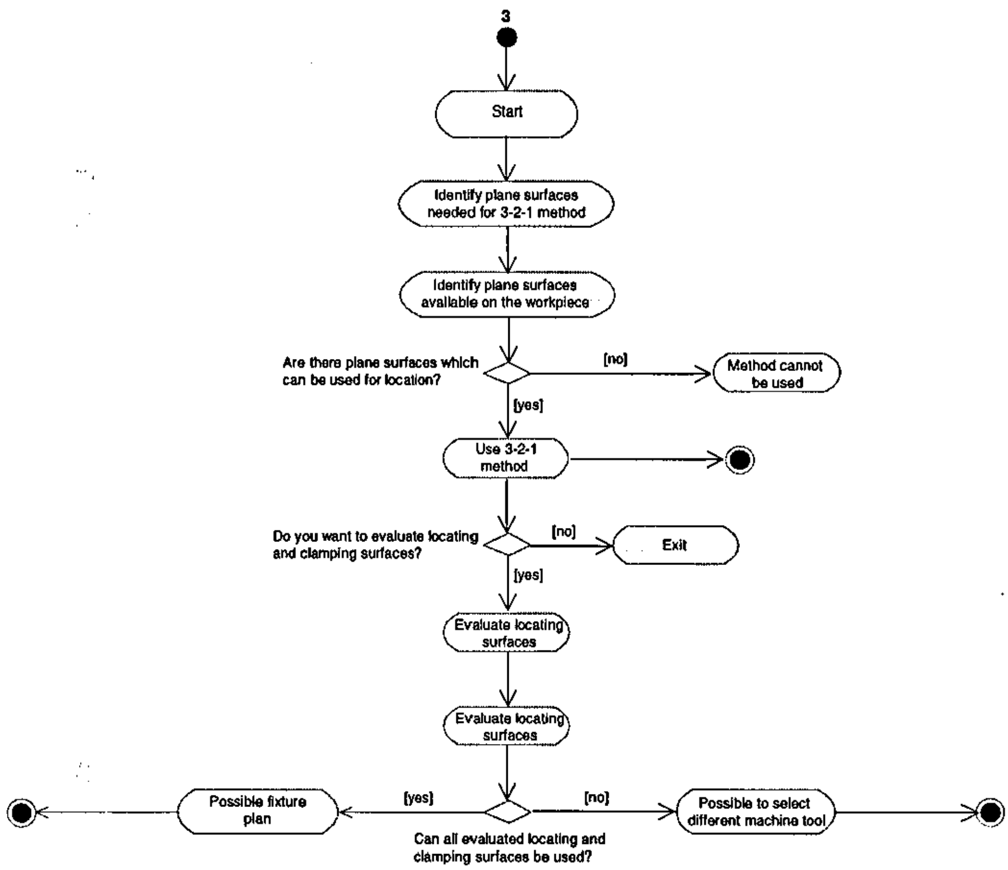


Figure 6.13 – Check the Applicability of 3-2-1 Method in UML Activity Diagram for Support Process Planning Application

To demonstrate this method described above, a prismatic workpiece has been used to show how this application utilised the fixturing information stored in the models. This support process planning will use the same prismatic workpiece example found in Figure 6.8. The prismatic workpiece has no hole that can be used for location and following the activity diagram in Figure 6.13 the 3-2-1 method is applied. If the evaluated locating and clamping surfaces can be used the support planning application will give advice to the user for a possible fixture plan and if the evaluated locating and clamping surfaces cannot be used, the application will advice to the user for a possible to select different machine tool.

6.4 Support Fixture Planning

The support fixture planning application is concerned with the selection of the locating surfaces, the clamping surfaces and the fixturing elements. It provides advice to the designer for possible fixturing methods to be used, locating surfaces, clamping surfaces and fixturing elements to be used. This application is supported by the fixturing information captured in the manufacturing model and product model.

Figure 6.14 shows that the support fixture planning application has three main activities, one being the select locating surfaces, second the select clamping surfaces and third the select fixturing elements. These activities require inputs of workpiece information stored in the product model; in particular these are geometry, dimensions/tolerances, feature to be machined, datum and spindle axis direction, locating surfaces and clamping surfaces, because these are the information needed in order to illustrate how the application be able to do the activities. From the manufacturing model the information of the machine tool, locating process and clamping process and modular fixturing elements are needed in these activities.

The modular fixturing elements are based from the Halder Modular Jig and Fixture Systems, (1994) and these selected modular fixturing elements are stored in the manufacturing model in association with the workpiece being utilised to explore this work. This selected modular fixturing elements are discussed in section 5.4.3.2. The author adopted the work of C.H. Chang, (1992) in the selection of the basic modular fixturing elements, which is discussed in section 5.2.2.2.

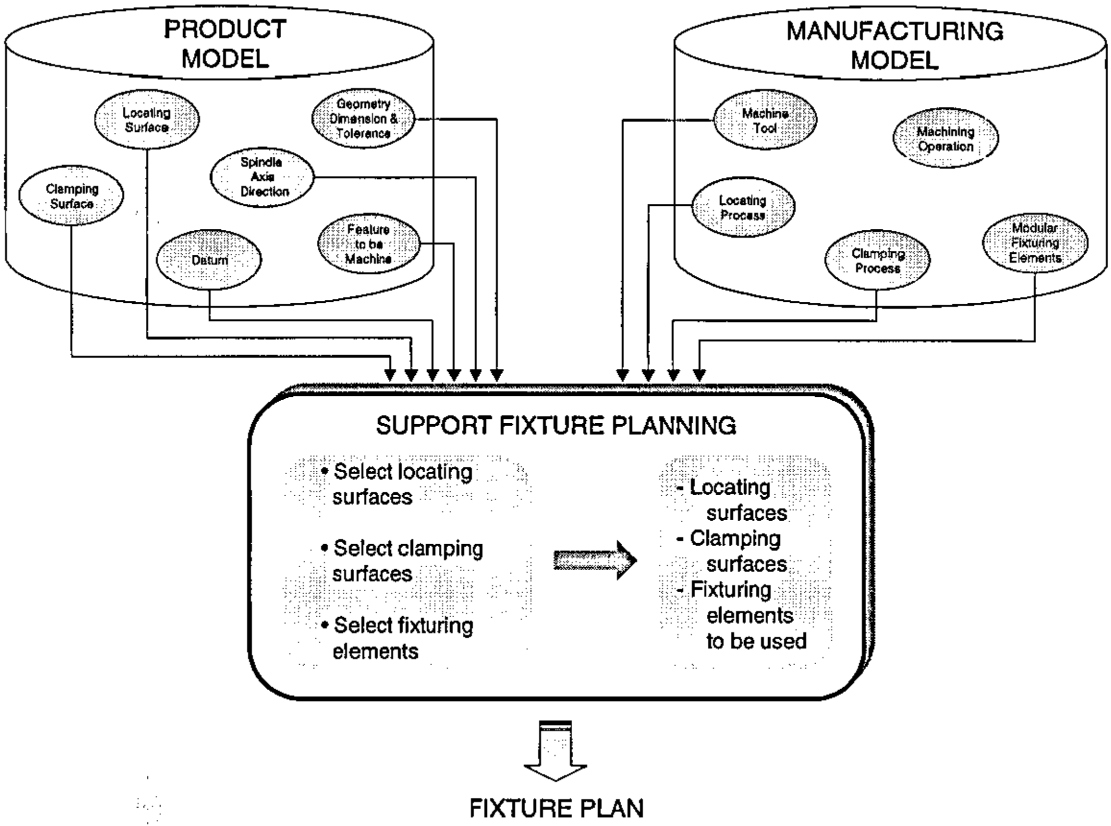


Figure 6.14 – Support Fixture Planning Activities

The locating process, which is discussed in section 5.2.1.1 and clamping process, which is discussed in section 5.2.1.2, are used for the exploration of this application. These fixturing processes have three methods, one being the radial, the second the concentric and third the 3-2-1 and the preferred priority is assumed in that order. This is because to have a decreasing complexity in dealing with the three fixturing methods. The radial method is complex because of the two holes which must be align accurately with its tolerances, the concentric with one hole is less complex than radial and the 3-2-1 that uses only plane surfaces.

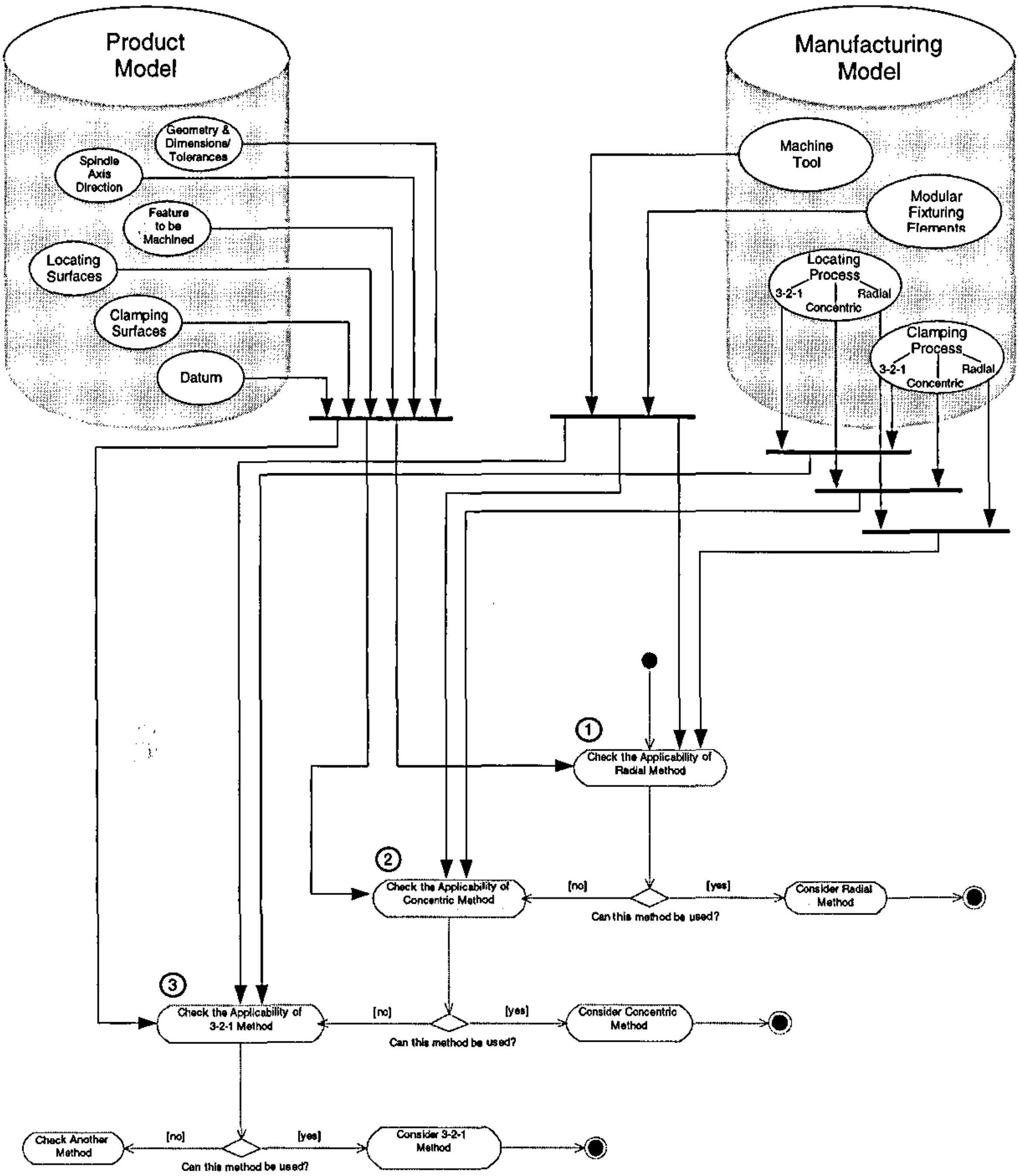


Figure 6.15 – Support Fixture Planning Activities in UML Activity Diagram

The discussions above refer to the high level activity diagram of support product design application and shows that the application is able to use the information in the models. The next paragraphs will present the breakdown of the numbered activities 1, 2 & 3 respectively from Figure 6.15.

Figure 6.15 shows the interactions of the information models and the activity diagram that represents the support fixture planning application. The first activity is "Check the applicability of Radial Method" and extracts information from the product model and information from the manufacturing model and evaluates the applicability of the radial method. The decision point "Can this method be used?" is answered by the support product design application based on the output from the first activity. The breakdown of the activity is shown in Figure 6.16.

If the radial method can be used, the system then through the "Consider radial method" activity identifies the locating and clamping features to be used. However, if the decision point response is negative the system will have on to consider the concentric method. The activity sequence is repeated for the concentric method. Once again if the decision point response is negative the system will have on to consider the 3-2-1 method. The detail's representations for "Check the Applicability of Concentric Method and "Check the Applicability of 3-2-1 Method are shown in Figure 6.18 and Figure 6.23 respectively.

Figure 6.16 shows the details of the "Check the Applicability of Radial Method" activity diagram for support fixture planning application. The activity sequence from the support product design application for the radial method is repeated until it reached the "Use radial method" activity where a decision point "Do you want to select locating, clamping surfaces and fixturing elements?", which the user provides the answer to this particular decision point and if the answer is "yes" it goes to the "Select locating surfaces" activity, then followed by "Select clamping surfaces" activity and the "Select fixturing elements" activity. If the answer is "no" it will "Exit" and back to the main window. The activity diagram of "Check the Applicability of Radial Method" for support fixture planning application shows that it has three main outputs; one being the "Locating surfaces" and second is the "Clamping surfaces" and third is the "Fixturing elements to be used". Each of these activities is highlighted with numbers and letters for breakdown to show the details in the succeeding paragraphs.

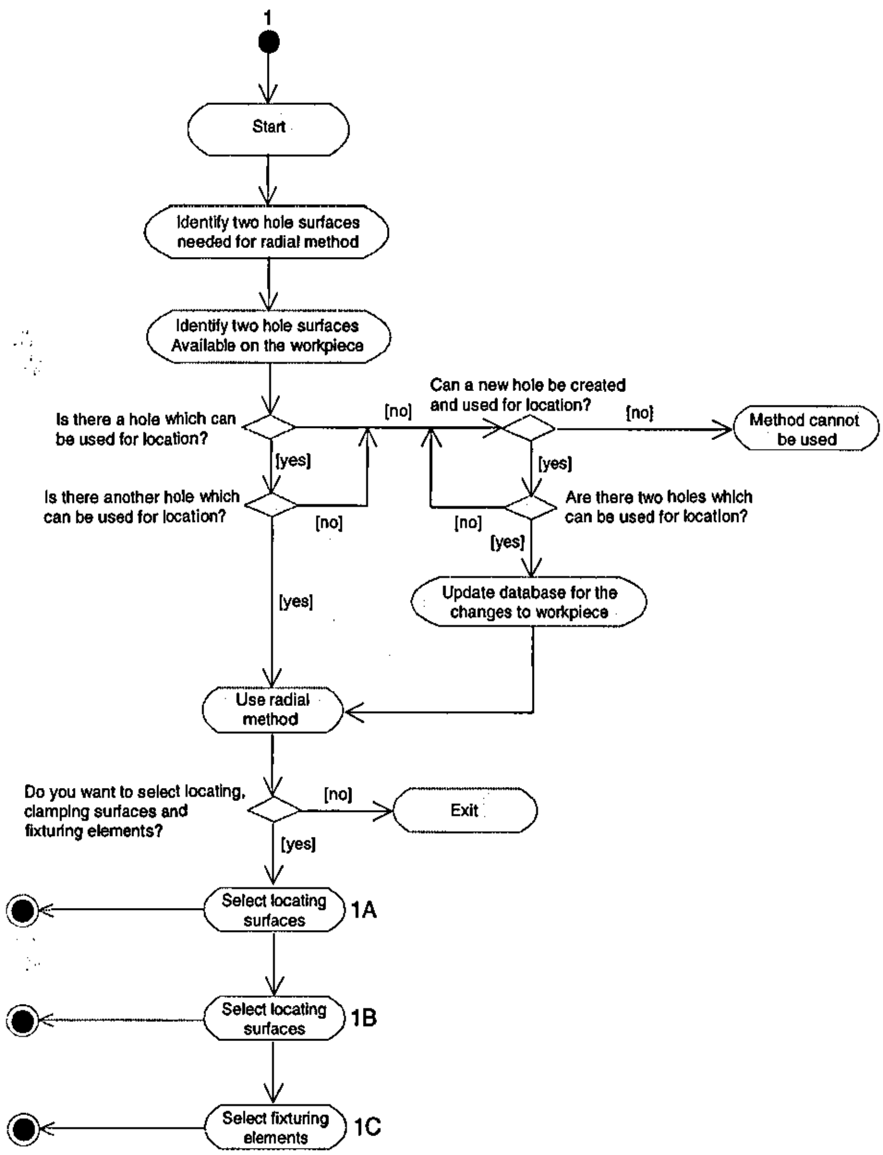


Figure 6.16 – Check the Applicability of Radial Method in UML Activity Diagram for Support Fixture Planning Application

Figure 6.17 illustrates the detail of "1A", an activity to "Select Locating Surfaces" for radial method. The figure shows the sequential activities of "Select Primary Locating Surface", "Select Secondary Locating Surface" and "Select Tertiary Locating Surface". To select each of these surfaces, the application will extract the information from the product model.

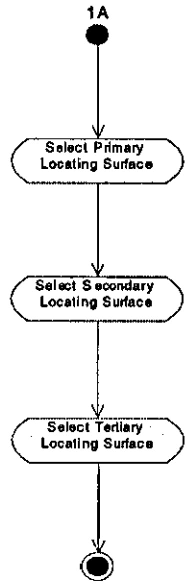


Figure 6.17 – Select Locating Surfaces for Radial Method

Figure 6.18 illustrates the detail of "1B", an activity to "Select Clamping Surfaces" for radial method. The figure shows the sequential activities of "Select Primary Clamping Surface", "Select Secondary Clamping Surface" and "Select Tertiary Clamping Surfaces". To select each of these surfaces, the application will extract the information from the product model.

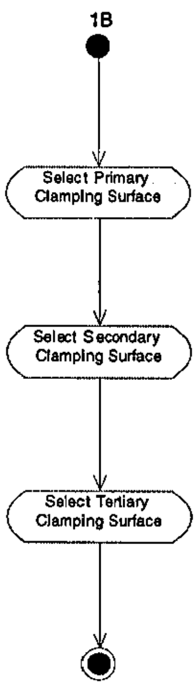


Figure 6.18 – Select Clamping Surfaces for Radial Method

Figure 6.19 illustrates the detail of "1C", an activity to "Select Modular Fixturing Elements" for radial method. The figure shows the sequential activities of "Select Base Plate", "Select Center Bolt" and Select Rest Button". To select each of these fixturing elements, the application will extract the information from the manufacturing model.

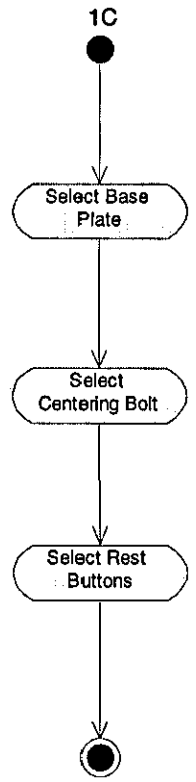
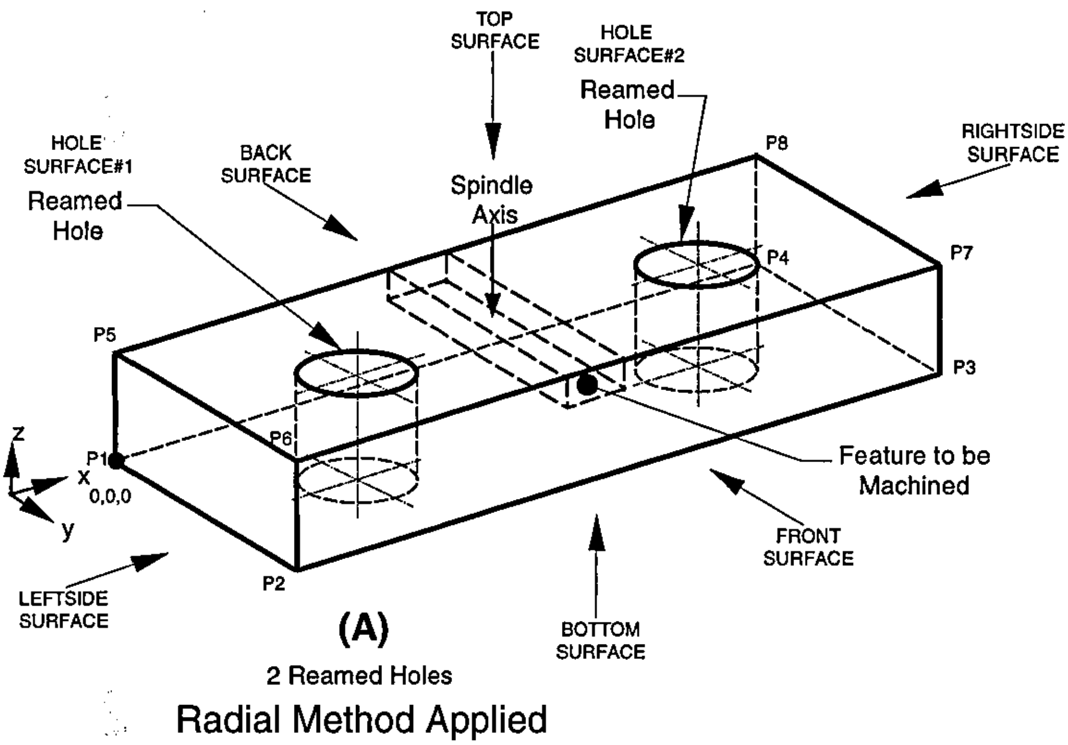


Figure 6.19 – Select Modular Fixturing Elements for Radial Method

To illustrate this method, a prismatic workpiece has been used to show how this application utilised the fixturing information stored in the models. This support fixture planning will use the same workpiece example found in Figure 6.4. The three variations on a workpiece at (A) two holes are reamed can be used for location and following the activity diagram in Figure 6.16, the radial method is applied. The variations on the workpiece at (B) and (C) suggest changes to the workpiece in order that the radial method can be applied. The variation on a workpiece at (A) will be used to show the selection of the locating surfaces, clamping surfaces and the selection of the modular fixturing elements for radial method.



LOCATING SURFACES:	
Primary Locating Surface	BOTTOM SURFACE
Secondary Locating Surface	HOLE_SURFACE#1
Tertiary Locating Surface	HOLE_SURFACE#2
CLAMPING SURFACES:	
Primary Clamping Surface	TOP_SURFACE
Secondary Clamping Surface	HOLE_SURFACE#1
Tertiary Clamping Surface	HOLE_SURFACE#2
MODULAR FIXTURING ELEMENTS:	
Base Plate	BASEPLATE_REF#
Centering Bolt	CENTERINGBOLT_REF#
Rest Buttons	RESTBUTTONS_REF#

Figure 6.17 – Prismatic Workpiece in Selecting Locating and Clamping Surfaces and Fixturing Elements for Radial Method

Figure 6.18 shows the details of the "Check the Applicability of Concentric Method" activity diagram for support fixture planning application. The activity sequence from the support product design application for the concentric method is repeated until it reached the "Use concentric method" activity where a decision point "Do you want to select locating, clamping surfaces and fixturing elements", which the user provides the answer to this particular decision point and if the answer is "yes" it goes to the "Select locating surfaces" activity, then followed by "Select clamping surfaces" activity and the "Select fixturing elements" activity. If the answer is "no" it will "Exit" and back to the main window. The activity diagram of "Check the Applicability of Concentric Method" for support fixture planning application shows that it has three main outputs; one being the "Locating surfaces" and second is the "Clamping surfaces" and third is the "Fixturing elements to be used".

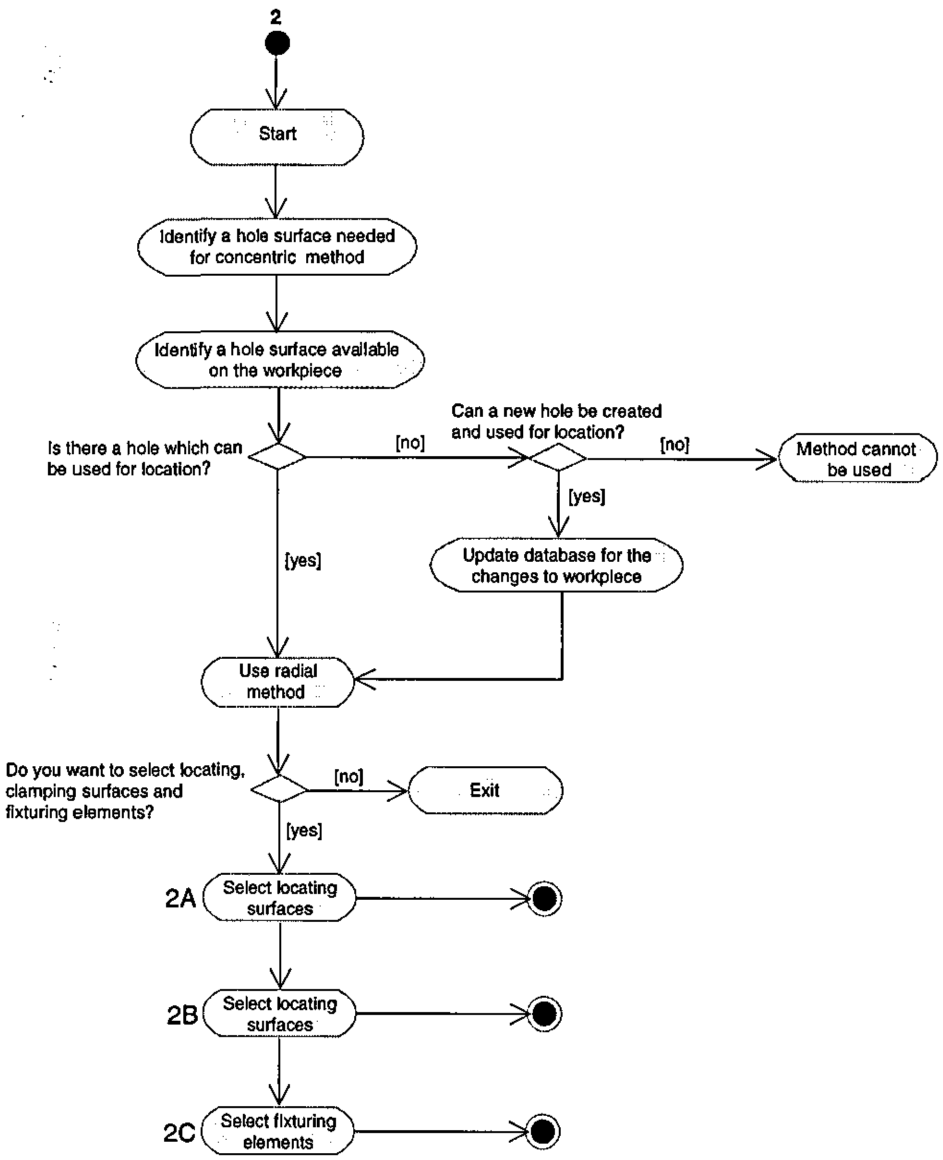


Figure 6.18 – Check the Applicability of Concentric Method in UML Activity Diagram for Support Fixture Planning Application

Figure 6.19 illustrates the detail of "2A", an activity to "Select Locating Surfaces" for concentric method. The figure shows the sequential activities of "Select Primary Locating Surface", "Select Secondary Locating Surface" and "Select Tertiary Locating Surface". To select each of these surfaces, the application will extract the information from the product model.

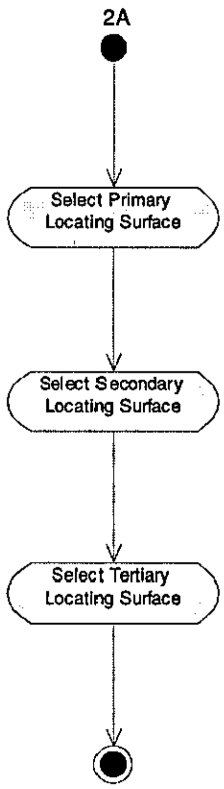


Figure 6.19 – Select Locating Surfaces for Concentric Method

Figure 6.20 illustrates the detail of "2B", an activity to Select Clamping Surfaces" for concentric method. The figure shows the sequential activities of "Select Primary Clamping Surface", "Select Secondary Clamping Surface" and "Select Tertiary Clamping Surfaces". To select each of these surfaces, the application will extract the information from the product model.

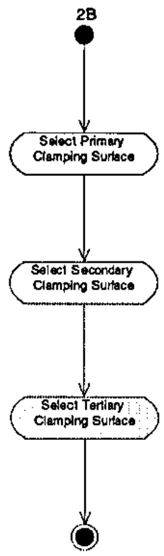


Figure 6.20 – Select Clamping Surfaces for Concentric Method

Figure 6.21 illustrates the detail of "2C", an activity to "Select Modular Fixturing Elements" for concentric method. The figure shows the sequential activities of "Select Base Plate", "Select Center Bolt", "Select Locating Pin", "Select Rest Buttons" and "Select Down Hold Clamp". To select each of these fixturing elements, the application will extract the information from the manufacturing model.

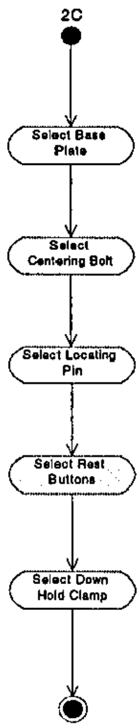
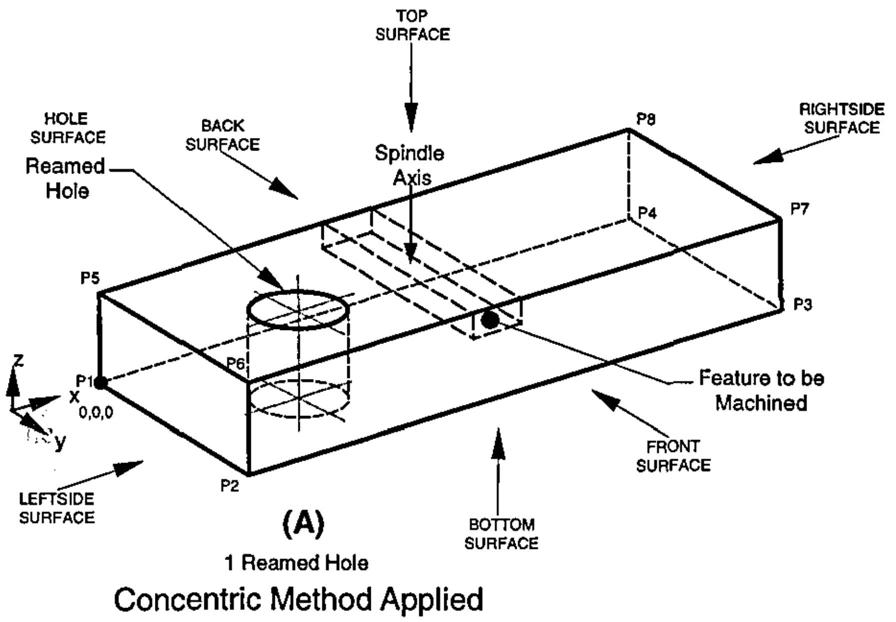


Figure 6.21 – Select Modular Fixturing Elements for Concentric Method

To demonstrate this method, a prismatic workpiece has been used to show how this application utilised the fixturing information stored in the models. This support fixture planning will use the same workpiece example found in Figure 6.6. The two variations on a workpiece at (A) one hole is reamed can be used for location and following the activity diagram in Figure 6.18, the concentric method is applied. The variation on the workpiece at (B) suggests changes to workpiece in order concentric method can be applied. The variation on a workpiece at (A) will be used to show the selection of the locating surfaces, clamping surfaces and the selection of the modular fixturing elements for concentric method.



LOCATING SURFACES:	
Primary Locating Surface	BOTTOM SURFACE
Secondary Locating Surface	HOLE_SURFACE
Tertiary Locating Surface	RIGHTSIDE_SURFACE
CLAMPING SURFACES:	
Primary Clamping Surface	TOP_SURFACE
Secondary Clamping Surface	HOLE_SURFACE
Tertiary Clamping Surface	LEFTSIDE_SURFACE
MODULAR FIXTURING ELEMENTS:	
Base Plate	BASEPLATE_REF#
Centering Bolt	CENTERINGBOLT_REF#
Locating Pin	LOCATINGPIN_REF#
Rest Buttons	RESTBUTTONS_REF#
Down Hold Clamp	DOWNHOLDCLAMP_REF#

Figure 6.22 – Prismatic Workpiece in Selecting Locating and Clamping Surfaces and Fixturing Elements for Concentric Method

Figure 6.13 shows the details of the "Check the Applicability of 3-2-1 Method" activity diagram for support fixture planning application. The activity sequence from the support product design application for the 3-2-1 method is repeated until it reached the "Use 3-2-1 method" activity where a decision point "Do you want to select locating, clamping surfaces and fixturing elements?", which the user provides the answer to this particular decision point and if the answer is "yes" it goes to the "Select locating surfaces" activity, then followed by "Select clamping surfaces" activity and the "Select fixturing elements". If the answer is "no" it will "Exit" and back to the main window. The activity diagram of "Check the Applicability of 3-2-1 Method" for support fixture planning application shows that it has three main outputs; one being the "Locating surfaces" and second is the "Clamping surfaces" and third is the "Fixturing elements to be used".

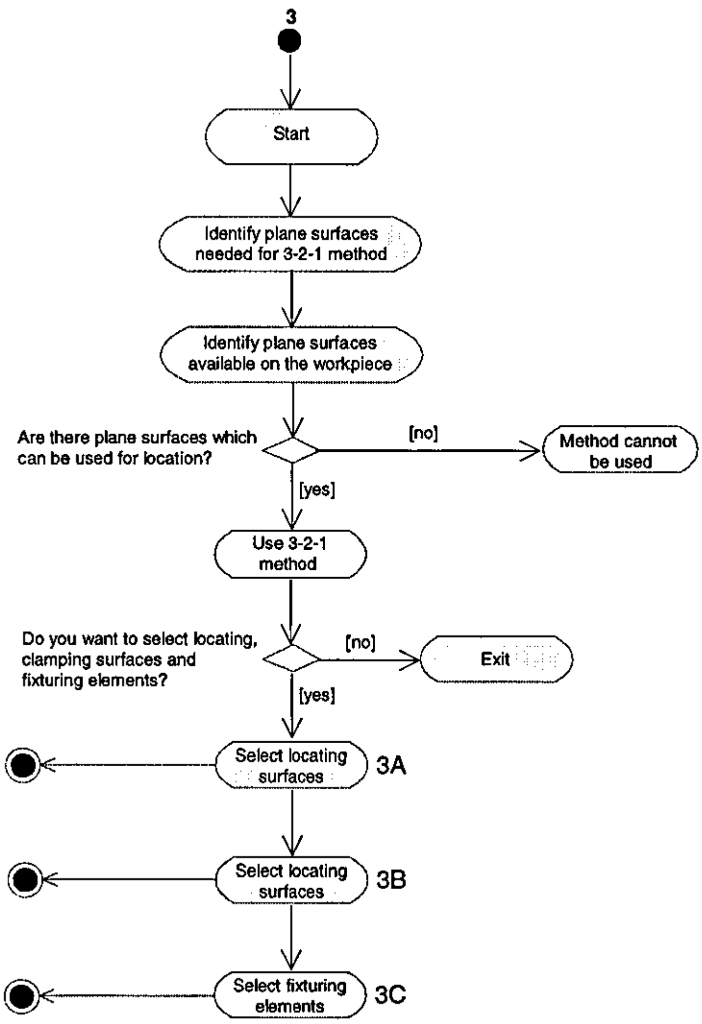


Figure 6.23 – Check the Applicability of 3-2-1 Method in UML Activity Diagram for Support Fixture Planning Application

Figure 6.24 illustrates the detail of "3A", an activity to "Select Locating Surfaces" for 3-2-1 method. This figure shows the sequential activities of "Select Primary Locating Surface", "Select Secondary Locating Surface" and "Select Tertiary Locating Surface". To select each of these surfaces, the application will extract the information from the product model.

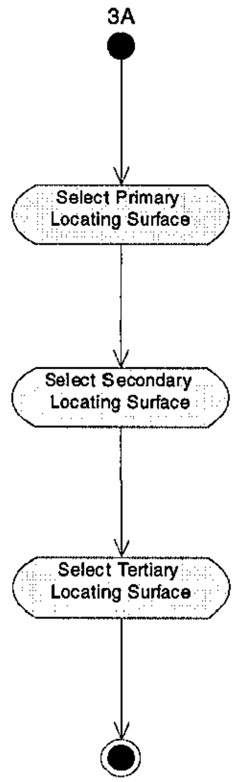


Figure 6.24 – Select Locating Surfaces for 3-2-1 Method

Figure 6.25 illustrates the detail of "3B", an activity to "Select Clamping Surfaces" for 3-2-1 method. This figure shows the sequential activities of "Select Primary Clamping Surface", "Select Secondary Clamping Surface" and "Select Tertiary Clamping Surfaces". To select each of these surfaces, the application will extract the information from the product model.

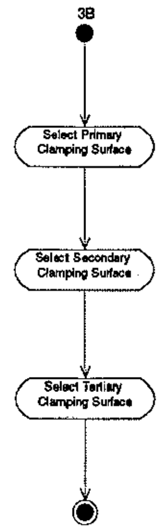


Figure 6.25 – Select Clamping Surfaces for 3-2-1 Method

Figure 6.26 illustrates the detail of "3C", an activity to "Select Modular Fixturing Elements" for 3-2-1 method. The figure shows the sequential activities of "Select Base Plate", "Select Rest Buttons" "Select Locating Pin", and "Select Clamp Element". To select each of these fixturing elements, the application will extract the information from the manufacturing model.

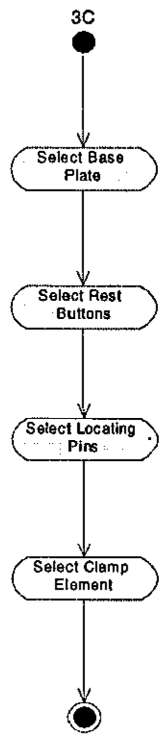
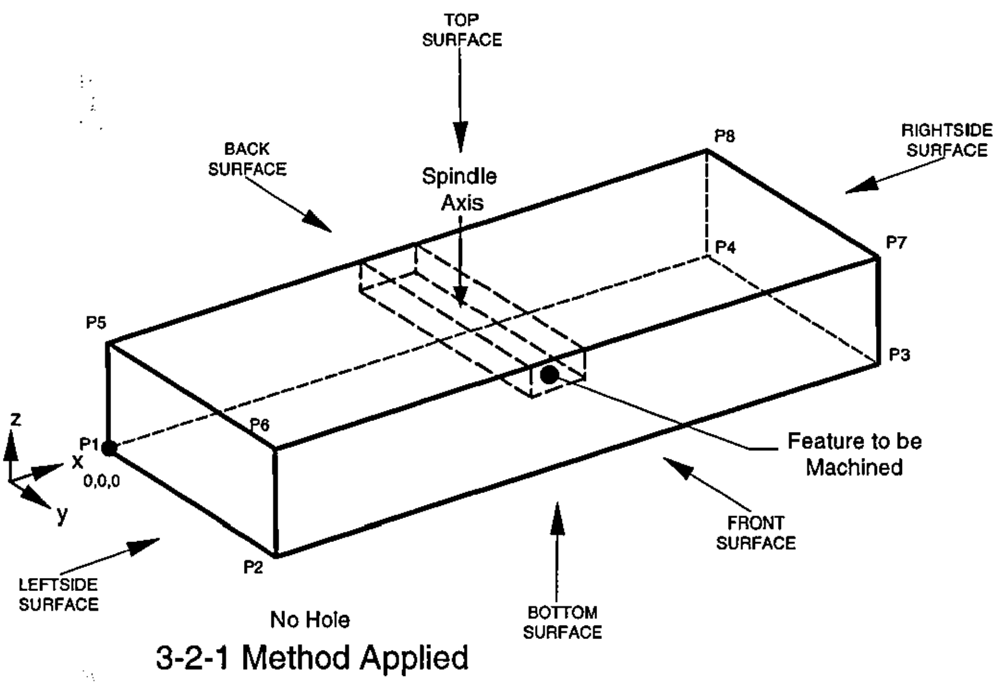


Figure 6.26 – Select Modular Fixturing Elements for 3-2-1 Method

To illustrate this method, a prismatic workpiece has been used to show how this application utilised the fixturing information stored in the models. This support fixture planning will use the same workpiece example found in Figure 6.6. This prismatic workpiece will be used to show the selection of the locating surfaces, clamping surfaces and the selection of the modular fixturing elements for 3-2-1 method, which presented in Figure 6.27.



LOCATING SURFACES:	
Primary Locating Surface	BOTTOM SURFACE
Secondary Locating Surface	BACK_SURFACE
Tertiary Locating Surface	RIGHTSIDE_SURFACE
CLAMPING SURFACES:	
Primary Clamping Surface	TOP_SURFACE
Secondary Clamping Surface	FRONT_SURFACE
Tertiary Clamping Surface	LEFTSIDE_SURFACE
MODULAR FIXTURING ELEMENTS:	
Base Plate	BASEPLATE_REF#
Rest Buttons	RESTBUTTONS_REF#
Locating Pins	LOCATINGPIN_REF#
Clamp Element	CLAMPELEMENT_REF#

Figure 6.27 – Prismatic Workpiece in Selecting Locating and Clamping Surfaces and Fixturing Elements for 3-2-1 Method

Figure 6.28 presents the general activity diagram for checking the applicability of the fixturing methods to be used in the support product design, support process planning and support fixture planning applications. From the figure, the first activity is the "Start" of the checking and then, the second activity is to "Identify the features needed for the fixturing method" and this information is drawn from the manufacturing model. It is followed by the third activity "Identify the features available on the workpiece" and this information is drawn from the product model.

The first decision point, "Are the features needed on the workpiece?" in which the applications provide the answers to the decision point. If the response is "yes", it will go to the fourth activity "Method can be used" and if the response is "no", it goes to the fifth activity "Identify the missing features?". From this activity, the second decision point "Can they be created?" in which the user provides the answer to this decision point. If the response is "yes", it goes to the sixth activity "Update database" and if the response is "no", it goes to the last activity "Method cannot be used".

In order that it can accommodate different fixturing methods and different kind features, the activity diagram should be in a general form as presented in Figure 6.28. As explained above, the fixturing methods and the features are not specific to one particular fixturing method and feature, but illustrated in a general query. However, the present system has to specify the fixturing method to be used and the features needed in order the applications is able to provide information support to particular design and manufacture activities of product design, process planning and fixture planning. This makes a constraint to this present system and it needs to be addressed in the future.

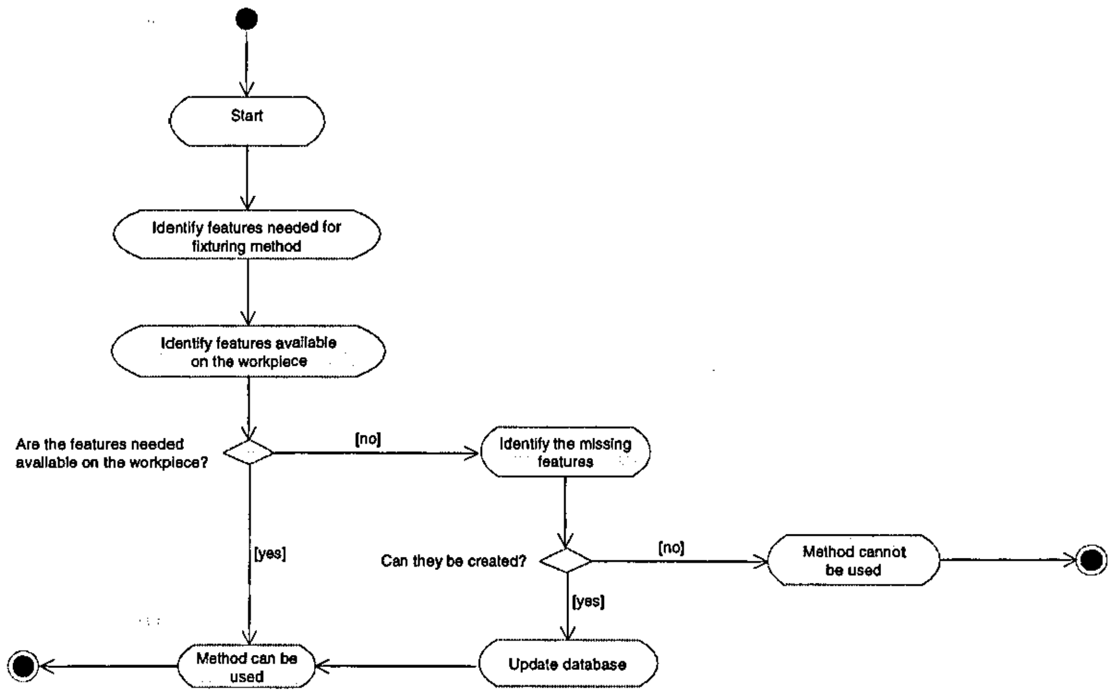


Figure 6.28 – The General Activity Diagram for Checking the Applicability of the Fixturing Methods

The next section discusses the fixturing information sharing across the applications of support product design, support process planning and support fixture planning with the information stored in the information models.

6.5 Fixturing Information Sharing Across the Applications

Figure 6.29 illustrates that the fixturing information models can provide support in design and manufacture activities of support product design, support process planning and support fixture planning of this research concept presented in Chapter 4. The figure shows that each of the applications utilised the information stored in the manufacturing model and product model in order to support these applications.

The utilisation of the information has shown how the structures defined for the product model and manufacturing model are able to support a data driven applications that require a fixturing information such as product design, process planning and fixture planning. Each of these applications is able to use the information stored in the information models. The information of the product related to fixturing, in particular these are "Geometry and Dimensions/Tolerances", "Feature to be Machined", "Spindle Axis Direction", "Datum", "Locating Surfaces" and "Clamping Surfaces" are the information stored in the product model. The information of the fixturing processes and resources, in particular "Locating Processes", "Clamping Processes", "Machining Operation", "Machine Tool" and "Modular Fixturing Elements" are the information stored in the manufacturing model.

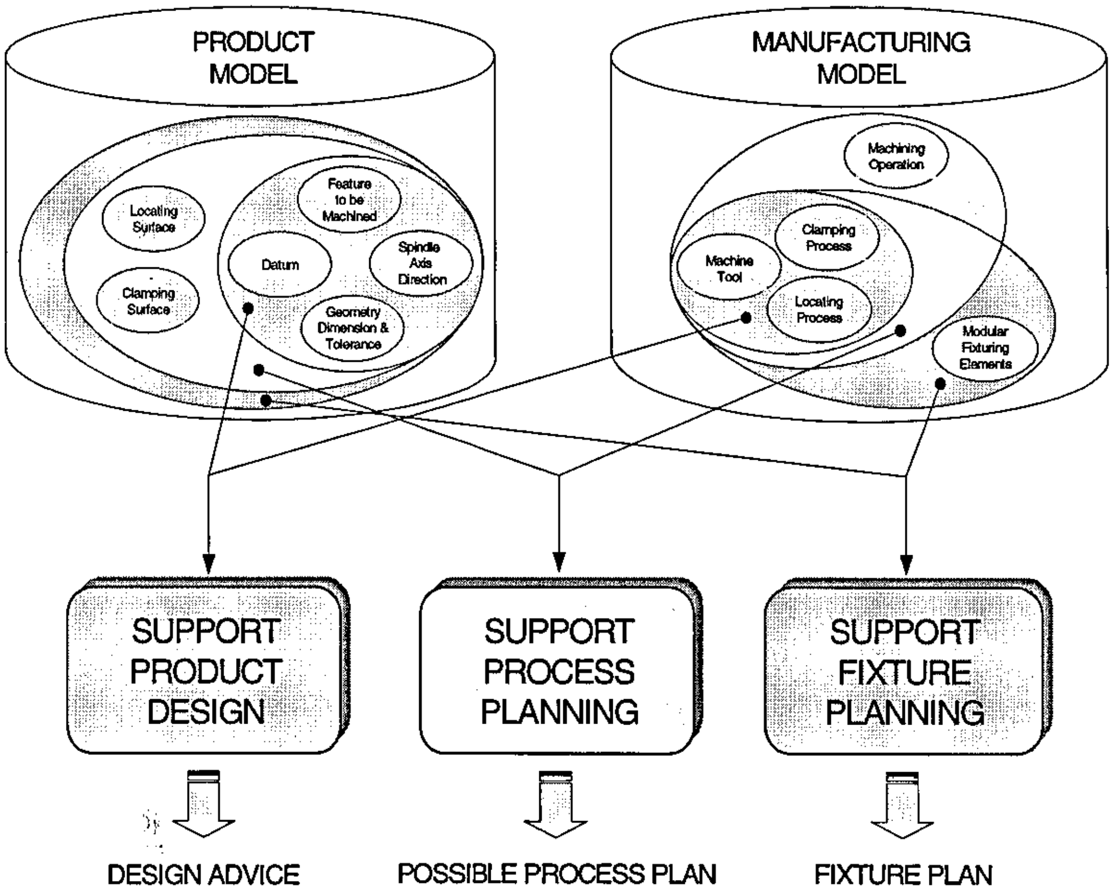


Figure 6.29 – Information Sharing in Design and Manufacture Applications

The design and manufacture applications of "Support Product Design", "Support Process Planning" and "Support Fixture Planning" were able to utilised the same fixturing information stored in the models and produced different outputs. The "Support Product Design" application having two different activities which is to identify (possible) locating surfaces and to identify (possible) clamping surfaces, then extracting the information from the models resulted two outputs and these are; one being the possible locating and clamping methods and second the suggested changes to workpiece.

The "Support Process Planning" application having two different activities which is to evaluate locating surfaces and to evaluate clamping surfaces, then extracting the information from the models resulted three outputs and these are; one being the possible fixture plan, second the suggested changes to machine tool, and third the suggested changes to set-up.

The "Support Fixture Planning" application having three different activities which is to select locating surfaces, to select clamping surfaces and to select fixturing elements, then extracting the information from the models resulted three outputs and these are; one being the locating surfaces, second the clamping surfaces, and third the fixturing elements to be used.

This chapter has presented how the fixturing information models are utilised to support particular design and manufacture applications of support product design, support process planning and support fixture planning. The activities of each application produce different outputs to determine how the workpiece might be located and held effectively. The role of the fixturing information models is to provide support by making the same information available to a range of design and manufacture applications when needed.

The next chapter presents the experimental work performed to assess the value of the approach taken.

Chapter 7

EXPERIMENTAL FIXTURING SYSTEM IMPLEMENTATION

7.1 Introduction

This chapter describes the experimental implementation of the system, which consists of the locating and clamping methods, and the selection of modular fixturing elements, that were conceptually described in Chapter 5. How this information can be utilised to support product design, process planning and design for fixturing were explored conceptually in Chapter 6. Section 7.2 presents the aims and scope of the experimental system as well as the implementation of the information models and the implementation of the user interface that allows the user to interact with the system. Section 7.3 focuses on the utilisation of the information models to support fixture planning and product design applications and section 7.4 is the summary of the chapter.

7.2 The Design and Implementation of the Experimental System

7.2.1 Aims and Scope of the Implementation Work

The experiments performed in this work have been focused on the exploration and definition of the fixturing information model structure and how this information model can provide support to design and manufacture applications. The fixture planning application is the direct beneficiary of the system for which it has the fixturing information stored in the models. Although fixture planning is not independent process and needs input from other applications, the author implemented another application that would take place in the early stage of design and manufacture. Therefore, the implementation of the system is tested in two applications and these are fixture planning and product design for fixturing. The implementation has been aimed at the following:

I. To present the level to which the fixturing information can be captured in a manufacturing model and a product model.

II. To demonstrate that the manufacturing model in conjunction with the product model can provide support to particular design and manufacture applications. These applications were:

   a) Support fixture planning - to generate fixture plan

   b) Support product design – to provide design advice for suggested changes to workpiece

The product geometry used in the experiments is prismatic workpieces in rectangular block form with all dimensions in millimetres.

7.2.2 Implementation of the Product Model

7.2.2.1 The General Description of the Implementation

The product fixturing information was implemented in accordance with the definition discussed in section 5.5.

Figure 7.1 illustrates the three prismatic workpieces as examples used for the exploration in this research. Figure 7.1(01) shows a prismatic workpiece in a rectangular form and all the surfaces have been already machined. The workpiece is to be drilled and reamed at the center. This prismatic workpiece is used to illustrate how support fixture planning able to use the 3-2-1 fixturing method stored in the manufacturing model in conjunction with the product model to result a fixture plan for this work-piece.

Figure 7.1(02) shows a prismatic workpiece in a rectangular form, which all the surfaces have been already machined. The workpiece has existing hole feature that is reamed. This reamed hole located at the center is used for location in milling a step feature in both ends of the workpiece. This prismatic workpiece is used to illustrate how support fixture planning able to use the concentric fixturing method stored in the manufacturing model in conjunction with the product model to result fixture plan for this workpiece.

Figure 7.1(03) presents a prismatic workpiece in a rectangular form, which is the top and bottom surfaces are already machined. The workpiece has existing two holes; one is a reamed hole and the other is a drilled hole. Two reamed holes are needed for location in order the four side surfaces of the workpiece can be milled. This prismatic workpiece is used to illustrate how support product design able to use the radial fixturing method stored in the manufacturing model in conjunction with the product model to result a design advice for suggested changes to workpiece.

(01)

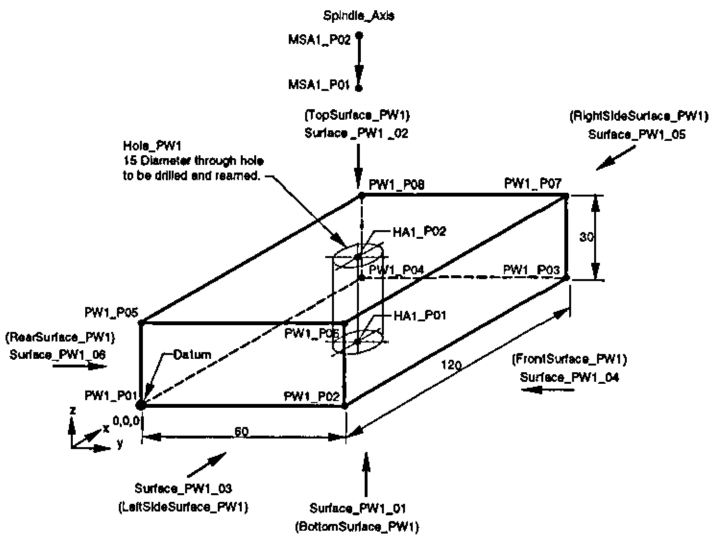
Prismatic_Workpiece_01:

Condition: - Finished surface requirements on all six surfaces.

Operation: - Drilling and reaming on a 15 diameter through hole.

Length: 120
Width: 60
Thickness: 30

PW1_P01 (x,y,z): 0,0,0
PW1_P02 (x,y,z): 0,60,0
PW1_P03 (x,y,z): 120,60,0
PW1_P04 (x,y,z): 120,0,0
PW1_P05 (x,y,z): 0,0,30
PW1_P06 (x,y,z): 0, 60,30
PW1_P07 (x,y,z): 120,60,30
PW1_P08 (x,y,z): 120,0,30



(02)

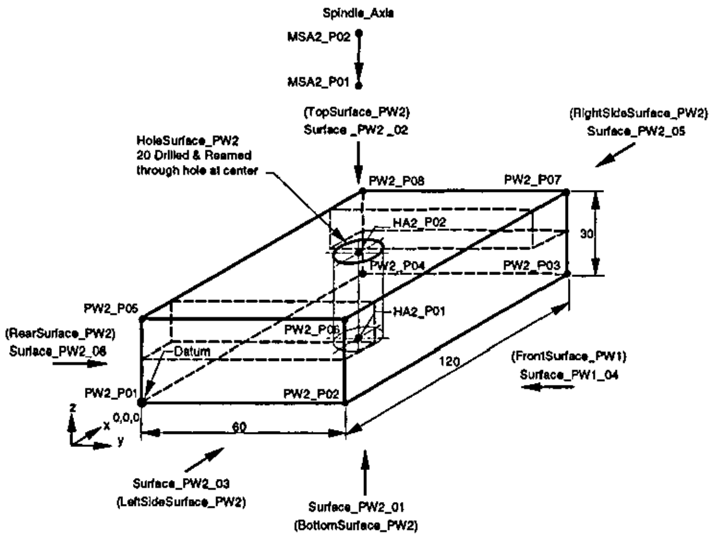
Prismatic_Workpiece_02:

Condition: - Finished surface requirements on all six surfaces.
- Existing hole: drilled and reamed

Operation: - Milling both ends on top surface

Length: 120
Width: 60
Thickness: 30

PW2_P01 (x,y,z): 0,0,0
PW2_P02 (x,y,z): 0,60,0
PW2_P03 (x,y,z): 120,60,0
PW2_P04 (x,y,z): 120,0,0
PW2_P05 (x,y,z): 0,0,30
PW2_P06 (x,y,z): 0, 60,30
PW2_P07 (x,y,z): 120,60,30
PW2_P08 (x,y,z): 120,0,30



(03)

Prismatic_Workpiece_03:

Condition: - Finished surface requirements on surfaces 01 & 02.
- Existing holes:
Hole1 - drilled and reamed
Hole2 - drilled

Operation: - Milling the four surfaces: PW3_P03, PW3_P04, PW3_P05 & PW3_P06

Length: 120
Width: 60
Thickness: 30

PW3_P01 (x,y,z): 0,0,0
PW3_P02 (x,y,z): 0,60,0
PW3_P03 (x,y,z): 120,60,0
PW3_P04 (x,y,z): 120,0,0
PW3_P05 (x,y,z): 0,0,30
PW3_P06 (x,y,z): 0, 60,30
PW3_P07 (x,y,z): 120,60,30
PW3_P08 (x,y,z): 120,0,30

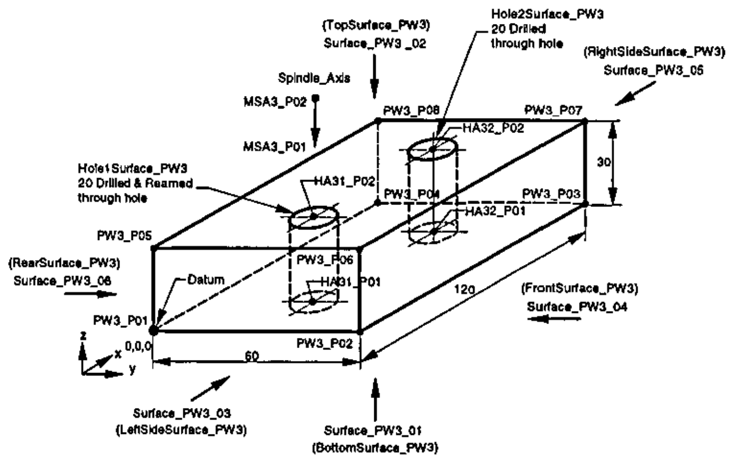


Figure 7.1 – The Prismatic Workpieces

The geometry definition of a prismatic workpiece is complex and must be analysed in a three-dimensional space. Figure 7.1 explores the example of prismatic workpieces where it is necessary to define the geometric points in order to determine its geometric shape. Therefore, geometric points have defined the surfaces of a prismatic workpiece. In Figure 7.1(01), to get the "BottomSurface_PW1" of this prismatic workpiece, it is defined by the following geometric points with their coordinates: PW1_P01 (0,0,0), PW1_P02 (0,60,0), PW1_P03 (120,60,0) and PW1_P04 (120,0,0). With the structure defined in UML class diagram in section 5.5.2, this allows the author to present the workpiece in the product model.

7.2.2.2 The Product Workpiece

The product workpiece implementation was based on a prismatic workpiece, which was conceptually explored in section 5.5 and represented by UML class diagrams. Each of the class has it own structure and all were implemented. Figure 7.2 illustrates in detail an example of the class structure of the class workpiece (WORKPIECE). The figure shows the structure of each class can be divided into four distinct parts which are represented in the figure by region "1", "2", "3" and "4".

The region "1" is used for naming and defining the type of class and whether if the class is a child of another class. The region "2" is used for defining the attributes of the class such as name, description and others. The values given to these attributes define the state of particular objects. The region "3" is used for defining the types of relationships between this class and other classes associated with it. The region "4" is used for declaring the member functions that will be called by different instances during the run time of the systems.

The class is defined in terms of its attributes and its association with other related classes. The attributes represent the identification of the class such as name, description and other information such as co-ordinates of lines and points. Association represents relationships with other classes such as surface can have one or many locating and clamping surfaces. Generalisation represents the inheritance of a class such as primary locating surface class inherits from the locating surface class The geometric information the product should be generated by a computer aided design system integrated with an application. However, developing this interface with a computer aided design system is not part of this research and assumed the information used has been generated in an integrated system.

(1)

```
#endif_WORKPIECE
#define_WORKPIECE
class WORKPIECE: public WORKPIECE

{
```

(2)

```
public:
      // Attributes
      odb_String                workpiece_name;
      odb_String                workpiece_mat_name;
      odb_String                workpiece_description;
      float                     length;
      float                     width;
      float                     height;
```

(3)

```
odb_List< odb_Ref<HOLE_FEATURE> > list_of_hole_feature inverse HOLE_FEATURE::associated_workpiece;
Inverse_odb_List(HOLE_FEATURE,associated_workpiece,odb_List) list_of_hole_feature;
odb_List< odb_Ref<SURFACE> > list_of_surfaces;  // inverse SURFACE::associated_workpiece;
odb_Ref<MACHINE_SPINDLE> an_associated_machine_spindle inverse MACHINE_SPINDLE::an_associated_workpiece;
Inverse_odb_Ref(MACHINE_SPINDLE,an_associated_workpiece,odb_Ref) an_associated_machine_spindle;
odb_List< odb_Ref<LOCATING_SURFACE> > list_of_locating_surfaces inverse LOCATING_SURFACE::associated_workpiece;
Inverse_odb_List(LOCATING_SURFACE,associated_workpiece,odb_List) list_of_locating_surfaces;
odb_List< odb_Ref<CLAMPING_SURFACE> > list_of_clamping_surfaces inverse CLAMPING_SURFACE::associated_workpiece;
Inverse_odb_List(CLAMPING_SURFACE,associated_workpiece,odb_List) list_of_clamping_surfaces;
odb_List< odb_Ref<MODULAR_FIXTURE> > list_of_fix_elem inverse MODULAR_FIXTURE::assoc_workpiece;
Inverse_odb_List(MODULAR_FIXTURE,assoc_workpiece,odb_List) list_of_fix_elem;
```

(4)

```
public:
      // constructor, destructor and operators
      WORKPIECE();
      WORKPIECE(const WORKPIECE &a);
      WORKPIECE(const char* name);
      ~WORKPIECE();
      WORKPIECE& operator=(WORKPIECE &a);
      int operator == (const WORKPIECE &a);
      odb_String get_workpiece_name();
      odb_String get_workpiece_mat_name();
      odb_String get_workpiece_description();
      float get_length_value();
      float get_width_value();
      float get_height_value();
      void put_workpiece_name(char* a_workpiece_name);
      void put_workpiece_mat_name(char* a_workpiece_mat_name);
      void put_workpiece_description(char* a_workpiece_description);
      void put_length_value(float a_length_value);
      void put_width_value(float a_width_value);
      void put_height_value(float a_height_value);
      int get_all_names(int* num_of_objects, int max_num_of_strings, char str_array[] [40]);
      odb_Ref<WORKPIECE> GetWorkpiecePointer(char* a_name);
      int hole_exist(void);
```

```
#ifndef __cctoddl
 PERSISTENT_END
#endif
};
```

Figure 7.2 – Product Workpiece Structure

7.2.3 Implementation of the Manufacturing Model

7.2.3.1 The General Descriptions of the Implementation

The fixturing processes and fixturing resources were implemented in accordance with the definition discussed in section 5.4. The manufacturing model structure of fixturing information is presented using the UML class diagrams. This provided the basis for the implementation of the manufacturing model using object-oriented programming in C++.

7.2.3.2 The Fixturing Processes

Figure 7.3 illustrates an example of the head files of fixturing process and its "cxx" sources file. The fixturing process is implemented based in accordance with definition explored in section 5.4.2.

The "LOCATING_PROCESS" and "CLAMPING_PROCESS" are having three different methods of locating and clamping and these are; 3-2-1 method, concentric method and the radial method. The figure also presented the class implementation of these methods. The locating process is having the "3-2-1_LOCATING_METHOD" class, "CONCENTRIC_LOCATING_METHOD" class and the RADIAL_LOCATING_METHOD" class, while the clamping process is having the "CLAMPING_3-2-1_METHOD" class, "CLAMPING_CONCENTRIC_METHOD class and the "CLAMPING_RADIAL_METHOD" class. The methods have been defined in each class to capture the capability of the process and to ensure that the fixturing processes can provide a support to design and manufacture activities in particular to support fixture planning and support product design applications.

```
#endif_FIXTURING_PROCESS
#define_FIXTURING_PROCESS
class FIXTURING_PROCESS: public odb_Persistent_Object
{
public:
        // Attributes
        odb_Stringproc_description;
        odb_Ref<SURFACE> associated_surface;  // inverse SURFACE::clamping_surface;
        odb_Ref<WORKPIECE> associated_workpiece inverse WORKPIECE::list_of_clamping_surfaces;
        odb_Ref<MODULAR_FIXTURE> assoc_fixture inverse
public:
        // constructor, destructor and operators
        FIXTURING_PROCESS();
        FIXTURING_PROCESS(const FIXTURING_PROCESS &a);
        FIXTURING_PROCESS(const char* name);
        ~FIXTURING_PROCESS();
        FIXTURING_PROCESS& operator=(FIXTURING_PROCESS &a);
        int operator == (const FIXTURING_PROCESS &a);
        odb_String get_proc_description();
        void put_proc_description(char* a_proc_description);
#ifndef __cctoddl
  PERSISTENT_END
#endif
};

#endif_LOCATING_PROCESS
#define_LOCATING_PROCESS
class LOCATING_PROCESS: public FIXTURING_PROCESS
{
public:
        // Attributes
        odb_String              loc_proc_name;
public:
        // constructor, destructor and operators
        LOCATING_PROCESS();
        LOCATING_PROCESS(const LOCATING_PROCESS &a);
        LOCATING_PROCESS(const char* name);
        ~LOCATING_PROCESS();
        LOCATING_PROCESS& operator=(LOCATING_PROCESS &a);
        int operator == (const LOCATING_PROCESS &a);
        odb_String get_loc_proc_name();
        void put_loc_proc_name(char* a_loc_proc_name);
#ifndef __cctoddl
  PERSISTENT_END
#endif
};

class 3-2-1_LOCATING_METHOD: public LOCATING_PROCESS
{
public:
        // Attributes
        odb_String              loc_proc_name;

public:
        // constructor, destructor and operators
        3-2-1_LOCATING_METHOD();
        3-2-1_LOCATING_METHOD(const 3-2-1_LOCATING_METHOD &a);
        3-2-1_LOCATING_METHOD(const char* name);
        ~3-2-1_LOCATING_METHOD();
        3-2-1_LOCATING_METHOD& operator=(3-2-1_LOCATING_METHOD &a);
        int operator == (const 3-2-1_LOCATING_METHOD &a);
        odb_String get_loc_proc_name();
        void put_loc_proc_name(char* a_loc_proc_name);

#ifndef __cctoddl
  PERSISTENT_END
#endif
};

class CONCENTRIC_LOCATING_METHOD: public LOCATING_PROCESS
{
public:
        // Attributes
        odb_String              loc_proc_name;

public:
        // constructor, destructor and operators
        CONCENTRIC_LOCATING_METHOD();
        CONCENTRIC_LOCATING_METHOD(const CONCENTRIC_LOCATING_METHOD&a);
        CONCENTRIC_LOCATING_METHOD(const char* name);
        ~CONCENTRIC_LOCATING_METHOD();
        CONCENTRIC_LOCATING_METHOD& operator=(CONCENTRIC_LOCATING_METHOD&a);
        int operator == (const CONCENTRIC_LOCATING_METHOD&a);
        odb_String get_loc_proc_name();
        void put_loc_proc_name(char* a_loc_proc_name);

#ifndef __cctoddl
  PERSISTENT_END
#endif
};

class RADIAL_LOCATING_METHOD: public LOCATING_PROCESS
{
public:
        // Attributes
        odb_String              loc_proc_name;

public:
        // constructor, destructor and operators
        RADIAL_LOCATING_METHOD();
        RADIAL_LOCATING_METHOD(const RADIAL_LOCATING_METHOD &a);
        RADIAL_LOCATING_METHOD(const char* name);
        ~RADIAL_LOCATING_METHOD();
        RADIAL_LOCATING_METHOD& operator=(RADIAL_LOCATING_METHOD&a);
        int operator == (const RADIAL_LOCATING_METHOD&a);
        odb_String get_loc_proc_name();
        void put_loc_proc_name(char* a_loc_proc_name);

#ifndef __cctoddl
  PERSISTENT_END
#endif
};

#endif_CLAMPING_PROCESS
#define_CLAMPING_PROCESS
class CLAMPING_PROCESS: public FIXTURING_PROCESS
{
public:
        // Attributes
        odb_Stringclam_proc_name;
public:
        // constructor, destructor and operators
        CLAMPING_PROCESS();
        CLAMPING_PROCESS(const CLAMPING_PROCESS &a);
        CLAMPING_PROCESS(const char* name);
        ~CLAMPING_PROCESS();
        CLAMPING_PROCESS& operator=(CLAMPING_PROCESS &a);
        int operator == (const CLAMPING_PROCESS &a);
        odb_String get_clam_proc_name();
        void put_clam_proc_name(char* a_clam_proc_name);
#ifndef __cctoddl
  PERSISTENT_END
#endif
};
```

FIXTURING_PROCESS.cxx

```
#include "stdafx.h"
#include <udefs.h>
#include "pris_work.hxx"

FIXTURING_PROCESS::FIXTURING_PROCESS()
{
}

FIXTURING_PROCESS::FIXTURING_PROCESS(const FIXTURING_PROCESS &a)
{
}

FIXTURING_PROCESS::FIXTURING_PROCESS(const char* name)
{
}

FIXTURING_PROCESS::~FIXTURING_PROCESS()
{
}

FIXTURING_PROCESS& FIXTURING_PROCESS::operator=(FIXTURING_PROCESS &a)
{
        return(a);
}

int FIXTURING_PROCESS::operator == (const FIXTURING_PROCESS &a)
{
        return(1);
}

odb_String FIXTURING_PROCESS::get_proc_description()
{
        return(proc_description);
}

void FIXTURING_PROCESS::put_proc_description(char* a_proc_description)
{
        proc_description = a_proc_description;
}
```

Figure 7.3 – The FIXTURING_PROCESS.cxx File

7.2.3.3 The Fixturing Resources

Figure 7.4 illustrates an example of the head files of fixturing resources and its "cxx" sources file. The fixturing resources are implemented based in accordance with definition explored in section 5.4.2. The UML class structure of modular fixturing elements presented in section 5.4.3.2 where the attributes were defined and implemented.

```
#endif_MODULAR_FIXTURE
#define_MODULAR_FIXTURE
class MODULAR_FIXTURE: public odb_Persistent_Object
{
public:
        // Attributes
        odb_String                    m
        odb_String                    m
        odb_List<odb_Ref< PLATE >
        PLATE::an_associated_fixtu
        odb_List<odb_Ref< LOCATING
        LOCATING_PIN::an_associate
        odb_List<odb_Ref< SCREWED_
        SCREWED_REST_BUTTON::an_as
        odb_List<odb_Ref< CLAMP_EL
        CLAMP_ELEMENT::an_associat
        odb_List<odb_Ref< DOWN_HOL
        DOWN_HOLD_CLAMP::an_associ
        odb_List<odb_Ref< CENTERIN
        CENTERING_BOLT::an_associa

#ifdef __cctoddl
odb_Ref<WORKPIECE> assoc_workpiece
#else
Inverse_odb_Ref(WORKPIECE,list_of_f
#endif
odb_Ref<FIXTURING_PROCESS> assoc_fi
FIXTURING_PROCESS::assoc_fixture;

public:
         // constructor, destructo
         MODULAR_FIXTURE();
         MODULAR_FIXTURE(const MOD
         MODULAR_FIXTURE(const cha
         ~MODULAR_FIXTURE();
         MODULAR_FIXTURE& operator
         int operator == (const MO
         odb_String get_mod_fix_na
         odb_String get_mod_fix_de
         void put_name(char* a_mod
         void put_description(char
         odb_Ref<WORKPIECE> MODULA
         int get_plate_associated_
         int max_num_of_strings, c
         int get_pin_associated_na
         int max_num_of_strings, c
         int get_button_associated
         int max_num_of_strings, c
         int get_clamp_associated_
         int max_num_of_strings, c
         int get_bolt_associated_n
         int max_num_of_strings, c
         int get_downhold_associat
         int max_num_of_strings, c

#ifndef __cctoddl
  PERSISTENT_END
#endif
};
```

```
MODULAR_FIXTURE.cxx

#include "stdafx.h"
#include <udefs.h>
#include "pris_work.hxx"

MODULAR_FIXTURE::MODULAR_FIXTURE()
{
}

MODULAR_FIXTURE::MODULAR_FIXTURE(const MODULAR_FIXTURE &a)
{
}

MODULAR_FIXTURE::MODULAR_FIXTURE(const char* name)
{
}

MODULAR_FIXTURE::~MODULAR_FIXTURE()
{
}

MODULAR_FIXTURE& MODULAR_FIXTURE::operator=(MODULAR_FIXTURE &a)
{
        return(a);
}

int MODULAR_FIXTURE::operator == (const MODULAR_FIXTURE &a)
{
        return(1);
}

odb_String MODULAR_FIXTURE::get_mod_fix_name()
{
        return(mod_fix_name);
}

odb_String MODULAR_FIXTURE::get_mod_fix_description()
{
        return(mod_fix_description);
}

void MODULAR_FIXTURE::put_name(char* a_mod_fix_name)
{
        mod_fix_name = a_mod_fix_name;
}

void MODULAR_FIXTURE::put_description(char* a_mod_fix_description)
{
        mod_fix_description = a_mod_fix_description;
}
```

Figure 7.4 – The MODULAR_FIXTURE.cxx File

7.2.4 The Implementation of the User Interface Dialogs

The user interface dialogs were designed to provide the user the access to different parts of the applications. This interface should link the information models to provide access to product model and manufacturing model to support the applications. This interface was developed in C++ programming language in the visual C++ environment using the Microsoft Foundation Class. The user interface is composed of a mainframe menu with several dialogs, which are going to be explained in the later part of this section. Figure 7.5 illustrates the mainframe menu window. In the mainframe menu as depicted in the figure, supports three functions called, "Support_Fixture_Planning", Support_Process_Planning" and "Support_Product_Design", which can be seen as menu option at the top of the screen.

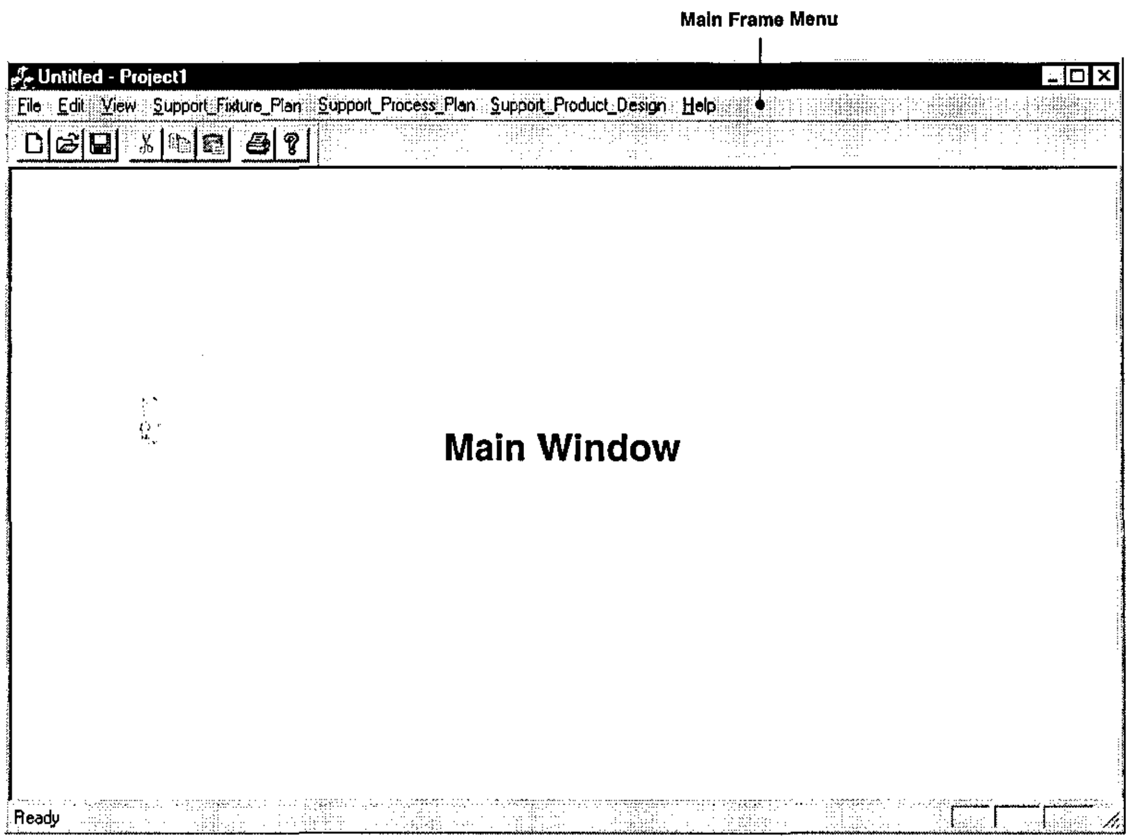


Figure 7.5 – The Mainframe Menu Window

The "Support_Fixture_Planning" function assists the user during the product work-piece modelling process, which has a sub-function, workpiece and has a view sub-function. These sub-functions are related only to view the workpiece list in the product model. The Figure 7.6 shows a "Workpiece List" dialog called by function workpiece view, this is the listing of all the prismatic workpieces stored in the product model. In the figure the "Prismatic_Workpiece_01" and "Prismatic_Workpiece_02" are highlighted because in this application these prismatic workpieces are used in the experiment.

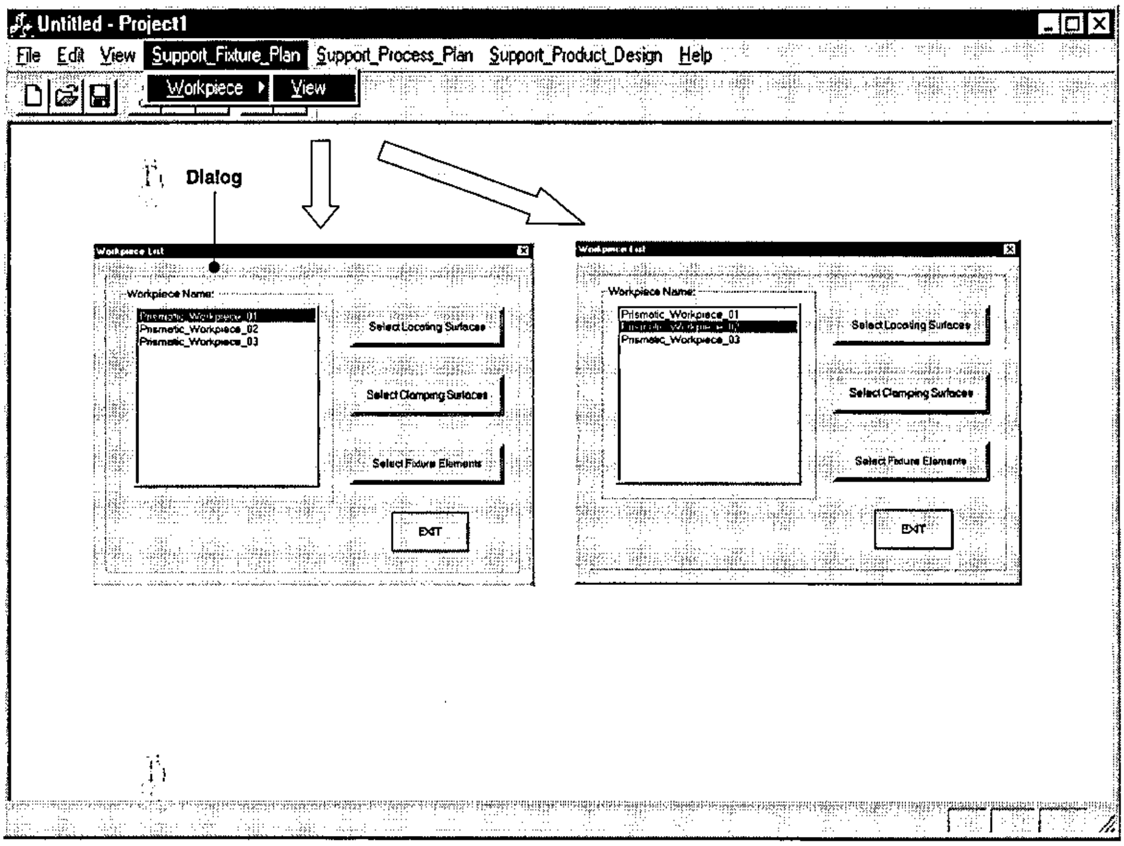


Figure 7.6 – The Workpiece List Dialog for Support_Fixture_Planning

The "Support_Product_Design" function assists the user during the product work-piece modelling process, which has a sub-function, workpiece and a view sub-function. These sub-functions are related only to view the workpiece list in the product model. The Figure 7.7 shows a "Workpiece List" dialog called by function workpiece view, this is the listing of all the prismatic workpieces stored in the product model. In the figure the "Prismatic_Workpiece_03" is highlighted because in this application these prismatic workpiece is used in the experiment.

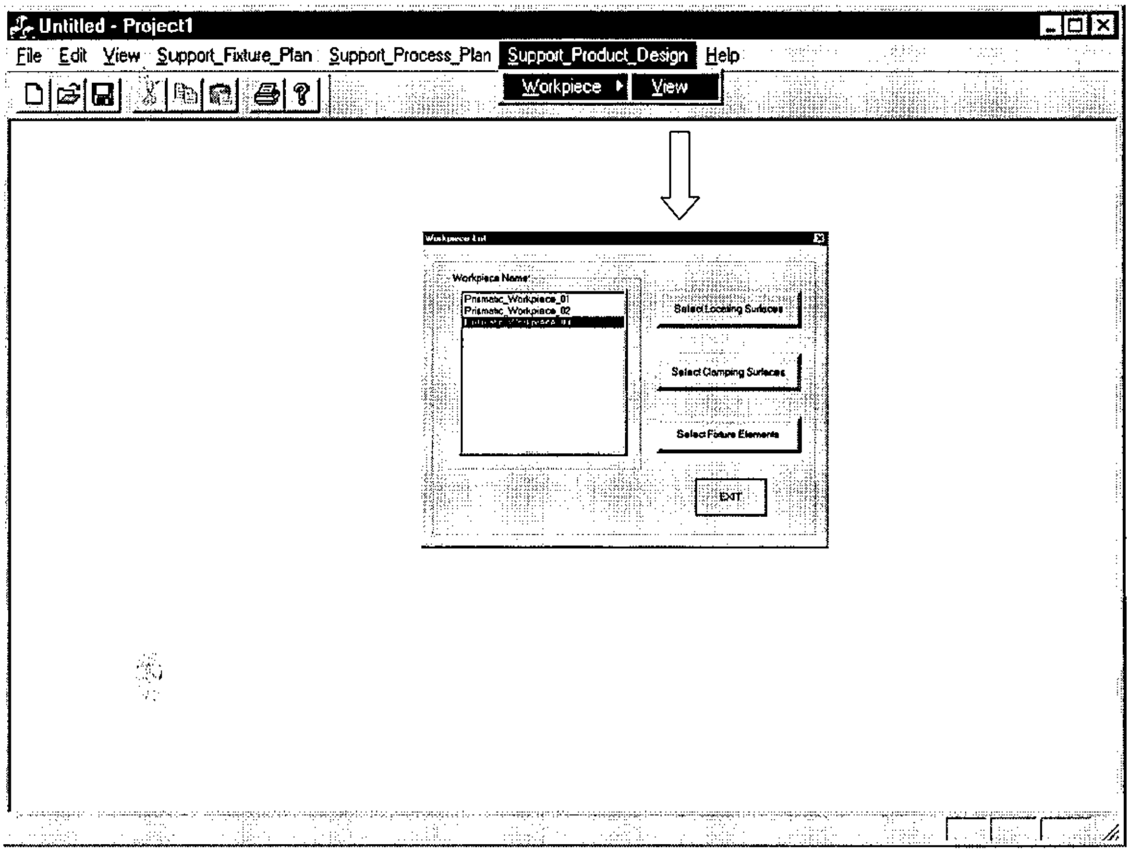


Figure 7.7 – The Workpiece List Dialog for Support_Product_Design

Figure 7.8 presents the "Workpiece List" dialog select buttons and these are "Select Locating Surfaces", "Select Clamping Surfaces", "Select Fixture Elements" and the "Exit" button. The "Select Locating Surfaces" button can be clicked and will call another dialog the "Locating Surfaces Selection", which lists the names of the locating surfaces. These surfaces are also presented with buttons and these are "Primary Locating Surface", "Secondary Locating Surface", Tertiary Locating Surface" and the "Exit" button. The locating surfaces selection dialog has boxes for the names of each surface once a locating surface has been selected. The "Select Clamping Surfaces" button can be clicked and will call another dialog the "Clamping Surfaces Selection", which lists the names of the clamping surfaces. It has also the "Primary Clamping Surface", "Secondary Clamping Surface", "Tertiary Clamping Surface" and the "Exit" buttons. The clamping surfaces selection dialog has boxes for the names of each surface once a clamping surface has been selected. The "Select Fixture Elements" button can be clicked and will call another dialog the "Fixture Elements Selection", which list the names of the modular fixture elements to be used in the applications. The "Exit" button once it is clicked will go back to the main window.

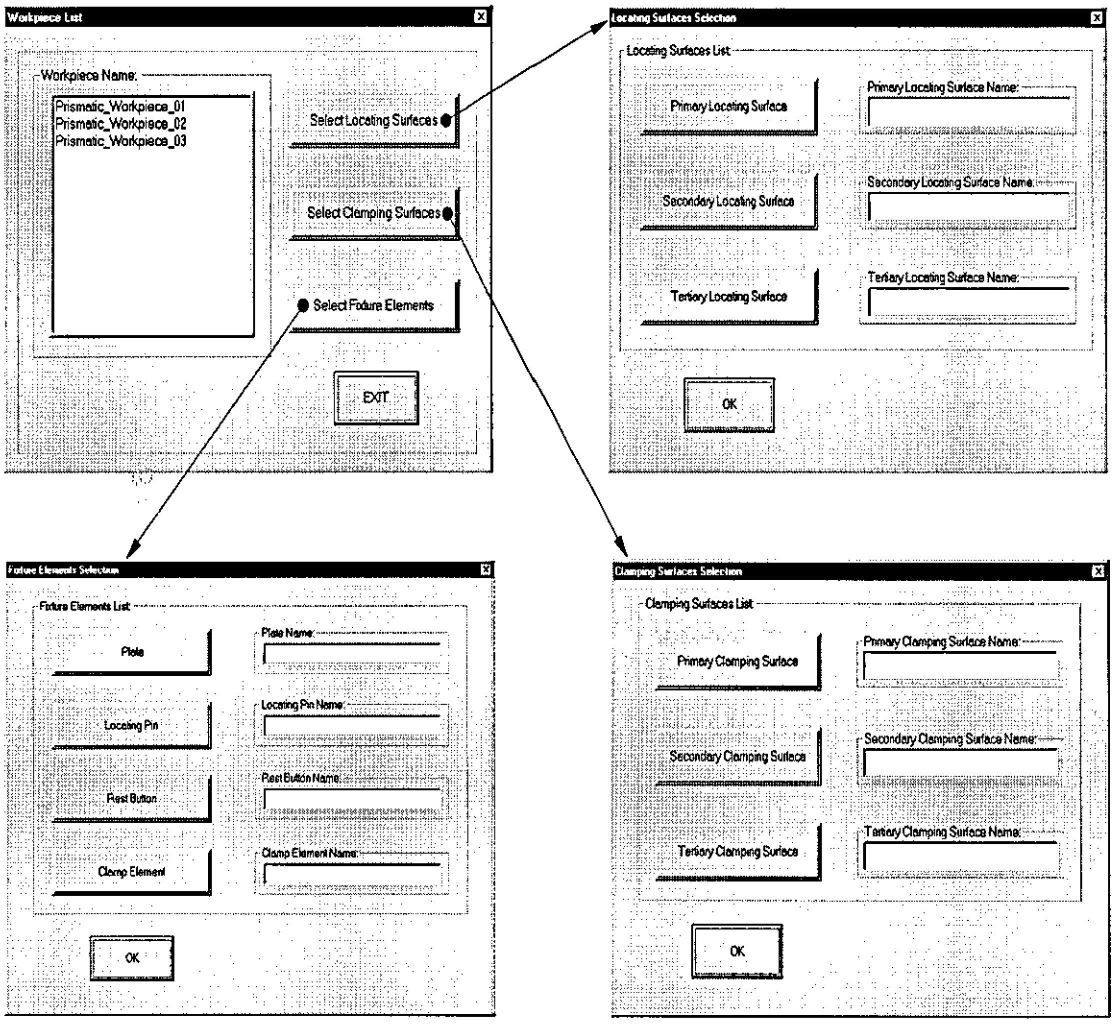


Figure 7.8 – The Workpiece List Dialog Select Buttons

7.3 The Experimental Utilisation of Fixturing Information Models to Support Fixture Planning and Support Product Design Applications

7.3.1 Support Fixture Planning – Experiment 1

7.3.1.1 General Description of Experiment

The experiments performed and described in this section demonstrates how the manufacturing model in conjunction with product model can provide the fixturing information for support fixture planning application to generate fixture plan of a particular prismatic workpiece by utilising the 3-2-1 and concentric fixturing methods. The aims can be listed below:

- How a 3-2-1 fixturing method in the manufacturing model can be utilised to generate a fixture plan in conjunction with the product model.

- How a concentric fixturing method in the manufacturing model can be utilised to generate a fixture plan in conjunction with the product model

7.3.1.2 Populating the Product Model

The experimental system used the SQL (Structure Query Language) of the UniSQL/X object-oriented database system in exploring this work. Figure 7.9 shows the UniSQL/X visual script main window. The visual script window will appear after entering the name of the database being created. The window will allow the user to write the scripts.

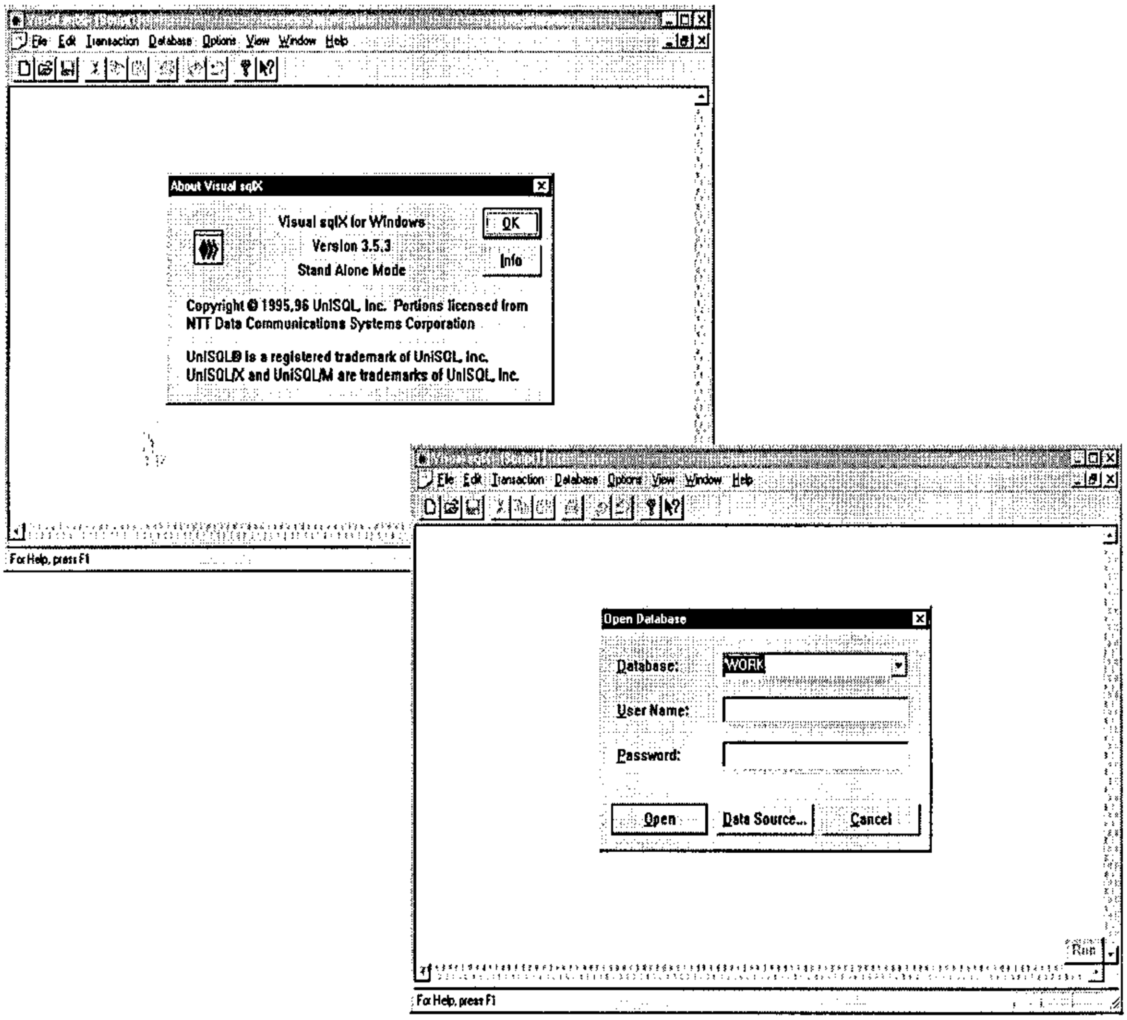


Figure 7.9 – The UniSQL/X Visual Script Main Window

Figure 7.10 illustrates the list of the three prismatic workpieces in the database with similar and identical information on them. The difference between the three prismatic workpieces are the hole feature in the list, which the first one has no hole feature on it, the second has one hole feature and the third has two hole features. The figure highlights the "Prismatic_Workpiece_01". The figure shows how the information of each prismatic workpiece has been presented in the database and these are highlighted with encircled letters and numbers that correspond to the information of each workpiece.

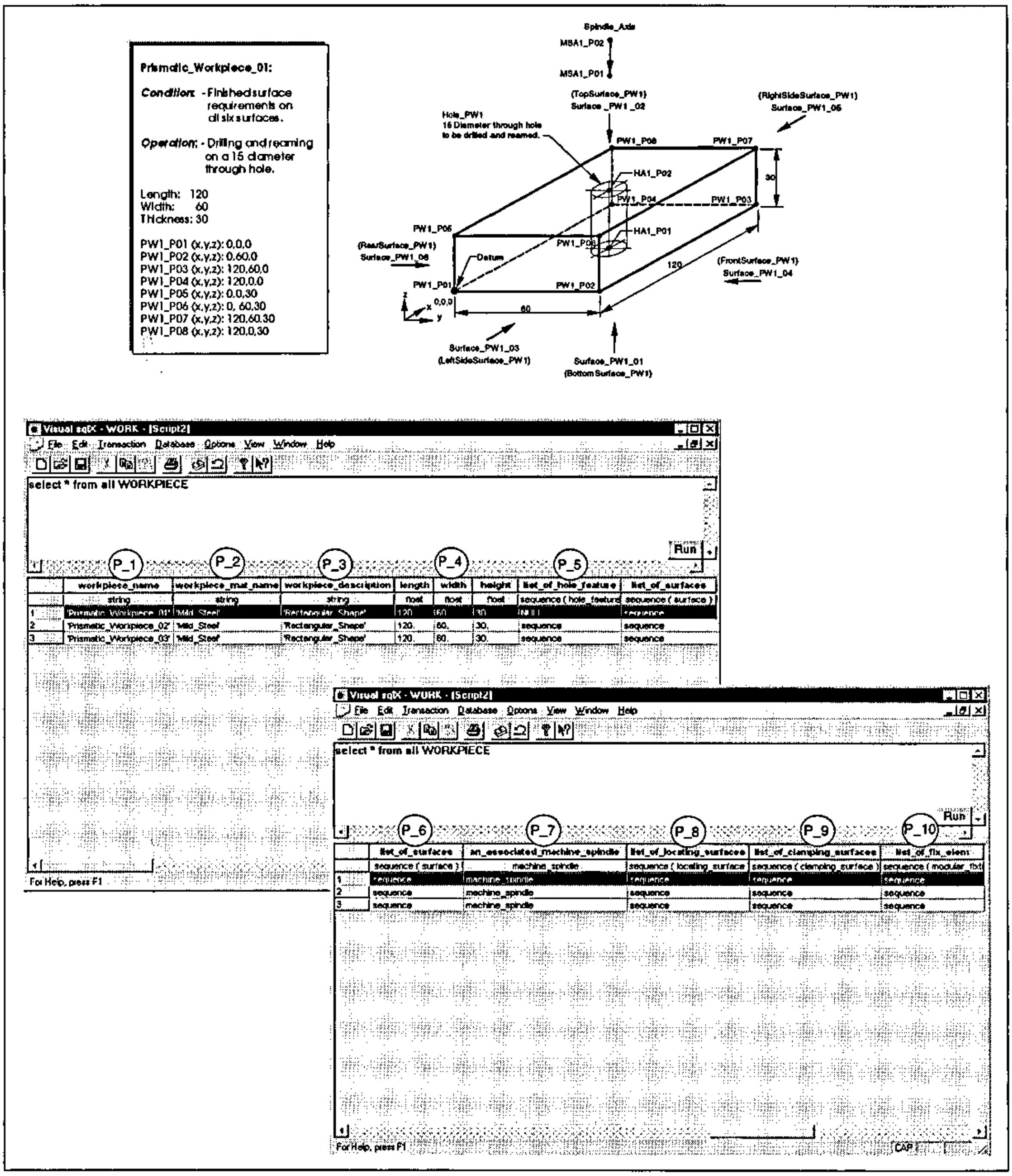


Figure 7.10 – The Prismatic_Workpiece_01 Representation Within the Product Model Database

Figure 7.11 shows an example of a surface presentation in the database. In the figure it used the "Prismatic_Workpiece_01" and the same procedures have been applied to all surfaces presentation in all three prismatic workpieces used in this experiment. From the figure once the "sequence" is clicked from list of surfaces "P_6", it opens another window, which contains the list of the six surfaces that represents the six surfaces of a rectangular shaped workpiece. Once a surface is clicked, then it opens a window, which contained the surface name, surface description and the list points. The list of points has a "sequence" which can be clicked to open another window that contained the list of the points. Four points present a surface, therefore every surface has a list of four points, which has an "x, y", and "z" coordinates. The list of points' window has a "sequence" and once it is clicked, it opens another window that contained the name of the points and the coordinates and its values. In the figure illustrating the first point of "Prismatic_Workpiece_01", therefore, the window gives the point name "PW1_P01" which has a coordinate and its values of "x = 0", "y = 0" and "z = 0".

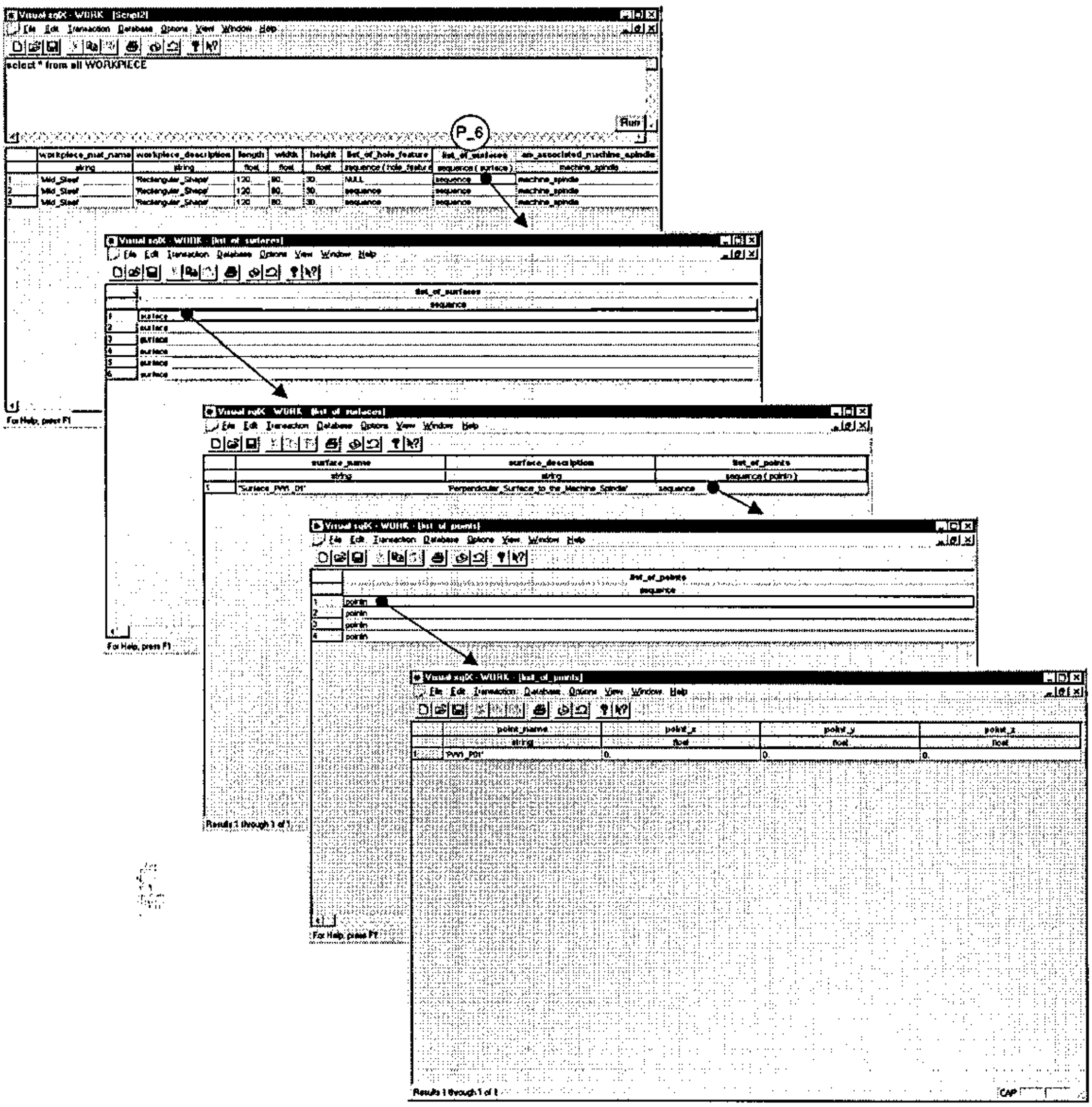


Figure 7.11 – An Example of a Surface Representation for Prismatic_Workpiece_01

Figure 7.12 shows the second prismatic workpiece used in this experiment. The workpiece is "Prismatic_Workpiece_02" and being highlighted in the figure. This prismatic workpiece has the same information with the other workpieces stored in the database, but the difference lies in the list of the hole feature "C_5" where this prismatic workpiece has one hole feature found in the list.

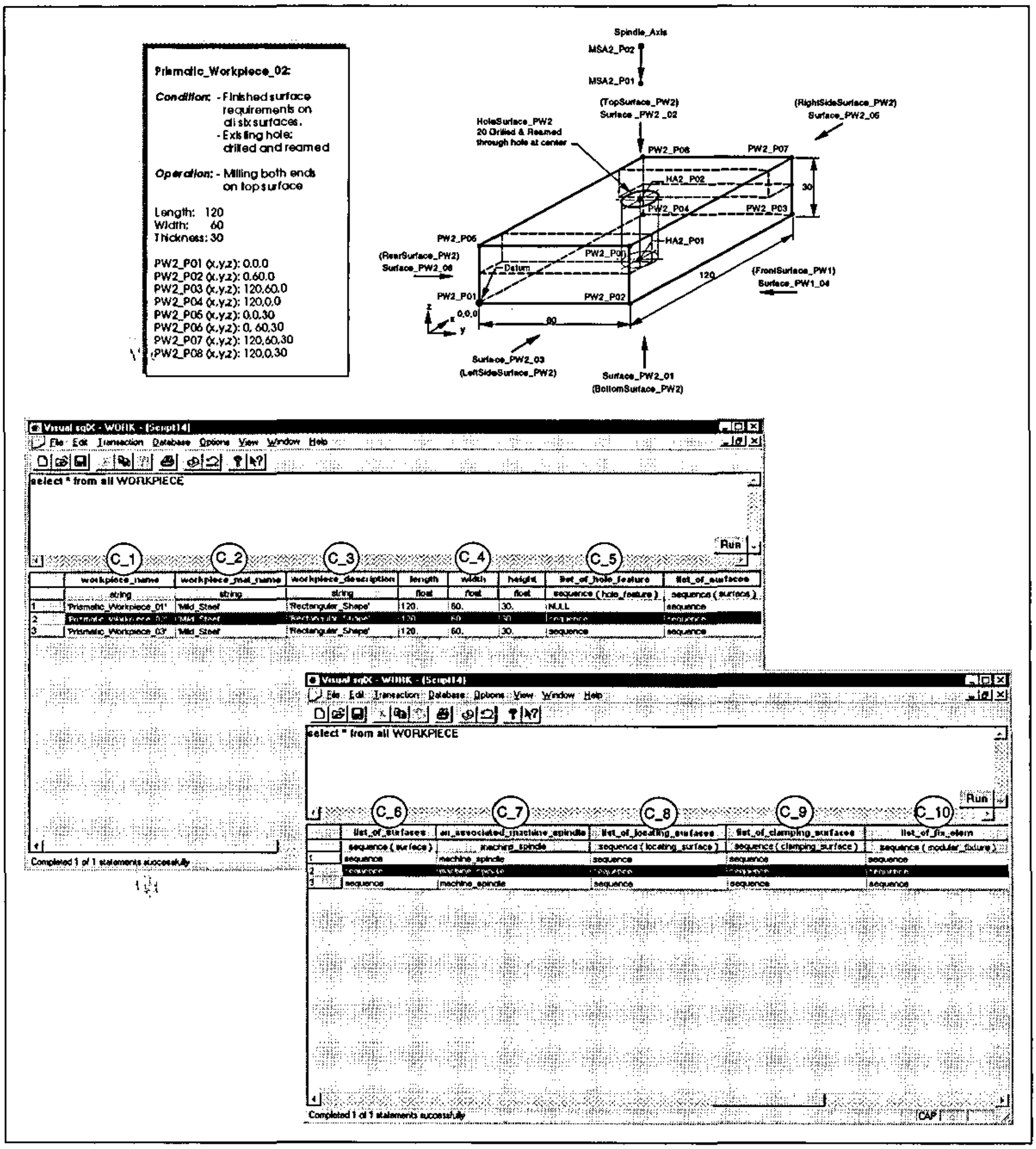


Figure 7.12 – The Prismatic_Workpiece_02 Representation Within the Product Model Database

Figure 7.13 illustrates the hole feature representation in the database. In the figure once the "sequence" is clicked, it opens a window where a hole feature is listed. This hole feature list can be clicked and displayed another window that contained the *hole name*, *hole diameter*, *hole description*, *association with axis* and *association with workpiece*. The axis of a hole feature can be clicked and displayed a window that contained the *axis name*, *axis description* and *list of points*. The list of points can be clicked to know the points that locate the axis of a hole feature on the workpiece and displayed a window that contained the list of two points. The first list can be clicked and displayed a window that contained the *point name*, and the "x", "y" and "z" coordinates and the same with the second list of point.

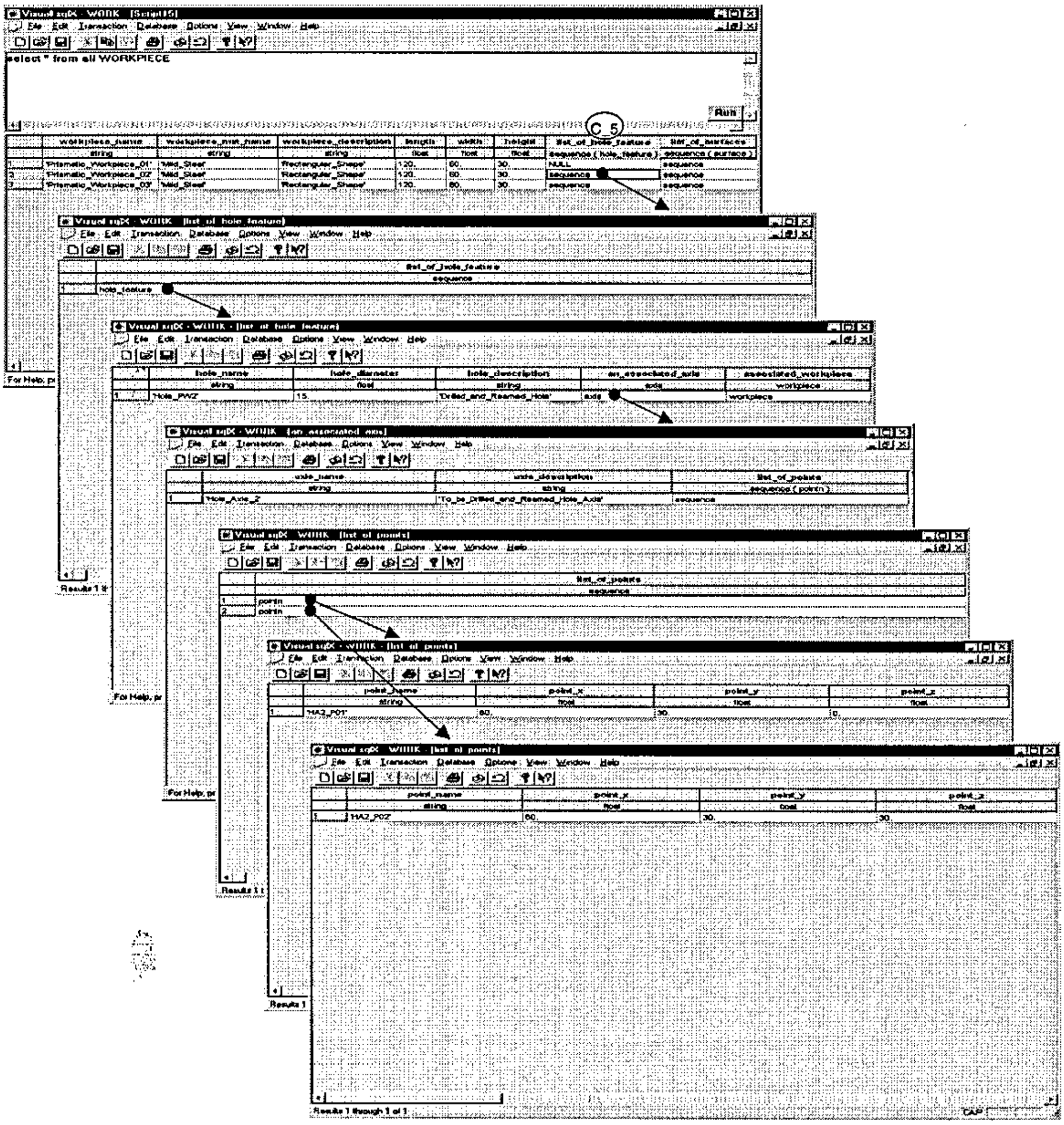


Figure 7.13 – The Hole Feature Representation for Prismatic_Workpiece_02

7.3.1.3 Populating the Manufacturing Model

The population of the data in the manufacturing model can be done in two steps; first populating the fixturing processes and second populating the fixturing recourses. The fixturing processes have two sub-processes, one being the locating and second being the clamping. The locating and clamping processes have three methods; one the 3-2-1, concentric and radial which were explored and presented in section 5.4.2.

Figure 7.14 shows the locating process, clamping process and the modular fixturing elements presentation in the database. Each of these are highlighted with an encircled letters. The highlighted "A", a database window that contained the locating process which have the "Radial_Locating_Method", "Concentric_Locating_Method" and "3-2-1_Locating_Method". The highlighted letter "B" another database window that contained the clamping process, which have the "Clamping_Radial_Location", "Clamping_Concentric_Location" and "Clamping_3-2-1_Location". The detail discussion on how these methods can be used to provide support to different applications is given in the succeeding sections.

The fxturing resources have been explored and presented in section 5.4.3. The modular fixturing elements were taken from Halder Modular Jig and Fixture Systems (1994). The selection for each of the fixturing elements to the corresponding prismatic workpiece used in this experiments were based from the work of Chang (1992), which is discussed in section 5.2.2.2.

In the figure the highlighted letter "C" and "C1" present the modular fixturing elements associated with "Prismatic_Workpiece_01". The highlighted letter "D" and "D1" present the modular fixturing elements associated with "Prismatic_Workpiece_02". The highlighted letter "E" and "E1" present the modular fixturing elements associated with "Prismatic_Workpiece_03". The modular fixturing elements listed in a window can be clicked and it gives the specific information that is discussed in section 5.4.3.2.

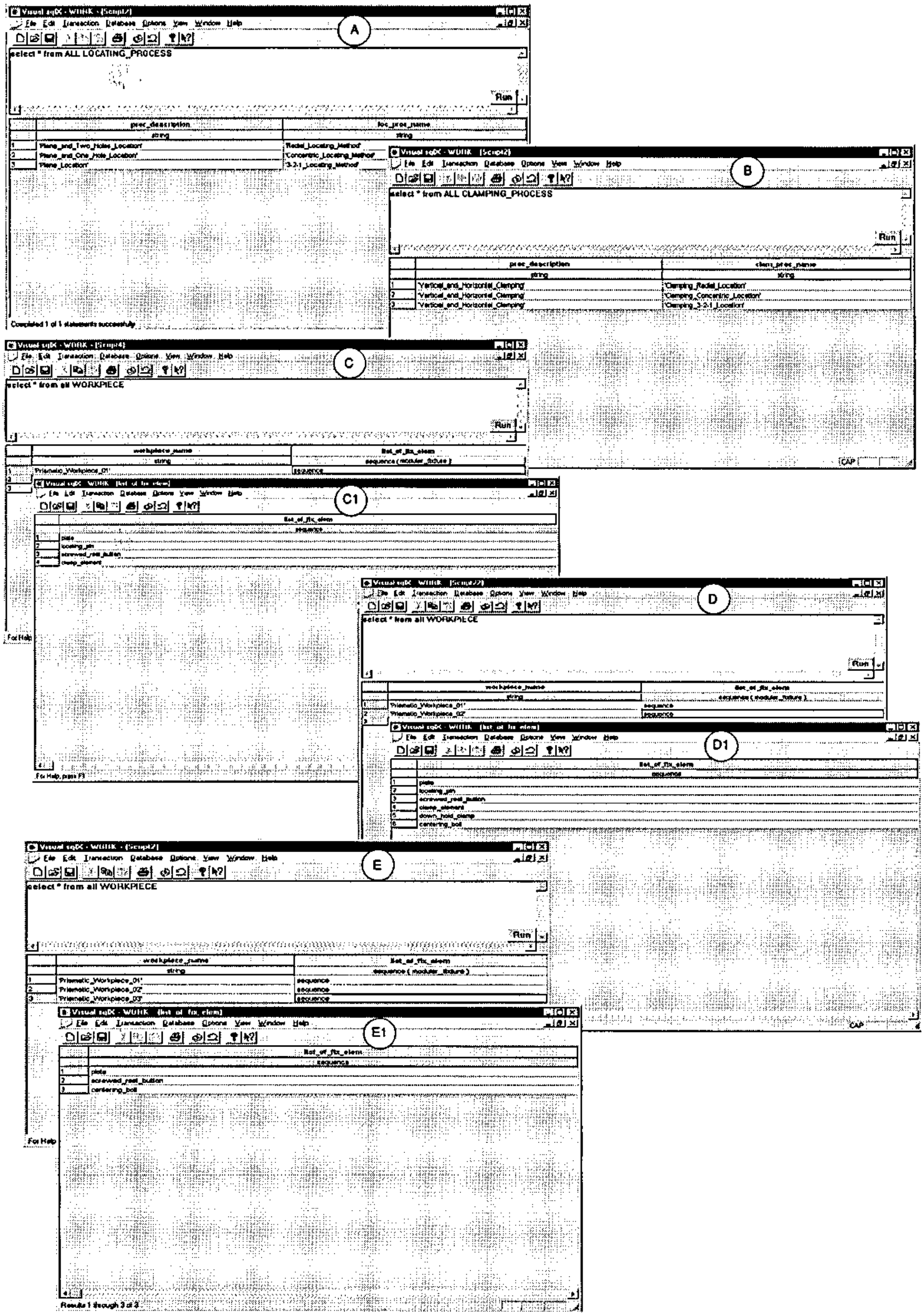


Figure 7.14 – The Fixturing Process and Resources Representation Within the Manufacturing Model Database

7.3.1.4 The 3-2-1 Method

This section explores the 3-2-1 fixturing method capability to generate a fixture plan by using the fixturing information in the database. The "Prismatic_Workpiece_01" shown in Figure 7.10 is used to demonstrate this method. To generate a fixture plan, the selection of locating surfaces, clamping surfaces are needed as well as the selection of the modular fixturing elements to be used. The 3-2-1 method uses the plane surfaces to locate and clamp the workpiece.

7.3.1.4.1 Select Locating Surfaces

The locating surfaces of a workpiece are composed of a primary locating surface, secondary locating surface and tertiary locating surface. In order to locate a workpiece each of these locating surfaces should be selected. The procedures in selecting these locating surfaces in this research work are based on the workpiece definition discussed in 5.5.2 and the fixturing method used discussed in 5.4.2.

Figure 7.15 shows the dialogs for selecting the locating surfaces. The first dialog "PLS" contained the list of workpiece, which in this case the "Prismatic_Workpiece_01" is highlighted. The "PLS" dialog has three main buttons and these buttons can be clicked to display another dialog. In the figure, the "Select Locating Surfaces" button is clicked and displayed the dialog "PLS_1" that contained the locating surfaces list. The "PLS_1" dialog contained the "Primary Locating Surface", "Secondary Locating Surface" and "Tertiary Locating Surface" buttons. The importance of the figure is where the names of the primary, secondary and tertiary locating surfaces can be seen in the dialog boxes.

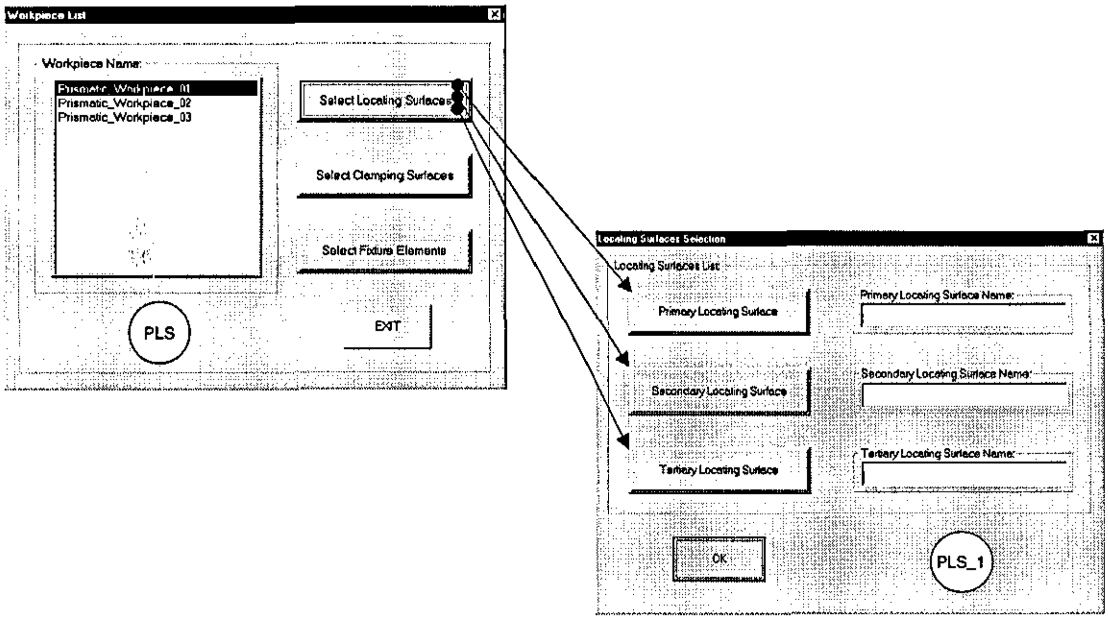


Figure 7.15 – The Dialogs for Selecting Locating Surfaces to Support Fixture Planning Using the 3-2-1 Method

Figure 7.16 presents the results for selecting the locating surfaces. The "Primary Locating Surface" button is clicked and the 3-2-1 method in the manufacturing model triggers the application to search in the database from the list of surfaces, the surface that is perpendicular to machine spindle axis and have points with different "z" values. The search may result to more than one surface found, but picked a surface that has points with the lowest "z" value. In the figure, the "PDB1" presents the window where the surface that has been picked is shown. The *locating surface name* is "BottomSurface_PW1" and *locating surface description* is "PrimaryLocatingSurface". The *associated surface* can be clicked and displayed the "PDB1_1" window that contained the *surface name* "Surface_PW1_01", *surface description* "Perpendicular Surface to the Machine Spindle" and *list of points*.

In selecting the "Secondary Locating Surface", the button is clicked and the 3-2-1 method in the manufacturing model triggers the application to search in the database from the list of surfaces, the surface that is parallel to machine spindle axis and have points with different "z" and "x" values. The search may result to more than one surface found, but picked a surface that has points with lower "y" value. From the figure, the "PDB1_2" presents the window where the surface that has been picked is shown. The *locating surface name* is "RearSurface_PW1" and *locating surface description* is "SecondaryLocatingSurface". The *associated surface* can be clicked and displayed the "PDB1_3" window that contained the *surface name* "Surface_PW1_06", *surface description* "Parallel Surface to the Machine Spindle" and *list of points*.

The selection of the "Tertiary Locating Surface", the button is clicked and the 3-2-1 method in the manufacturing model triggers the application to search in the database from the list of surfaces, the surface that is parallel to machine spindle axis and have points with different "z" and "y" values. The search may result to more than one surface found, but picked a surface that has points with higher "x" value. In the figure, the "PDB1_4" presents the window where the surface that has been picked is shown. The *locating surface name* is "RightSideSurface_PW1" and *locating surface description* is "TertiaryLocatingSurface". The *associated surface* can be clicked and displayed the "PDB1_5" window that contained the *surface name* "Surface_PW1_05", *surface description* "Parallel Surface to the Machine Spindle" and *list of points*.

The figure also illustrates the dialog "PLS_1" which was the dialog displayed when the "Select Locating Surface" button was clicked and still empty. After each of the selection for primary locating surface, secondary locating surface and tertiary locating surface, the database is updated and lists the locating surfaces that was being picked by the application and placed it in the dialog boxes. The results of the selection for locating surfaces are the following:

Locating Surfaces	
Primary Locating Surface Name:	"BottomSurface_PW1"
Secondary Locating Surface Name:	"RearSurface_PW1"
Tertiary Locating Surface Name:	"RightSideSurface_PW1"

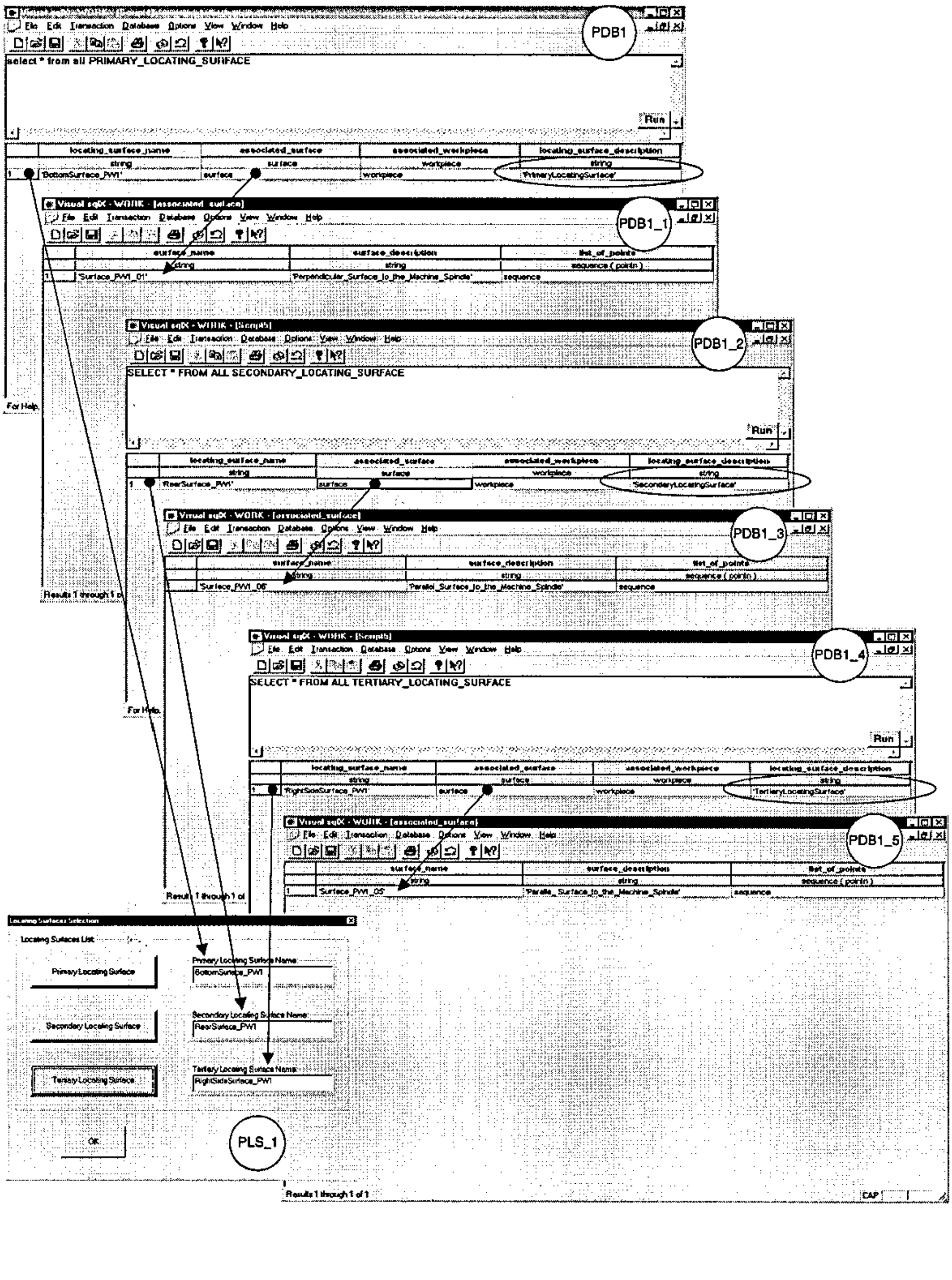


Figure 7.16 – The Results for Selecting Locating Surfaces

7.3.1.4.2 Select Clamping Surfaces

The clamping surfaces of a workpiece are generally surfaces opposite of the locating surfaces and composed of a primary, secondary and tertiary clamping surface. In order to clamp a workpiece each of these clamping surfaces should be selected. The procedures in selecting these locating surfaces in this research work are based on the workpiece definition discussed in 5.5.2 and the fixturing method used discussed in 5.4.2. Figure 7.17 presents the dialogs for selecting the clamping surfaces. The first dialog "PCS" contained the list of workpiece, which in this case the "Prismatic_Workpiece_01" is highlighted. The dialog has three main buttons and these buttons can be clicked to display another dialog. In the figure, the "Select Clamping Surfaces" button is clicked and displayed the dialog "PCS_1" that contained the clamping surfaces list. The "PCS_1" dialog contained the "Primary Clamping Surface", "Secondary Clamping Surface" and "Tertiary Clamping Surface" buttons. The importance of the figure is where the names of the primary, secondary and tertiary clamping surfaces can be seen in the dialog boxes.

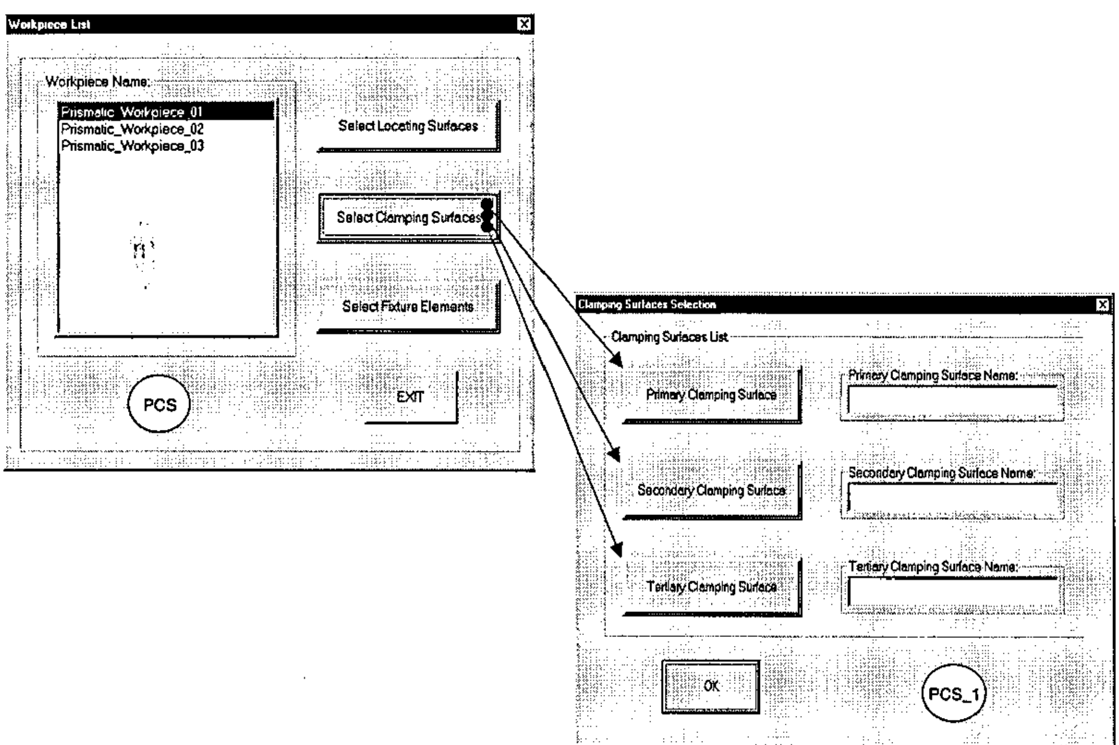


Figure 7.17 – The Dialogs for Selecting Clamping Surfaces to Support Fixture Planning Using the 3-2-1 Method

Figure 7.18 presents the results for selecting the clamping surfaces. When the "Primary Clamping Surface" button is clicked, the 3-2-1 method in the manufacturing model triggers the application to search in the database from the list of surfaces, the surface that is perpendicular to machine spindle axis and have points with different "z" values. The search may result to more than one surface found, but picked a surface that has points with higher "z" value. In the figure, the "PDB2" presents the window where the surface that has been picked is shown. The *clamping surface name* is "TopSurface_PW1" and *clamping surface description* is "PrimaryClampingSurface". The "sequence" under *associated surface* can be clicked and to display another window that will contain the *surface name*, *surface description* and *list of points*.

In selecting the "Secondary Clamping Surface", the button is clicked and the 3-2-1 method in the manufacturing model triggers the application to search in the database from the list of surfaces, the surface that is parallel to machine spindle axis and have points with different "z" and "x" values. The search may result to more than one surface found, but picked a surface that has points with higher "y" value. From the figure, the "PDB2_1" presents the window where a surface that has been picked is shown. The *clamping surface name* is "FrontSurface_PW1" and *clamping surface description* is "SecondaryClampingSurface".

The selection of the "Tertiary Clamping Surface", the button is clicked and the 3-2-1 method in the manufacturing model triggers the application to search in the database from the list of surfaces, the surface that is parallel to machine spindle axis and have points with different "z" and "y" values. The search may result to more than one surface found, but picked the surface that has points with lower "x" value. In the figure, the "PDB2_2" presents the window where the surface that has been picked is shown. The *clamping surface name* is "LeftSideSurface_PW1" and *clamping surface description* is "TertiaryClampingSurface". The figure also illustrates the dialog "PCS_1" which displayed the results in the dialog boxes for "Select Clamping Surface" and these results are the following:

Clamping Surfaces	
Primary Clamping Surface Name:	"TopSurface_PW1"
Secondary Clamping Surface Name:	"FrontSurface_PW1"
Tertiary Clamping Surface Name:	"LeftSideSurface_PW1"

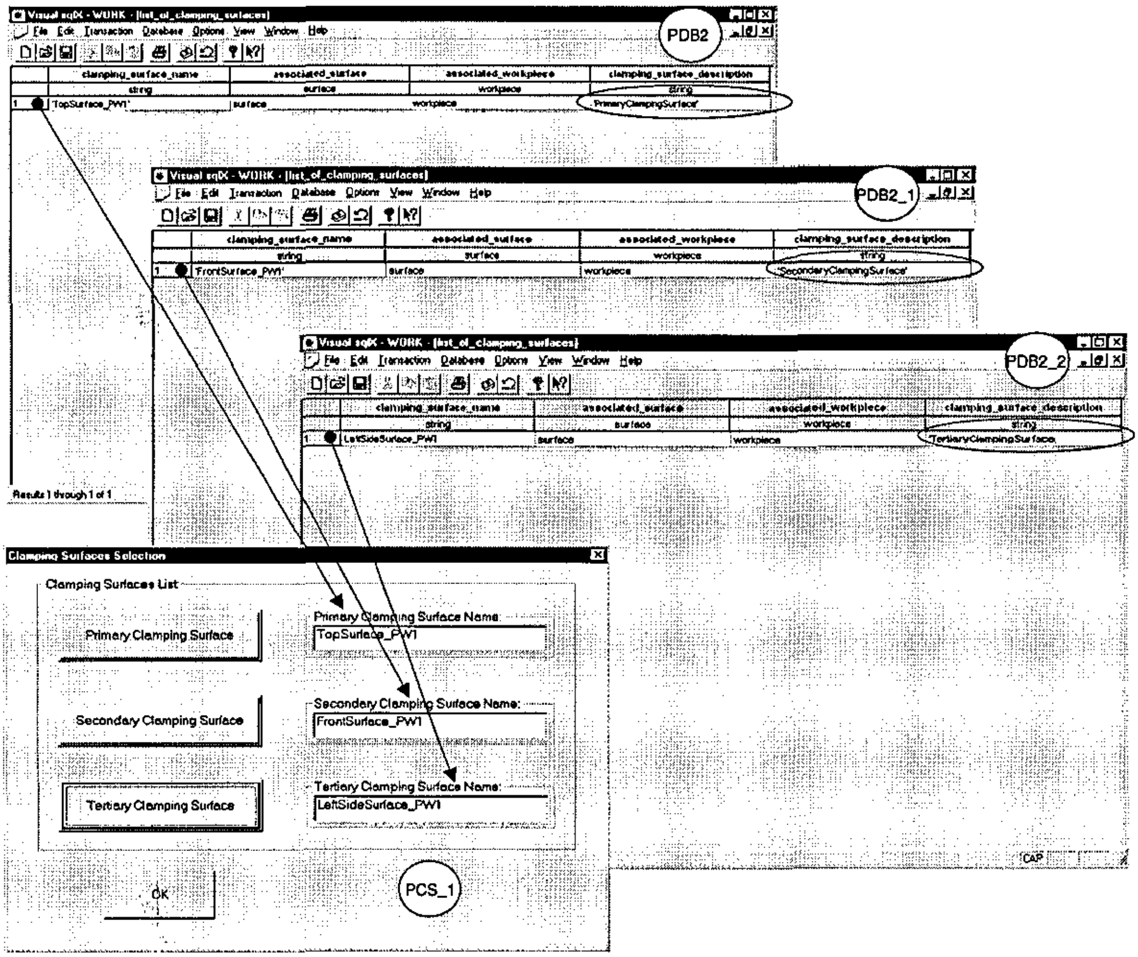


Figure 7.18 – The Results for Selecting Clamping Surfaces

7.3.1.4.3 Select Fixturing Elements

In this research work the modular fixturing elements are pre-selected based on the work of Chang (1992) and these fixturing elements are associated to a prismatic workpiece with a reference number. The same way with the name of surfaces and name of points are attached to a particular prismatic workpiece with its reference number as "TopSurface_PW1" for a surface name or "PW1_P01" for a point name. The "PW1" is the workpiece reference number stands for the "Prismatic_Workpiece_01", so for fixturing elements it will be like "BasePlate_PW1", and it means that a base plate is for "Prismatic_Workpiece_01". The general information needed for the fixturing elements was stored in the database taken from the Halder Modular Jig and Fixture Systems product catalogue.

Figure 7.19 presents the dialogs for selecting the fixture elements. The first dialog "PFE" contained the list of workpiece, which in this case the "Prismatic_Workpiece_01" is highlighted. The dialog has three main buttons and these buttons can be clicked to display another dialog. In the figure, the "Select Fixture Elements" button is clicked and displayed the dialog "PFE_1" that contained the modular fixture elements list. The "PFE_1" dialog contained the names of the modular fixture elements stored in the database for a "Prismatic_Workpiece_01".

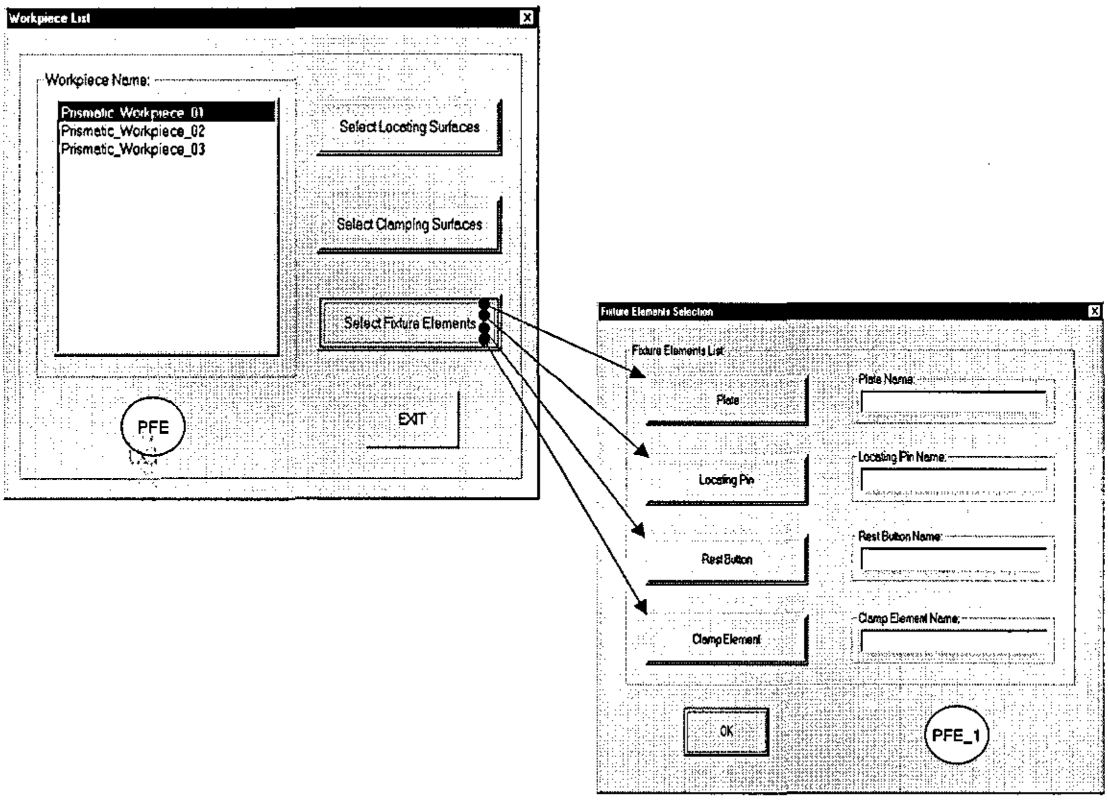


Figure 7.19 – The Dialogs for Selecting Fixture Elements to Support Fixture Planning Using the 3-2-1 Method

Figure 7.20 presents the results of the "Select Fixture Elements" buttons. The "PDB3" window shows *mod_fix_name* of the four modular fixture elements and the *assoc_workpiece*. The workpiece under the *assoc_workpiece* and can be clicked to display another window. The "PDB3_1" window contained the *workpiece_name*, which in this case is the "Prismatic_Workpiece_01" and the *list_of_fix_elem* of which can be clicked and displayed the "PDB3_2" window that contained the *list_of_fix_elem*. Each of the names in the list can be clicked and displayed the information of the specific fixture element and the same with other windows, "PDB3_3" for a "plate", "PDB3_4" for a "locating pin", "PDB3_5" for a "rest button" and "PDB3_6" for a "clamp element". Each window of the modular fixturing elements contained other information such as description of a fixture element, function, material name, degrees of freedom and catalogue numbers. There are other information stored in the database for each modular fixture element being used in this work.

The figure also illustrates the dialog "PFE_1" which was the dialog displayed when the "Select Fixture Element" button was clicked and still empty. The buttons of this dialog are the names the modular fixture elements and each of this buttons can be clicked and searched in the database of the name of the modular fixturing element that has been associated to a particular prismatic workpiece with its reference number, and picked that name of the fixture element and placed it in the dialog boxes. The results in selecting the modular fixturing elements are the following:

Modular Fixturing Elements	
Plate Name:	"BasePlate_PW1"
Locating Pin Name:	"Self_Aligning_Pad_PW1"
Rest Button Name:	"ScrewedRestButtonPW1"
Down Hold Clamp Name:	"ClampElement_PW1"

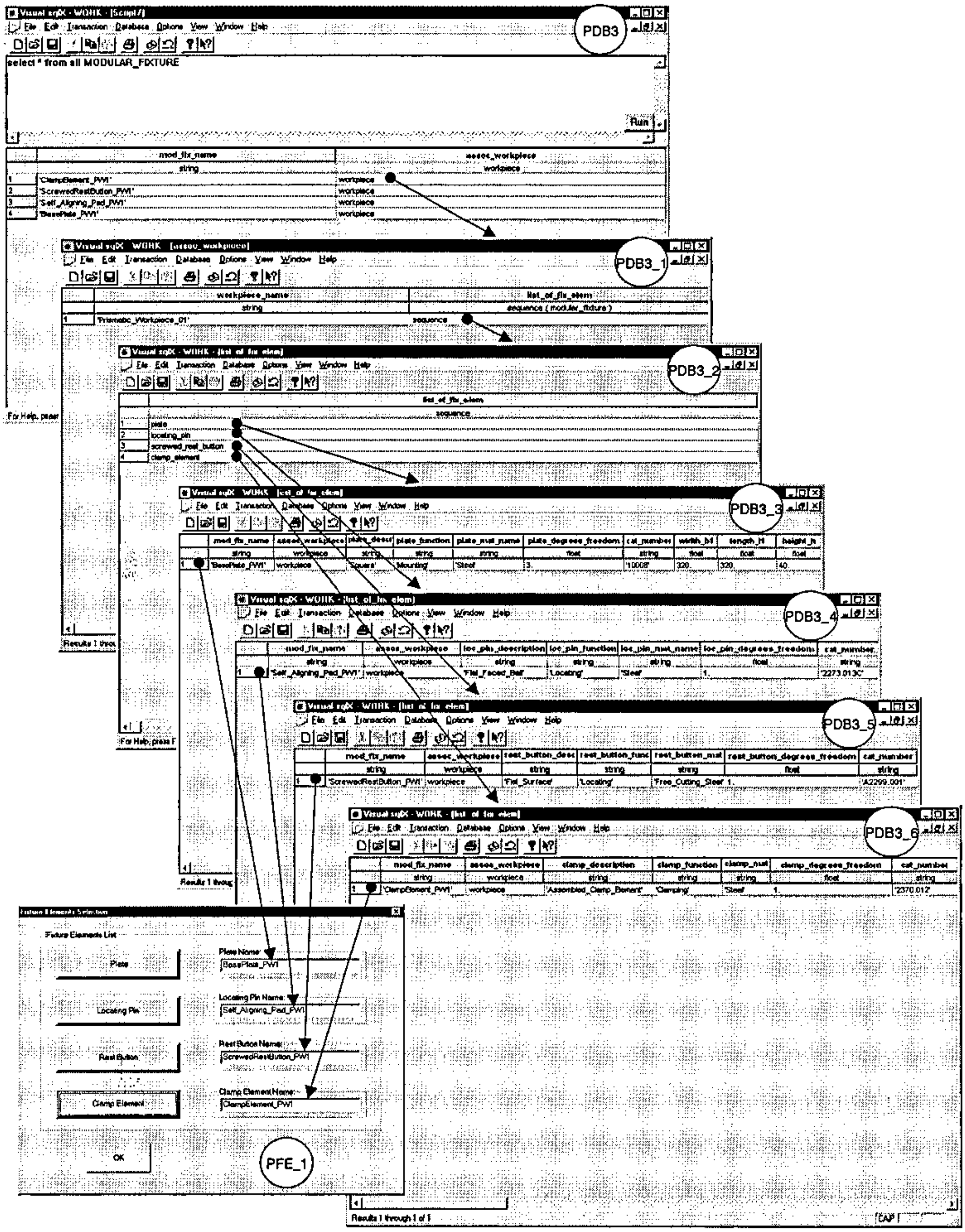


Figure 7.20 – The Results for Selecting Fixture Elements

7.3.1.5 The Concentric Method

This section explores the concentric fixturing method capability to generate a fixture plan by using the fixturing information in the database. The "Prismatic_Workpiece_02" shown in Figure 7.12 is used to demonstrate this method. To generate a fixture plan, the selection of locating surfaces, clamping surfaces are needed as well as the selection of the modular fixturing elements to be used. The concentric method uses a reamed hole feature to locate and clamp a workpiece.

7.3.1.5.1 Select Locating Surfaces

The procedures in selecting these locating surfaces in this research work are based on the workpiece definition discussed in 5.5.2 and the fixturing method used discussed in 5.4.2. Figure 7.21 presents the dialogs for selecting the locating surfaces. The first dialog "CLS" contained the list of workpiece, which in this case the "Prismatic_Workpiece_02" is highlighted. In the figure, the "Select Locating Surfaces" button is clicked, and flagged out a message "A Reamed Hole in the List" in "CLS_1" window. This means the application found a hole feature in the database for this particular prismatic workpiece. Pressing the "OK" button, and flagged out another message "Use Hole for Locating and Clamping" in "CLS_2" window. This means the hole feature can be use for locating and clamping of the workpiece. After pressing the "OK" button, the "CLS_1" dialog is displayed that contained the locating surfaces list. The "CLS_1" dialog contained the "Primary Locating Surface", "Secondary Locating Surface" and "Tertiary Locating Surface" buttons. The importance of the figure is where the names of the primary, secondary and tertiary locating surfaces can be seen in the dialog boxes.

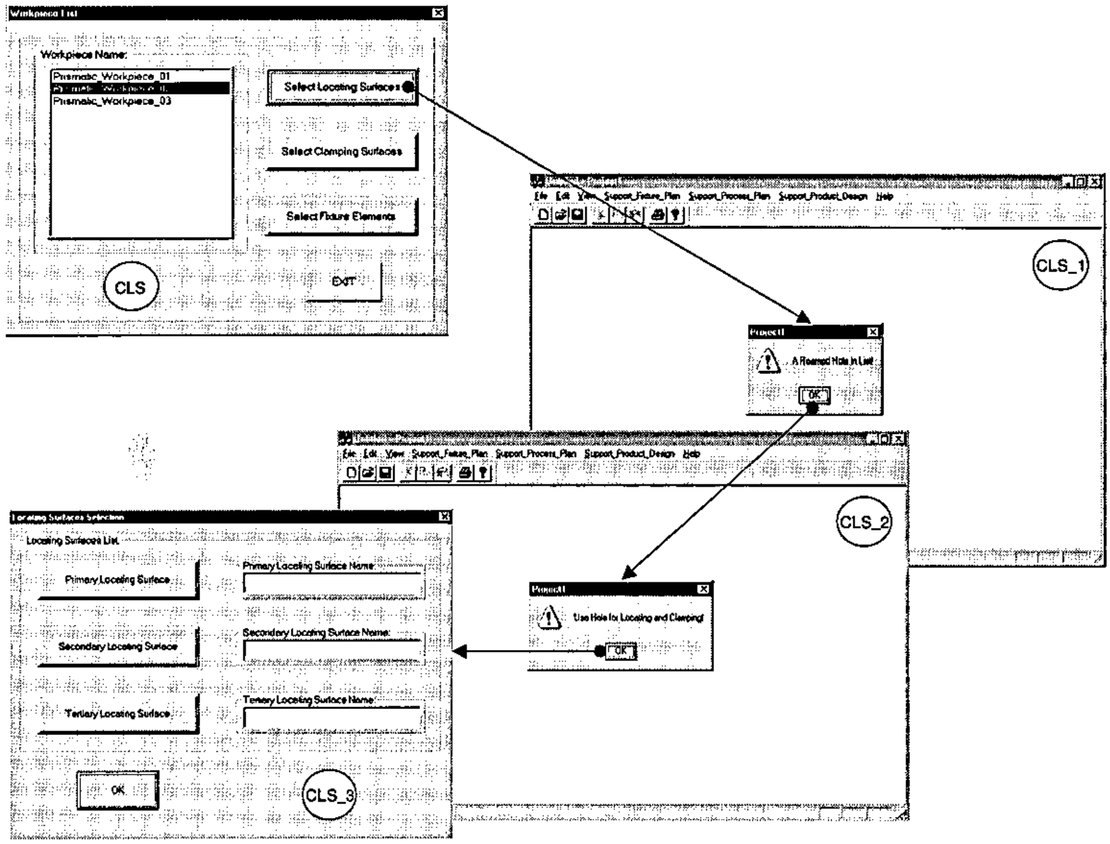


Figure 7.21 – The Dialogs for Selecting Locating Surfaces to Support Fixture Planning Using the Concentric Method

Figure 7.22 presents the results for selecting the locating surfaces. The procedures in selecting the primary locating surface in concentric method is the same in a 3-2-1 method and have been discussed earlier. In the figure, the "CDB1" presents the window where the surface that has been picked is shown. The *locating surface name* is "BottomSurface_PW2" and *locating surface description* is "PrimaryLocatingSurface". The "sequence" under *associated surface* can be clicked and to display another window that will contain the *surface name*, *surface description* and *list of points.*

In selecting the "Secondary Locating Surface", the button is clicked and the concentric method in the manufacturing model triggers the application to search in the database the list of a reamed hole feature surface, and picked the hole surface. From the figure, the "CDB1_1" presents the window where the hole surface that has been picked is shown. The *locating surface name* is “HoleSurface_PW2” and *locating surface description* is “SecondaryLocatingSurface”.

The selection procedures for tertiary locating surface in a concentric method is the same in a 3-2-1 method and have been discussed earlier. In the figure, the “CDB1_2” presents the window where the surface that has been picked is shown. The *locating surface name* is “RearSurface_PW2” and *locating surface description* is “TertiaryLocatingSurface”. The figure also illustrates the dialog “CLS_3” which displayed the results in the dialog boxes for “Select Locating Surface” and these results are the following:

Locating Surfaces	
Primary Locating Surface Name:	"BottomSurface_PW2"
Secondary Locating Surface Name:	"HoleSurface_PW2"
Tertiary Locating Surface Name:	"RearSurface_PW2"

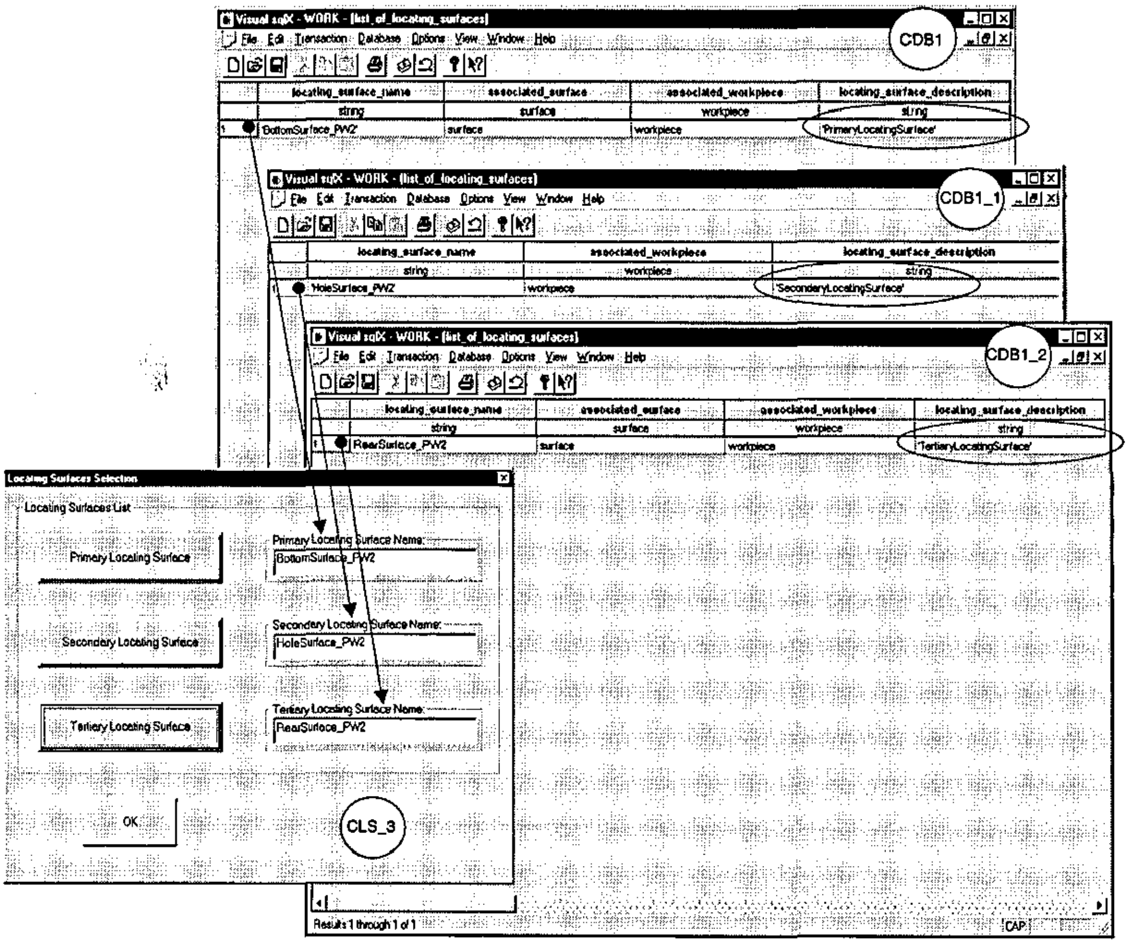


Figure 7.22 – The Results for Selecting Locating Surfaces

7.3.1.5.2 Select Clamping Surfaces

The procedures in selecting the clamping surfaces in this research work are based on the workpiece definition discussed in 5.5.2 and the fixturing method used discussed in 5.4.2. Figure 7.23 presents the dialogs for selecting the clamping surfaces. The first dialog "CCS" contained the list of workpiece, which in this case the "Prismatic_Workpiece_02" is highlighted. In the figure, the "Select Clamping Surfaces" button is clicked and displayed the dialog "CCS_1" that contained the clamping surfaces list. The "CCS_1" dialog contained the "Primary Clamping Surface", "Secondary Clamping Surface" and "Tertiary Clamping Surface" buttons. The importance of the figure is where the where the names of the primary, secondary and tertiary clamping surfaces can be seen in the dialog boxes.

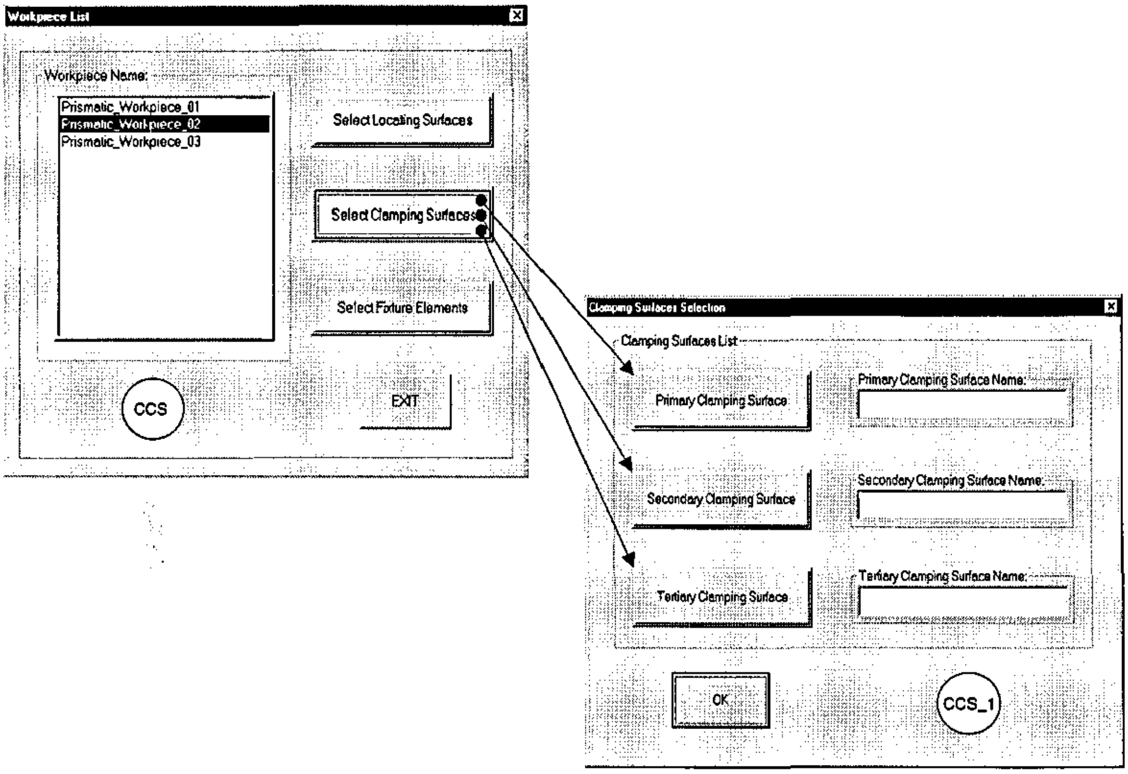


Figure 7.23 – The Dialogs for Selecting Clamping Surfaces to Support Fixture Planning Using the Concentric Method

Figure 7.24 presents the results for selecting the clamping surfaces. The procedures for selecting the primary clamping surface in a concentric method are the same in a 3-2-1 method and have been discussed earlier. In the figure, the "CDB2" presents the window where the surface that has been picked is shown. The *clamping surface name* is "TopSurface_PW2" and *clamping surface description* is "PrimaryClampingSurface".

The selection procedures for secondary clamping surface in a concentric method is the same in selecting the secondary locating surface in a 3-2-1 method, which a hole surface is picked from the database. In the figure, the "CDB2_1" presents a window where a hole surface that has been picked is shown. The *clamping surface name* is "HoleSurface_PW2" and *clamping surface description* is "SecondaryClampingSurface".

The procedures in selecting the tertiary clamping surface for concentric method are the same in a 3-2-1 method and have been discussed earlier. In the figure, the "CDB2_2" presents the window where the surface that has been picked is shown. The *clamping surface name* is "FrontSurface_PW1" and *clamping surface description* is "TertiaryClampingSurface". The figure also illustrates the dialog "CCS_1" which displayed the results in the dialog boxes for "Select Clamping Surface" and these results are the following:

Clamping Surfaces	
Primary Clamping Surface Name:	"TopSurface_PW2"
Secondary Clamping Surface Name:	"HoleSurface_PW2"
Tertiary Clamping Surface Name:	"FrontSurface_PW2"

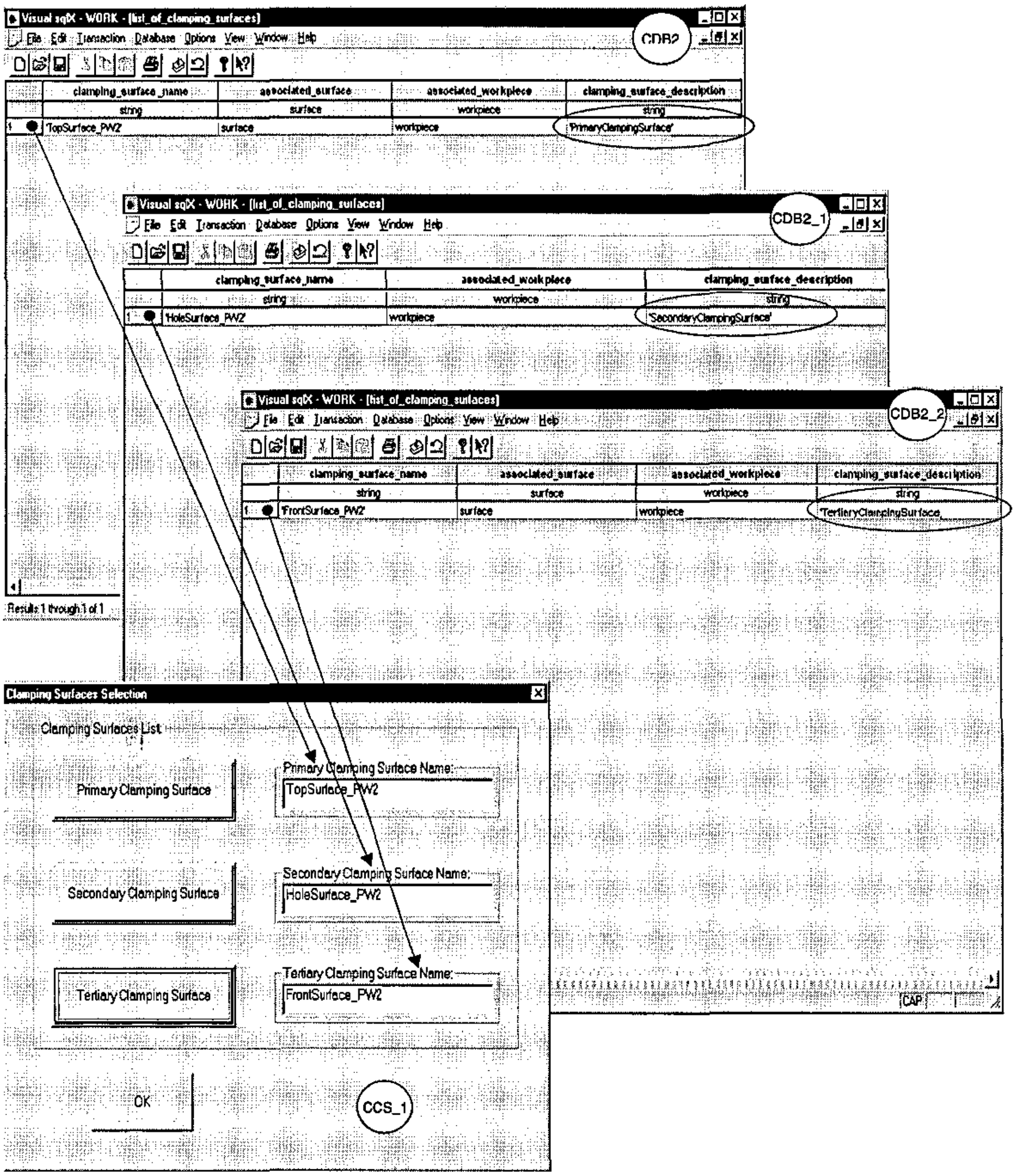


Figure 7.24 – The Results for Selecting Clamping Surfaces

7.3.1.5.3 Select Fixturing Elements

The selection procedures of the modular fixturing elements are the same as discussed in the 3-2-1 method. The fixturing elements are also associated to a prismatic workpiece with a reference number. The same way with the name of surfaces and name of points are attached to a particular prismatic workpiece with its reference number as "TopSurface_PW2" for a surface name or "PW2_P01" for a point name. The "PW2" is the workpiece reference number stands for the "Prismatic_Workpiece_02.

Figure 7.25 presents the dialogs for selecting the fixture elements. The first dialog "CFE" contained the list of workpiece, which in this case the "Prismatic_Workpiece_02" is highlighted. In the figure, the "Select Fixture Elements" button is clicked and displayed the dialog "CFE_1" that contained the modular fixture elements list. The "CFE_1" dialog contained the names of the modular fixture elements stored in the database for a "Prismatic_Workpiece_02".

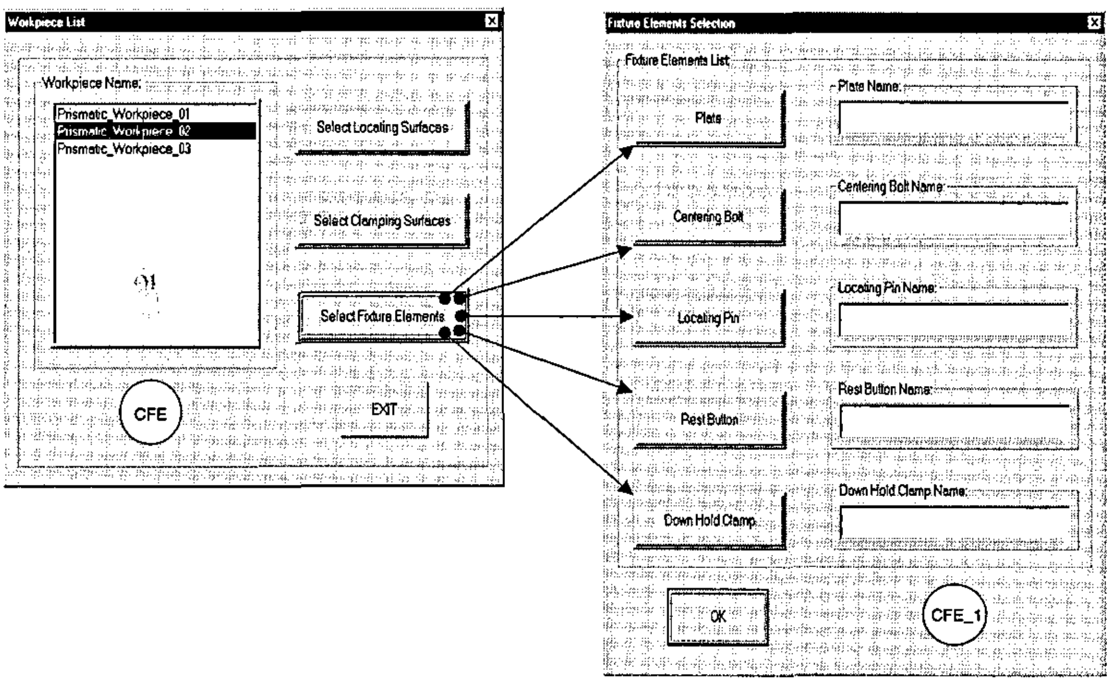


Figure 7.25 – The Dialogs for Selecting Fixture Elements to Support Fixture Planning Using the Concentric Method

Figure 7.26 presents the results of the "Select Fixture Elements" buttons. The "CDB3" window contained the *workpiece_name*, which in this case is the "Prismatic_Workpiece_02" is highlighted and the *list_of_fix_elem* of which can be clicked and displayed the "CDB3_1" window that contained the list of the six modular fixutring elements.

Each of the names in the list can be clicked and displayed the information of the specific fixture element and the same with other windows, "CDB3_2" for a "plate", "PDB3_3" for a "locating pin", "PDB3_4" for a "rest button" and "PDB3_6" for a "down hold clamp". Each window of the modular fixturing elements contained other information such as description of a fixture element, function, material name, degrees of freedom and catalogue numbers. There are other information stored in the database for each modular fixture element being used in this work. The figure also illustrates the dialog "CFE_1" which displayed the results in the dialog boxes for "Select Fixture Elements" and these results are the following:

Modular Fixturing Elements	
Plate Name:	"BasePlate_PW2"
Centering Bolt Name:	"CenteringBolt_PW2"
Locating Pin Name:	"Self_Aligning_Pad_PW2"
Rest Button Name:	"ScrewedRestButtonPW2"
Down Hold Clamp Name:	"ClampElement_PW2"

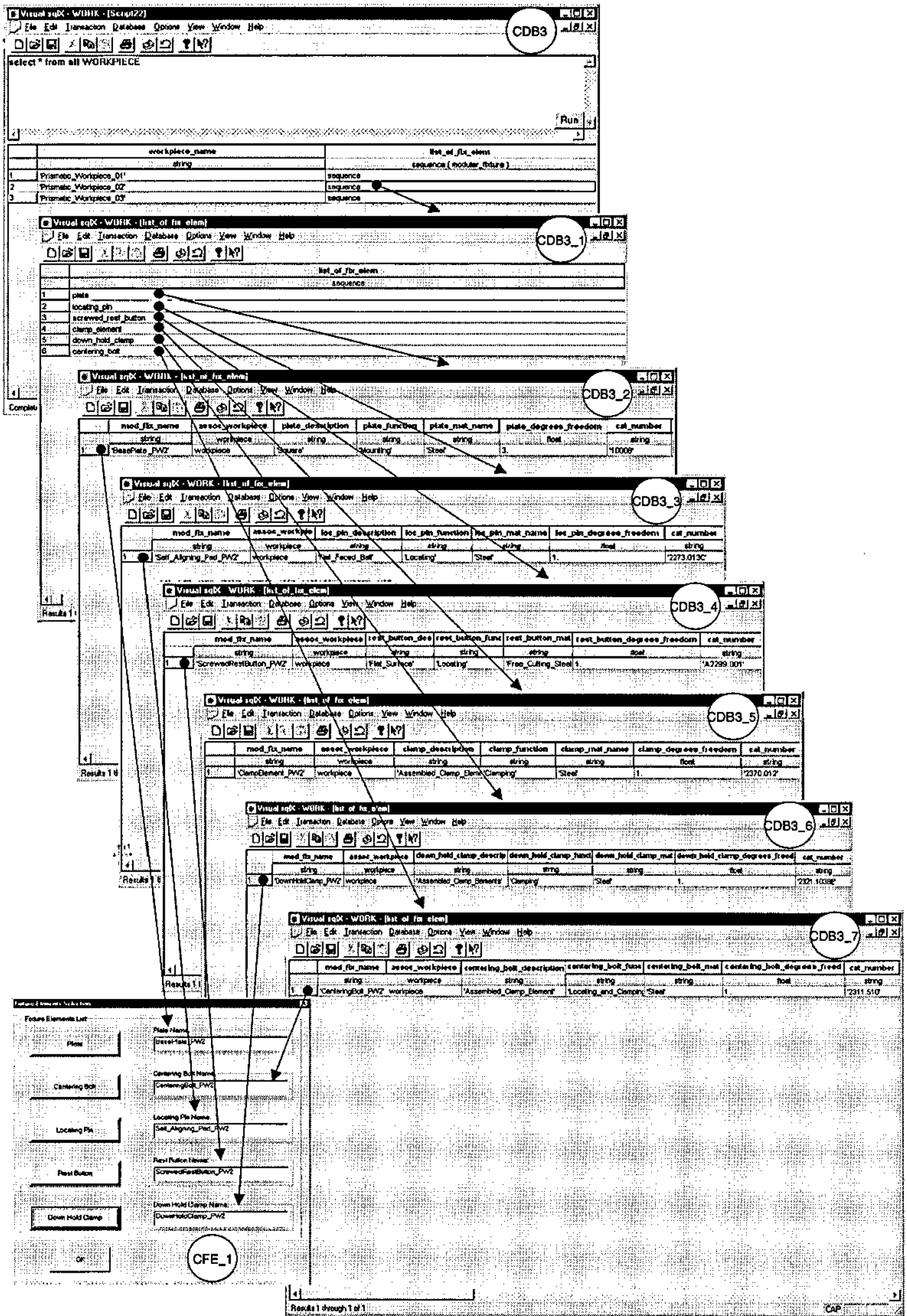


Figure 7.26 – The Results for Selecting Fixture Elements

7.3.1.6 Evaluation of the Results

The section has explored the capabilities of the manufacturing model in conjunction of a product model to give useful support in the support fixture planning application by utilising the 3-2-1 and concentric methods to generate a fixture plan of a work-piece. The experiment has shown following:

- that the support fixture planning was able to utilise the 3-2-1 fixturing method to provide useful support to generate fixture plan by selecting the locating surfaces, clamping surfaces and the modular fixture elements to be used for a particular prismatic workpiece ("Pismatic_Workpiece_01") and the results are as follows:

Locating Surfaces	
Primary Locating Surface Name:	"BottomSurface_PW1"
Secondary Locating Surface Name:	"RearSurface_PW1"
Tertiary Locating Surface Name:	"RightSideSurface_PW1"
Clamping Surfaces	
Primary Clamping Surface Name:	"TopSurface_PW1"
Secondary Clamping Surface Name:	"FrontSurface_PW1"
Tertiary Clamping Surface Name:	"LeftSideSurface_PW1"
Modular Fixturing Elements	
Plate Name:	"BasePlate_PW1"
Locating Pin Name:	"Self_Aligning_Pad_PW1"
Rest Button Name:	"ScrewedRestButton_PW1"
Clamp Element Name:	"ClampElement_PW1"

- that the support fixture planning was able to utilise the concentric fixturing method to provide useful support to generate fixture plan by selecting the locating surfaces, clamping surfaces and the modular fixture elements to be used for a particular prismatic workpiece ("Prismatic_Workpiece_02") and the results are as follows:

Locating Surfaces	
Primary Locating Surface Name:	"BottomSurface_PW2"
Secondary Locating Surface Name:	"HoleSurface_PW2"
Tertiary Locating Surface Name:	"RearSurface_PW2"
Clamping Surfaces	
Primary Clamping Surface Name:	"TopSurface_PW2"
Secondary Clamping Surface Name:	"HoleSurface_PW2"
Tertiary Clamping Surface Name:	"FrontSurface_PW2"
Modular Fixturing Elements	
Plate Name:	"BasePlate_PW21"
Centering Bolt Name:	"Centering_Bolt_PW2"
Locating Pin Name:	"Self_Aligning_Pad_PW2"
Rest Button Name:	"ScrewedRestButton_PW2"
Down Hold Clamp Name:	"DownHoldClamp_PW2"

7.3.2 Support Product Design – Experiment 2

7.3.2.1 General Description of Experiment

The experiment performed and described in this section demonstrates how the manufacturing model in conjunction with product model can provide the fixturing information for support product design application to give design advice for suggested changes to workpiece by using radial fixturing method. The aim can be listed below:

- How a radial fixturing method in the manufacturing model can provide design advice for suggested changes to workpiece in conjunction with product model.

7.3.2.2 Populating the Product Model

Figure 7.27 shows the third prismatic workpiece used in this experiment. The "Prismatic_Workpiece_03" which is highlighted in the figure contained the same information with other the prismatic workpieces being used in this work. The difference lies on the hole features, which in this workpiece have two existing hole features.

Two reamed holes are needed for locating and clamping in this method using the hole features. This prismatic workpiece is used to illustrate how support product design able to use the radial fixturing method stored in the manufacturing model in conjunction with the product model to result a design advice for suggested changes to workpiece.

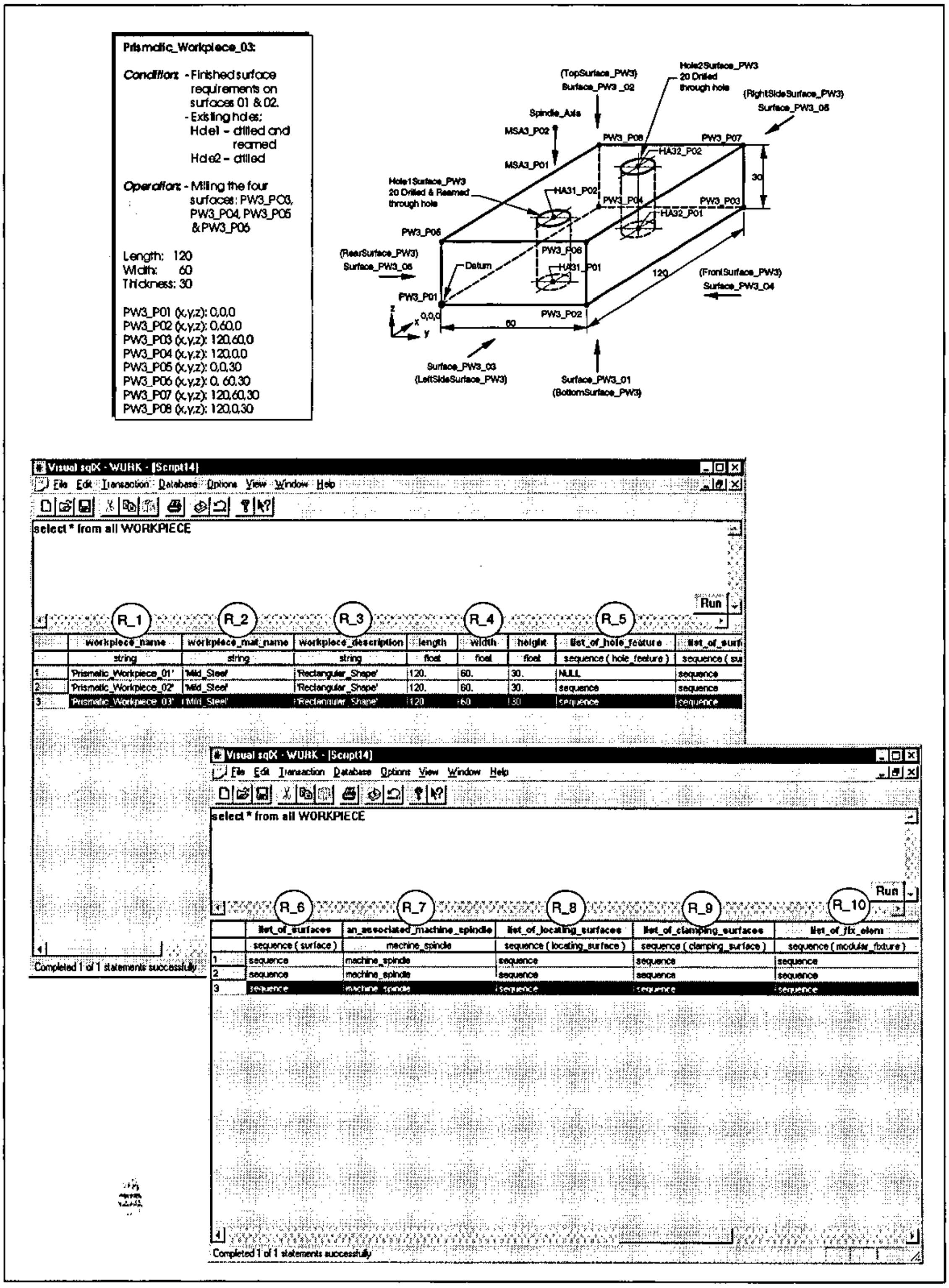


Figure 7.27 – The Prismatic_Workpiece_03 Representation Within the Product Model Database

Figure 7.28 illustrates the hole feature representation in the database. The figure presented that there are two existing hole features in the workpiece and shows the information that are stored in the database.

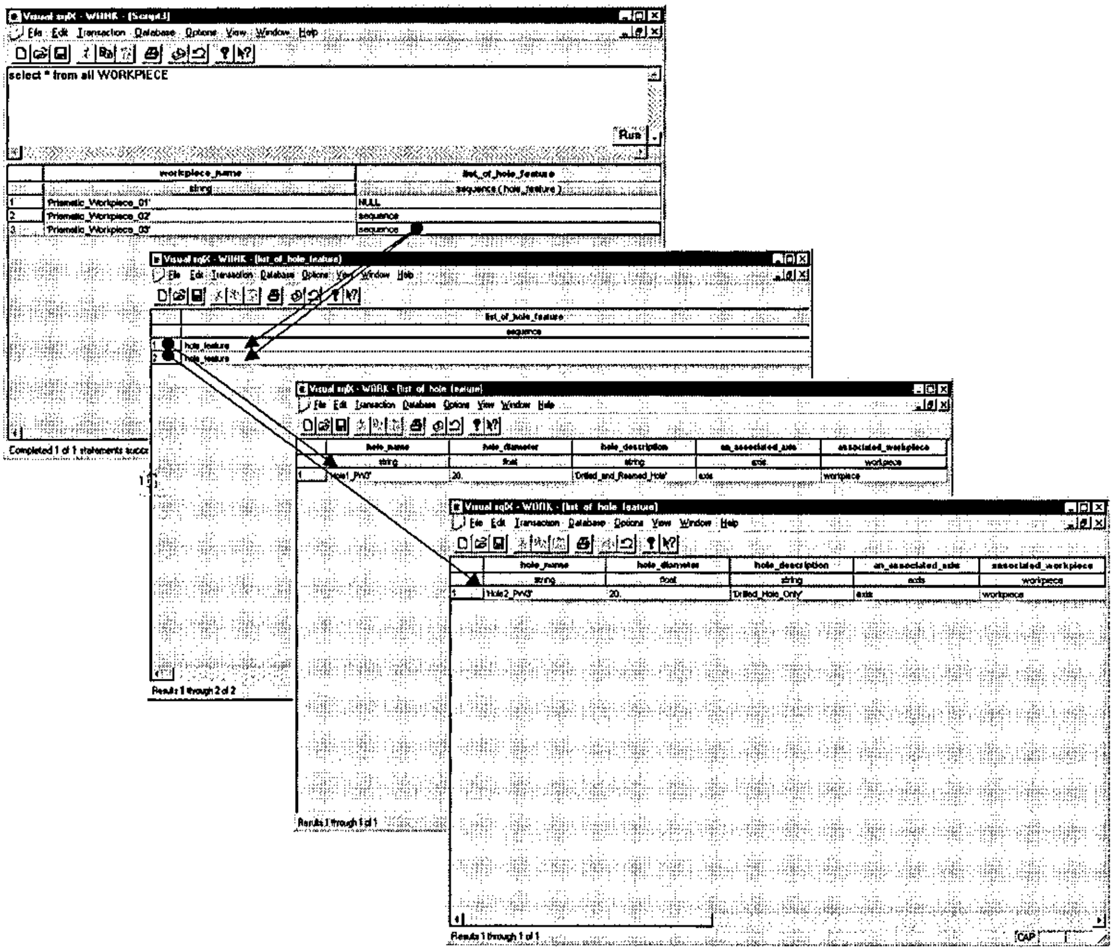


Figure 7.28 – Example of Hole Feature Representation for Prismatic_Workpiece_03

7.3.2.3 Utilising the Data in Manufacturing Model

The experiment conducted in this section have utilised the same set of information that is stored in the manufacturing model as used in the previous experiment. These are the information related to fixturing processes and fixturing resources, which are made available to provide useful design advice in support product design application.

7.3.2.4 Design Advice based from the Radial Method

This section explores the radial fixturing method capability to provide design advices and selection of a possible locating and clamping surfaces using the fixturing information in the database. The "Prismatic_Workpiece_03" shown in Figure 7.27 is used to demonstrate this method. The radial method uses two reamed holes to locate and clamp a workpiece.

7.3.2.5.1 Select Locating Surfaces

Figure 7.29 presents the dialogs for selecting the locating surfaces. The first dialog "RLS1" contained the list of workpiece, which in this case the "Prismatic_Workpiece_03" is highlighted. In the figure, the "Select Locating Surfaces" button is clicked and flagged out a message "Two Holes in the List, one is a Reamed Hole and another is a Drilled Hole" in the "RLS1_1" window. This means the application found two hole features in the database for this workpiece. Pressing the "OK" button, flagged out another message "Can the Drilled Hole be Reamed?" in the "RLS1_2" window. In this case the inquiry can be answered by pressing a "yes" or "no" buttons. The user can select which button to press. Pressing the "yes" the application will flag message to ream the hole. In this case, the "no" button is pressed and flags out a message "Can a NEW HOLE be made and Reamed at the center of the workpiece?" in the "RLS1_3 window. The inquiry can be answered by pressing a "yes" or " no" buttons. Pressing the "yes" button the application will send the message to the database and add the new hole feature in the list. Then, it flags out a message "THREE HOLES FOUND. Two Reamed Holes and One Drilled Hole" in the "RLS1_4" window. Pressing the "OK" button, flagged out a message "Use the Two Reamed Holes for Locating and Clamping" in the "RLS1_5" window. Then, pressing the "OK" button flagged out a message "Do you want to Select Locating Surfaces, Clamping Surfaces and Fixture Elements?" in the "RLS1_6" window. Pressing the "yes" button, displayed the "RLS1_7" dialog that contained the locating surfaces list. The "RLS1_3" window demonstrates the capability of the radial method to provide a design advice for suggested changes to workpiece by adding a new hole on the workpiece.

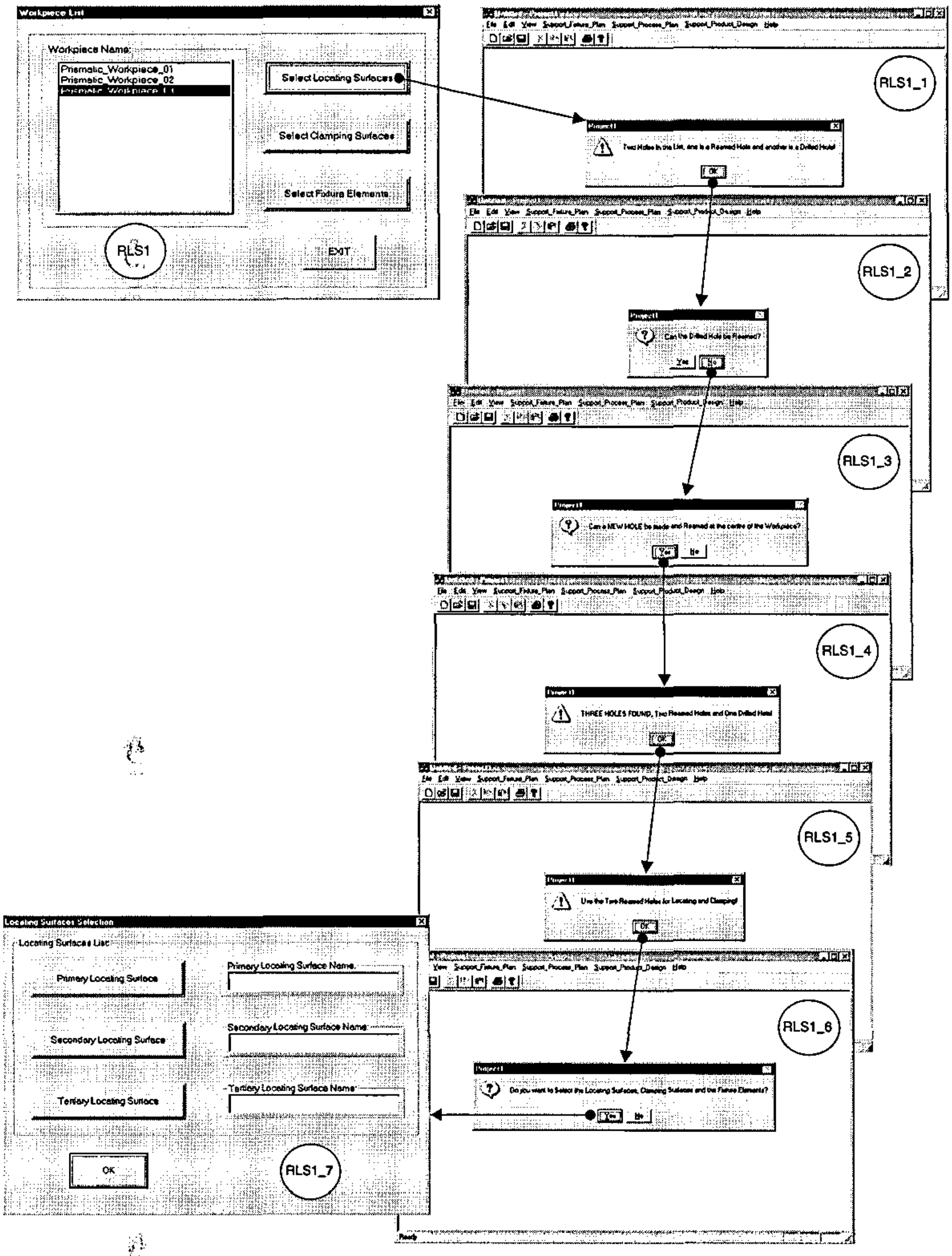


Figure 7.29 – The Dialogs for Selecting the Locating Surfaces to Support Product Design Using the Radial Method

Figure 7.30 presents the results after creating a new hole to the workpiece. The figure shows a third hole added in the list of list of hole feature in the database. The third hole feature has hole a name "Hole3_PW3", hole diameter of "20", hole description of "CenterHole_Drilled_and_Reamed". This means that after pressing the "yes" button in "RLS1_3" window the database added the third hole and update the list of hole feature that have been stored. The result for design advice is:

Design Advice
Suggested Changes to Workpiece: "Create a New Reamed Hole at the Center"

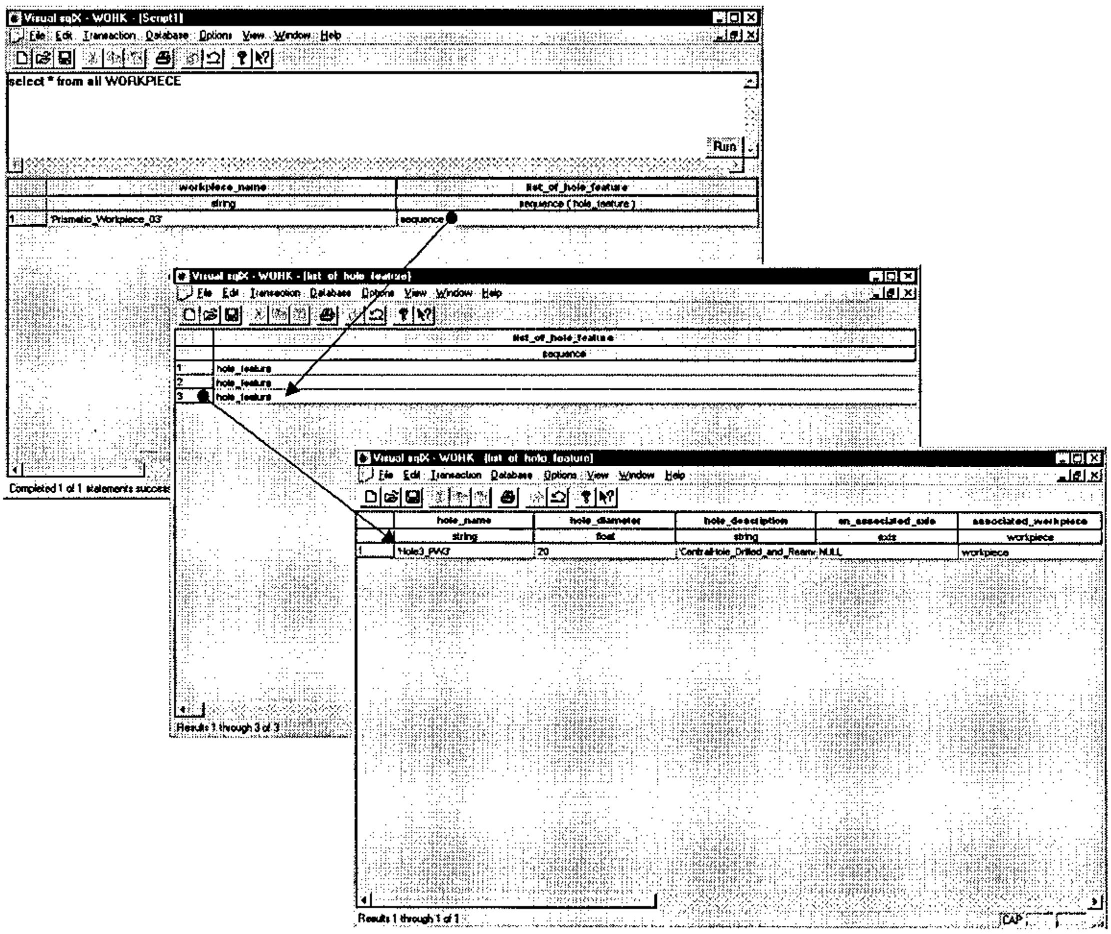


Figure 7.30 – The Results After Creating a New Hole Feature

Figure 7.31 presents the results for selecting the locating surfaces. The procedures in the selection of the locating surfaces are completed and successful as in the first experiment. The figure shows the primary locating surface name is "BottomSurface_PW3" and the locating surface description is "PrimaryLocatingSurface". The secondary locating surface name is "Hole1Surface_PW3" and the locating surface description is "SecondaryLocatingSurface". The tertiary locating surface name is "Hole3Surface_PW3" and the locating surface description is "TertiaryLocatingSurface".

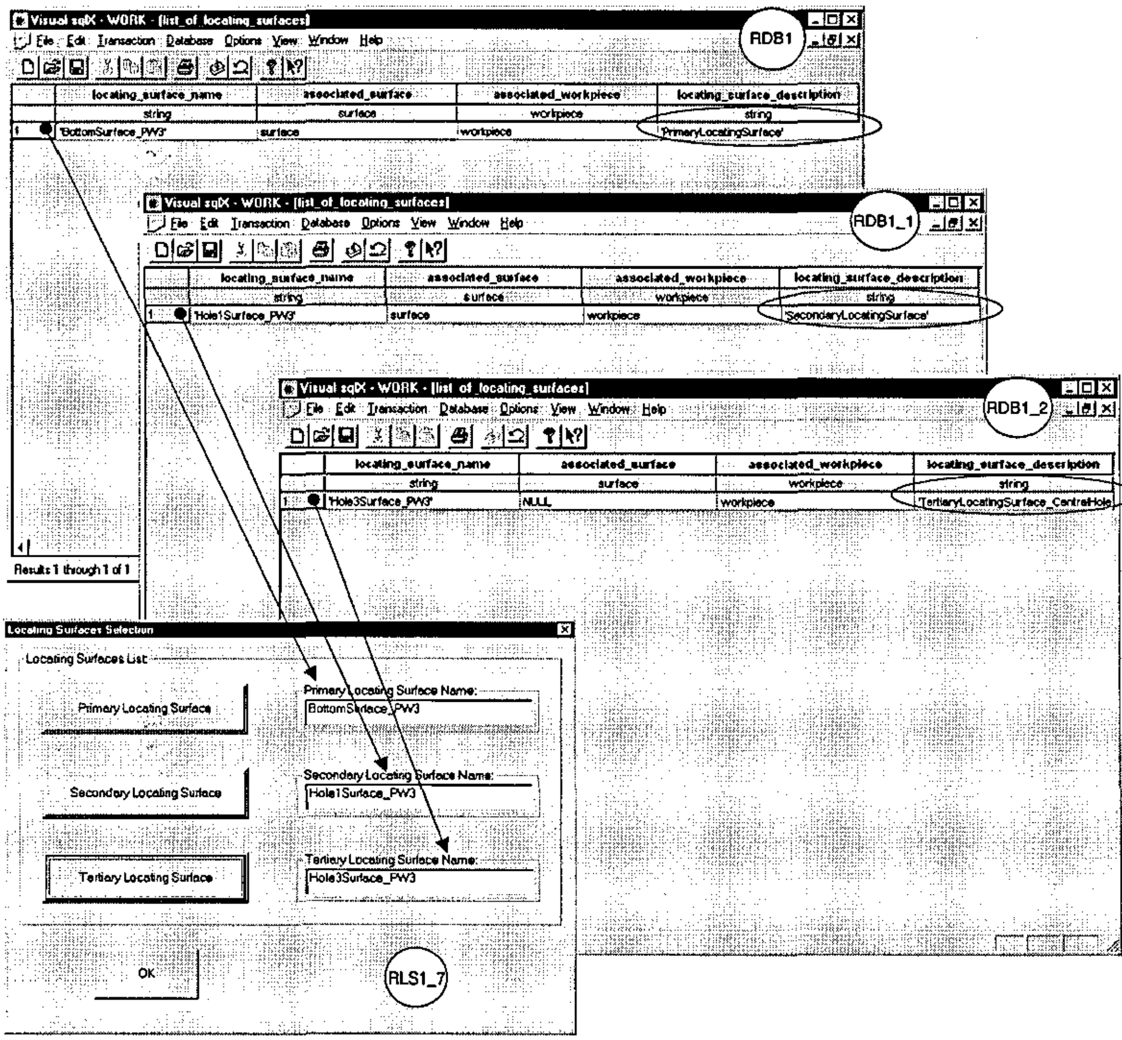


Figure 7.31 – The Results for Selecting Locating Surfaces

7.3.2.5.2 Select Clamping Surfaces

Figure 7.32 presents the results for selecting the clamping surfaces. The procedures in the selection of the clamping surfaces are completed and successful as in the first experiment. The figure shows the primary clamping surface name is "TopSurface_PW3" and the clamping surface description is "PrimaryClampingSurface". The secondary clamping surface name is "Hole1Surface_PW3" and the clamping surface description is "SecondaryClampingSurface". The tertiary clamping surface name is "Hole3Surface_PW3" and the clamping surface description is "TertiaryClampingSurface".

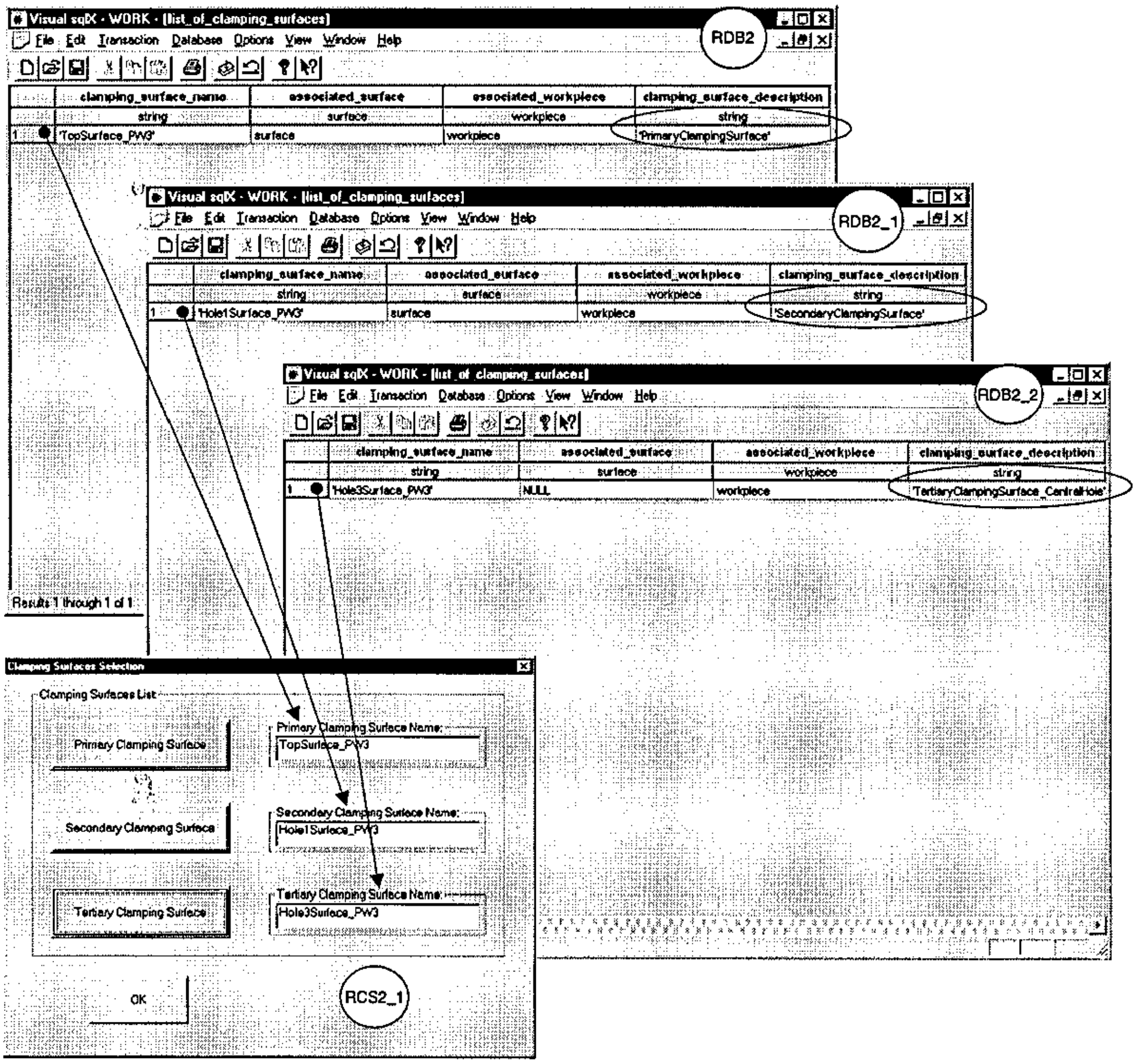


Figure 7.32– The Results for Selecting Clamping Surfaces

Figure 7.33 presents the windows where the flagged out messages for the alternative advice to the user when the "no" button is pressed at "RLS1_3" window in Figure 7.30. The significance of Figure 7.36 as shown, the radial method is able to provide the design advice for suggested changes to workpiece as depicted in Figure 7.30 by pressing the "yes" button and by pressing the "no" button is able to provide an alternative advice and in this case, flagging a message "Consider the 3-2-1 Method" for locating and clamping the workpiece. The result for alternative design advice is:

Design Advice	
Alternative Design Advice:	"Consider the 3-2-1 Method"

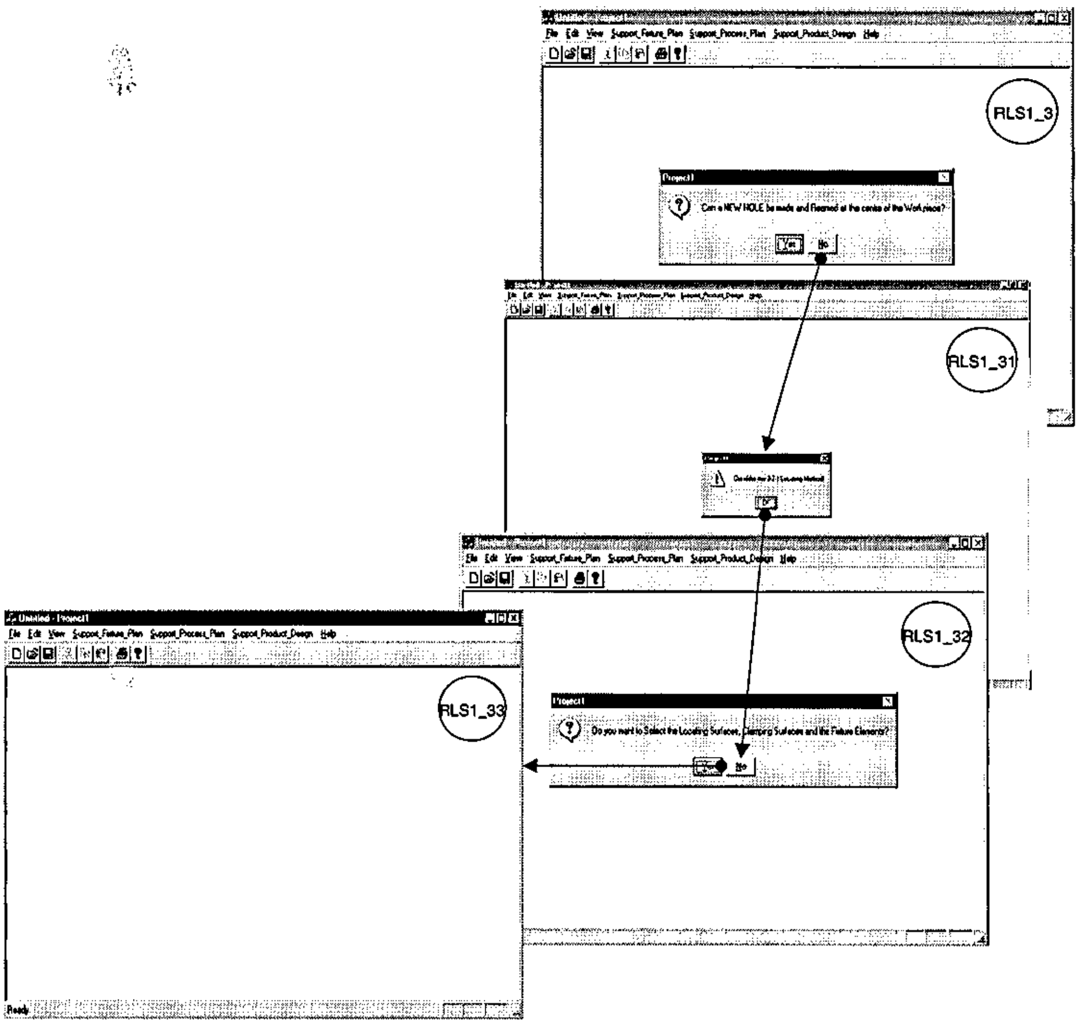


Figure 7.33 – The Flagged Message for Alternative Advice

7.3.2.5 Evaluation of the Results

The section has explored the capabilities of the manufacturing model in conjunction of a product model to give useful support in the support product design application by utilising the radial method to provide design advice to the user and able to select the possible locating surfaces, clamping surfaces and the modular fixture elements to be used. The experiment has shown following:

- that the support product design application was able to utilise the radial fixturing method to give useful support by providing design advice for suggested changes to workpiece.

Design Advice	
Suggested Changes to Workpiece:	"Create a New Reamed Hole at the Center"
Alternative Advice:	"Consider the 3-2-1 Locating Method"

7.4 Summary

This chapter has discussed the implementation of the experimental system and the experimental work carried out by the author to explore the utilisation of the manufacturing model in conjunction with the product model to provide support to particular design and manufacture applications of support fixture planning and support product design. The implementation was in three stages; implementation of the product model, implementation of the manufacturing model and the implementation of the user interface dialogs. The product model was implemented according to the concepts discussed in section 5.5 and the manufacturing model was implemented according to the concepts discussed in section 5.4. The implementation of the user dialogs, which are used by the user to interact with the system.

The author has shown through the experimental system that structures defined in the manufacturing model and product model which have the fixturing related information were able to provide useful support to particular design and manufacture application of support fixture planning and support product design. The structure defined in the product model allows to be utilised as a source workpiece fixturing related information and the manufacturing model structure was able to hold the 3-2-1, concentric and radial fixturing methods and the modular fixturing elements which can be utilised to support the two applications. The support fixture planning and support product design applications designed to asses the structure of the manufacturing model is able to run in the background of the system using common information and producing different results.

Chapter 8

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

8.1 Introduction

The research work described in this thesis has explored the presentation of fixturing information in an information modelling environment such that this information be made available to a range of design and manufacture applications. The fixturing information presentations within the manufacturing model have been implemented to explore the research concept in conjunction with the product model. This chapter presents the discussion of the approach of this thesis, which is found in section 8.2, followed by the conclusions reached in section 8.3 and the recommendations for further work in section 8.4.

8.2 Discussion

8.2.1 Modelling Fixturing Information

This research has shown how fixturing information structure can be defined to support to a range of design and manufacture applications. The manufacturing model that contained the fixturing process of locating and clamping and their methods as well as the fixturing resources, which supports the particular design and manufacture applications of fixture planning, process planning and product design for fixturing in conjunction with a product model that contained the product information have been presented. The work provides a novel contribution in the area of fixturing research within its context of integrated information systems. The work in this research is the first attempt to capture the fixturing methods and fixturing elements and represented in an information model environment.

The approach taken in this research work provides information support to a range of design and manufacture applications, and also provides methods in locating and clamping for selected prismatic workpieces by utilising the 3-2-1, concentric and radial fixturing methods available in the manufacturing model. One result of this work has been a journal publication [Bugtai & Young, 1998], which describes the initial structures in the manufacturing model and the product model. The publication also brings about the general ideas of how fixturing planning, process planning and product design support applications interact with these information models. This publication can be found in Appendix D.

The work reported in this thesis has significantly contributed to fixturing information model research, however, issues related to tolerances, irregular-surfaced workpiece and error in locating and clamping has to be addressed in future work. This research work has used a three-axis machine tool to demonstrate the approach taken, but using a four-axis or a five-axis machine tool and the effect of the cutting force has to be explored in further investigation in order to provide more comprehensive support in this fixturing system.

This work has employed the use of modular fixtures as fixturing resources, due to the considerable advantages that modular fixturing systems could offer such as reusability, reduced lead-time to assemble and dis-assemble and standard fixturing elements availability on the shelves. However, further work can be expanded to investigate the use of dedicated fixtures, which needs to be designed from scratch in order to locate and clamp a workpiece that modular fixtures could not handle.

8.2.2 Product Information

The research concept of this work considered a prismatic workpiece to be used to assess the value of the approach taken. The author assumed that the information in the product model concerning the workpiece has been through with a pre-process plan and there were procedures taken to come up with the information into the model. However, the author believes that the algorithms on how this information being selected should be incorporated in future investigation.

The geometric information is required to define the shape, the individual surfaces and features of each prismatic workpiece into the database. There was the possibility for the author in linking to a CAD system during the course of the research, but due to time constraint the author opted not to link with a CAD system. However, the research work defined the shape, surfaces and features of a prismatic workpiece by its geometric points, which constrained the geometry of workpiece that can be stored in the database. Therefore, there is a need to link to a CAD system to accommodate greater complexity of geometry for workpieces. With CAD capabilities that include analysis on complex geometry, it can directly and easily store the workpiece information into the database.

The prismatic workpieces in a rectangular block form have been used in the experiments performed in section 7.3 to assess the approach taken in this research was completed and has been successful using the three different prismatic workpieces stored in the database. However, further work will be required to include the rotational workpiece and irregular-surfaced workpiece in order to determine to what extent the information models can provide support to this type of workpieces.

8.2.3 Utilising the Information Models

The research has shown that the information models can provide support for a range of design and manufacture activities of support product design, support process planning and support fixture planning in which the concept is presented in Chapter 4.

The utilisations of the information models showed that there have been sharing of information across the design and manufacture applications and have produced different results. However, the approach is limited in utilising the information available in the manufacturing model, especially the fixturing methods and the fixturing elements. This may require more exploration to cover other fixturing methods and different kind of fixturing elements aside from modular fixtures.

The experiments performed in section 7.3 has been successful to illustrate that the support fixture planning application and support product design application were able to utilised the information stored in the manufacturing model and in the product model. The utilisation of the information models has shown how the structures defined in the product model and manufacturing model were able to support a data-driven applications that require a fixturing information inputs. However, the structure of the fixturing support system is based by the three fixturing methods of 3-2-1, concentric and radial that are available in the manufacturing model. Therefore, the effect of adding information into the database and the capability of the support systems to cope with the changes has to be explored in future work.

8.2.4 The Experimental Environment

The fixturing experimental system was developed based on object-oriented approach and for this reason a UniSQL/X object-oriented database was used to give support to the system. The object-oriented database has been used successfully to capture the class structure of the fixturing information models. Inside of the database the relationships can be defined in terms of the structure and behaviour between classes. The UML class diagrams were used to show in detail the classes and their attributes necessary for providing the manufacturing model and product model with the capability of being a source of information.

The UniSQL/X database has a sufficient capability for exploration of the research ideas presented in this thesis. However, it is not adequate for the development of a commercial system because it has shown limitations in terms of integration with

Visual C++ environment as is not possible to open the database and the application at the same time. In effect to overcome this difficulty the database is closed first before opening the application.

8.3 Conclusions

- The research work has contributed in the area of advancing the understanding of integrated information system in design and manufacture to support product designers and manufacturing engineers by defining a representation of fixturing capability within an information model environment.
- An integrated fixturing information system based on the use of combined manufacturing model and product model has been defined to provide an information sharing environment for range of design and manufacture applications.
- It has been shown that the capability of fixturing processes can be represented in a manufacturing model that captures the locating process and clamping process and their methods as well as the modular fixturing elements as the fixturing resources.
- It has been shown that fixturing information structures defined in the manufacturing model and product model can serve as a source of information that provide a useful support to particular design and manufacture activities in fixture planning, process planning and product design for fixturing.
- It has been shown that having the defined structures for the product model and manufacturing model allow them to have information interactions in order to support the concurrent product development design process.

- By providing the support product design, support process planning and support fixture planning experimental applications with a common source of information, their integration became possible. The utilisation of the product model and manufacturing model as the source of fixturing information proved to be effective in a concurrent engineering environment.

- The research has shown that the use of the IDEF0 and UML methodologies proved to be effected in the definition of the structures for the manufacturing model, product model and in the design of the experimental system. The IDEF0 allowed the understanding and the capture of the information at high level, while UML methodology helped in the creation of the detailed attributes for the classes defined.

- An experimental system has been implemented using UniSQL/X object-oriented database and C++ programming language environment. This system has been used successfully to explore the research ideas using the structures defined in the manufacturing model and product model.

- The implementation of the experimental system has shown that the information models can be utilised to provide a common sources of information to generate fixture plan for support fixture planning application and to provide design advice for product design application.

8.4 Recommendations for Future Work

- This research has shown that information models was able to provide a common source of information to a range design and manufacture applications of support product design, support process planning and support fixture planning. However, the effect of an update in the database with addition for new information and the capability of the support systems to cope with the changes have to be explored.

- This thesis has utilised prismatic workpiece geometry to assess the approach taken of this research work. However, there is a need to explore how the fixturing information models can provide support to rotational workpiece, irregular-surfaced workpiece and complex geometry workpieces.

- There is a need to incorporate the database with a commercial CAD system to generate the geometry of the workpieces and the fixturing elements utilising the functionality of the CAD package and store these information in the product model and manufacturing model respectively. In the experimental system, only simple geometric manipulation has been considered, but in a commercial system more complex geometric manipulations is required.

- The introduction of the concurrent engineering philosophy in the area of product design and manufacture can be only achieved by integration and therefore, the trend of future research is towards a system that reflects a whole integration. Until recently, most research has been focused on development of systems that deals with machining fixtures. However, there is a need to extend this in the future to cover the fixturing of other manufacturing processes such as involved in assembly fixtures, inspection fixtures and welding fixtures.

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Appendix – A

IDEF0 Activity Modeling Tool

Activity modelling gives a way of representing activities, the data that they require, the data that they produce, and their relations to other activities. By doing this type of modelling there is a greater chance of success in providing a valid representation of activity relationships and their data flows.

One technique of representing activities and interrelationships is IDEF0, which stands for ICAM definition language; a representation technique based a Structured Analysis Design Technique (SADT). The name follows from the US airforce ICAM programme, where the technique was used to consider and overall concept for CIM. The technique has also proved valuable in industry in helping the understanding of how aspects of companies' business operate [Colquhoun *et al.*, 1993]. IDEF0 has been used successfully in research programmes and industrial applications to model manufacturing activities.

The United States Air Force commissioned the developers of SADT to develop a function modeling method for analyzing and communicating the functional perspective of a system. Effective IDEF0 models help to organize the analysis of a system and to promote good communication between the analyst and the customer. IDEF0 is useful in establishing the scope of an analysis, especially for a functional analysis. As a communication tool, IDEF0 enhances domain expert involvement and consensus decision-making through simplified graphical devices. As an analysis tool, IDEF0 assists the modeler in identifying what functions are performed, what is needed to perform those functions, what the current system does right, and what the current system does wrong [NIST, 1993]. Thus, IDEF0 models are often created as one of the first tasks of a system development effort.

The IDEF0 graphic language has two basic components, boxes and arrows. Each box represents a single activity. Arrows represent interactions such as data flows between activities. Boxes and arrows are combined in diagrams which themselves support higher-level activities. An IDEF0 model is an organized sequence of diagrams with supporting text. A high level or context diagram with a single box represents the whole subject. Apart from the context diagram, which can only have one activity, each diagram should contain between three and six activities. Each box in a diagram can itself be the subject of a breakdown and hence produce a lower level diagram. This process can continue until the desired level of detail is reached. A letter and a number (this is shown in the bottom left hand corner of each diagram) denote each level or diagram. The context diagram by convention is referred to as node A-0. The breakdown of the context is denoted as A0. A1 refers to the breakdown of the first activity of A0, A2 to the second activity of A0 and so on, as shown in Figure – A.1.

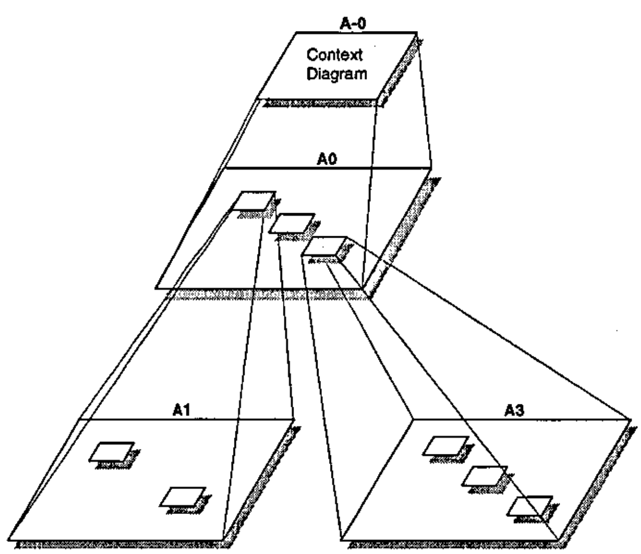


Figure A-A.1 - Breakdown of Higher Level Activities

The arrows show constraint relationships of data flows between activities. Each arrow is labelled with its content. Arrows can be combined or split. The arrows entering or leaving a box correspond to those entering or leaving the diagram that breaks down that box. The way in which an arrow can affect a box is subdivided into four classes: input, output, control and mechanism. The IDEF0 language limits these to each touch different sides of the box as shown in Figure - A.2. Thus control enters the top of the box, input to output flows from left to right and mechanisms enter the base. By necessity an activity will always have some form of control. It is often difficult to distinguish between control and input although the latter must by definition undergo some transformation during the course of the activity. Where input and control coincide, then only a control entry is shown. Sometimes an arrow may be applicable to all the lower level activities. To make the diagrams clearer and easier to read, such arrows may be tunneled to indicate that they are applicable to all the sub-activities. A pair of brackets around the arrowhead shows this.

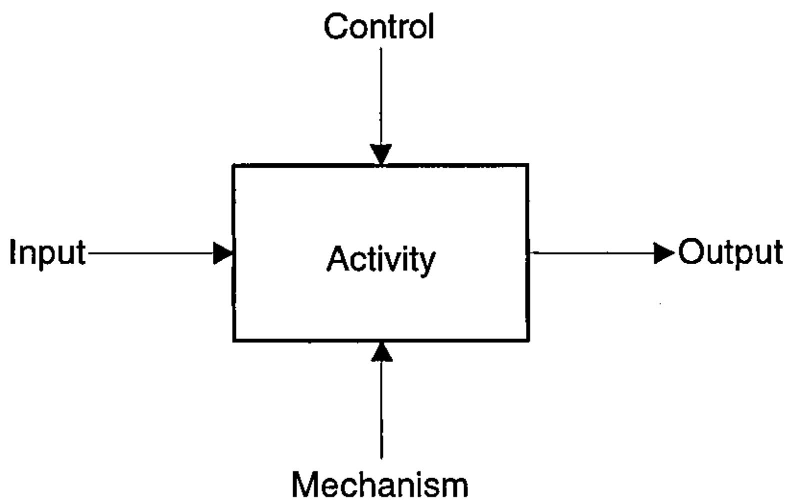


Figure A-A.2 – IDEF0 Function Box and Interface Arrows

The box and arrow graphics of an IDEF0 diagram show the function as a box and the interfaces to or from the function as arrows entering or leaving the box. To express functions, boxes operate simultaneously with other boxes, with the interface arrows constraining when and how operations are triggered and controlled. The basic syntax for an IDEF0 model is shown in the figure above.

IDEF0 concepts designed to enhance communication include the following:

- Diagrams based on simple box and arrow graphics.
- English text labels to describe boxes and arrows and glossary and text to define the precise meanings of diagram elements.

- The gradual exposition of detail featuring a hierarchical structure, with the major functions at the top and with successive levels of subfunctions revealing well bounded detail breakout.

- A node chart that provides a quick index for locating details within the hierarchic structure of diagrams.

- The limitation of detail to no more than six subfunctions on each successive function.

In IDEF0 diagrams, not all the activities shown at a level need to be performed for all cases. It may be that some activities may be bypassed in which case the input to those activities would remain unchanged. While some diagrams naturally follow a sequence in time, this is not implied by the model breakdown. IDEF0 shows only the possible activities and data flows between them - any time sequence is given as part of the supporting text. Each IDEF0 model must have a defined purpose and viewpoint since these will affect the way the model is developed.

The rules of IDEF0 require sufficient rigor and precision to satisfy needs without overly constraining the analyst. IDEF0 rules include the following:

- Control of the details communicated at each level (three to six function boxes at each level of decomposition).
- Bounded Context (no omissions or additional out-of-scope detail).
- Diagram Interface Connectivity (Node numbers, Box numbers, C-numbers, and Detail Reference Expression).
- Data Structure Connectivity (ICOM codes and the use of parentheses).
- Unique Labels and Titles (no duplicated names).
- Syntax Rules for Graphics (boxes and arrows).
- Data Arrow Branch Constraint (labels for constraining the data flow on branches).
- Input versus Control Separation (a rule for determining the role of data).
- Data Arrow Label Requirements (minimum labeling rules).

- Minimum Control of Function (all functions require at least one control).
- Purpose and Viewpoint (all models have a purpose and viewpoint statement).

The primary strength of IDEF0 is that the method has proven effective in detailing the system activities for function modeling, the original structured analysis communication goal for IDEF0. Their inputs, outputs, controls, and mechanisms (ICOMs) can describe activities. Additionally, the description of the activities of a system can be easily refined into greater and greater detail until the model is as descriptive as necessary for the decision-making task at hand.

One problem with IDEF0 is the tendency of IDEF0 models to be interpreted as representing a sequence of activities. While IDEF0 is not intended to be used for modeling activity sequences, it is easy to do so. The activities may be placed in a left to right sequence within decomposition and connected with the flows. It is natural to order the activities left to right because, if one activity outputs a concept that is used as input by another activity, drawing the activity boxes and concept connections is clearer. Thus, without intent, activity sequencing can be imbedded in the IDEF0 model.

In cases where activity sequences are not included in the model, readers of the model may be tempted to add such an interpretation. This anomalous situation could be considered a weakness of IDEF0. However, to correct it would result in the corruption of the basic principles on which IDEF0 is based and hence would lose the proven benefits of the method. The abstraction away from timing, sequencing, and decision logic allows concision in an IDEF0 model. However, such abstraction also contributes to comprehension difficulties among readers outside the domain. This particular problem has been addressed by the IDEF3 method.

Appendix - B

The Unified Modeling Language - UML

Introduction

This section describes the methodology adopted for realisation of this research. Object-Oriented Technology has proven itself as higher quality engineering software systems. Object-oriented programming Languages such as C++ has evolved to address the tactical issue of implementing automated solutions. Standards for object-oriented databases, user interfaces, and distributed object manager have begun to emerge, each addressing some different functional aspect of software systems. In this research the description of the computational viewpoint will be based on UML - Unified Modelling Language [Booch *et al.*, 1999].

The object-oriented approach to software development is based on modelling objects from a real world (e.g. walls, slots, pockets, machining process, etc.) offering also advantages if compared to algorithmic approaches, which are conventional. Such advantages are better for understanding the requirements; handling of complex systems; creating a smaller system due to use of common mechanisms in different parts of the system and as well as leading to less complexity; and making it easy to enhance and maintain software systems [Booch, 1994].

The UML is the results of the merging of three modelling methods; Booch, OMT (Object Modeling Technique) and Objectory, taking some concepts from other methods. UML is a language used to specify, visualise and document the artefacts of an object-oriented system under development [Quatrani, 1998].

The graphical diagrams are for representing the elements of the system from different perspectives. The UML language has nine different types of diagrams: Class, Object, Use-case, Sequence, Collaboration, Statechart, Activity, Component and Deployment.

However, the author has only used the class and activity diagrams for the exploration of the research concepts and to represent the modelling of the fixturing information. These diagrams are described in the succeeding paragraphs.

Class Diagram

To the Object-Oriented methodology a class is a set of objects, which share common structure and behaviour while an object is an instance of a class. A class diagram is a part of the object-oriented design notation. It demonstrates the classes and their relationships that exist in the logical design of a system.

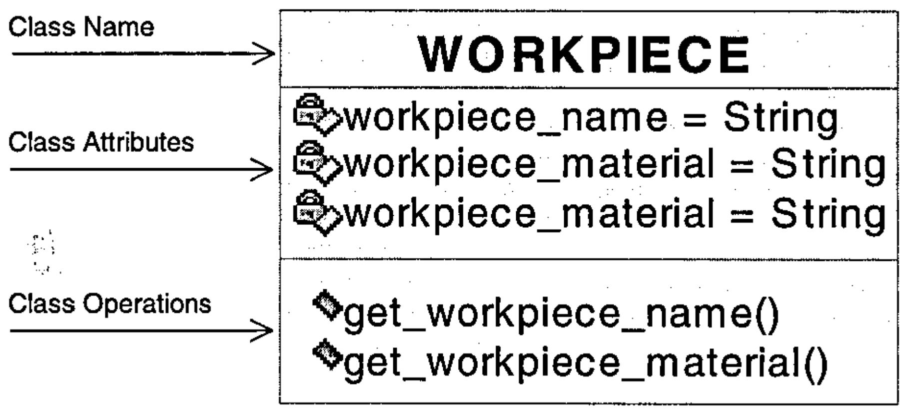


Figure A-B1 – Class Diagram Representation

The class diagrams represent the internal structure and relatioships between objects. Each object is represented by its name, attributes and operations as shown in Figure A-B1. The class is represented by a rectangle and the relationship with other objects are represented in three associations; generalisation, aggregation and association. These relationships are explained in the figures below:

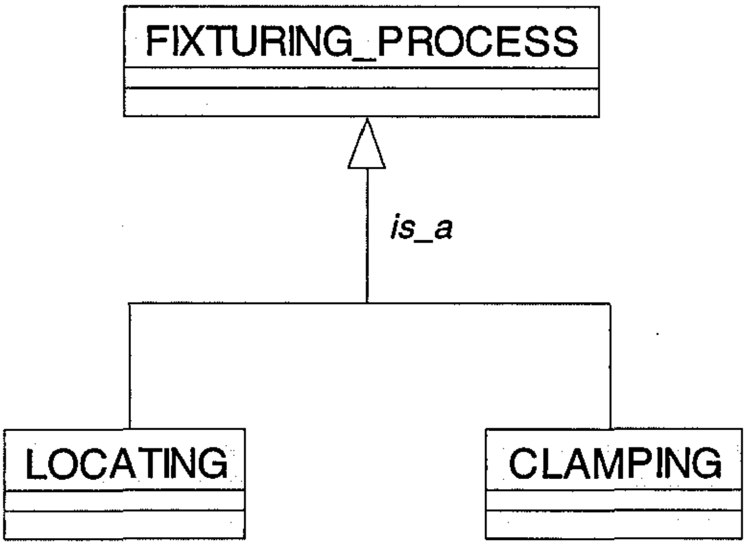


Figure A-B2 – Generalisation Relationship

Generalisation represents the inheritance of the object as depicted in Figure A-B2. In this case the objects of the classes "LOCATING" and "CLAMPING" inherit from the object of the class "FIXTURING_PROCESS". The class "FIXTURING_PROCESS" is considered as a parent class while the classes "LOCATING" and "CLAMPING" are considered as children.

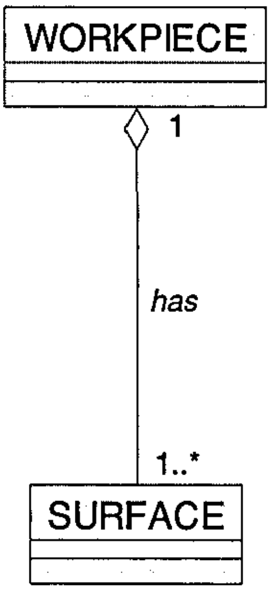


Figure A-B3 – Aggregation Relationship

Aggregation represents the possession between objects as shown in Figure A-B3. In this case one object of the class "WORKPIECE" can aggregates (hold) one or many objects of the class "SURFACE".

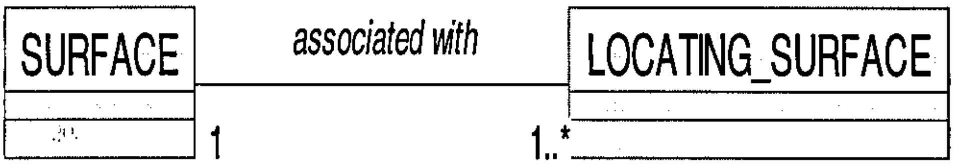


Figure A-B4 – Association Relationship

Association represents the link between objects as shown in Figure A-B4. In this case the object of the class "SURFACE" can be associated to one or many objects of the class "LOCATING_SURFACE".

Activity Diagram

An Activity diagram is a special case of a state diagram in which all of the states are action states in which all of the transition is triggered by completion of the actions in the source states. The entire activity diagram is attached to a class or to the implemetation of an operation. The purpose of this diagram is to focus on flows driven by internal processing. Activity diagrams contains, transitions between the activities, decision points and synchronization bars. In UML, activities represented as rectangles with rounded edges, transitions are drawn as directed arrows, decision ponts are shown diamonds and synchronization bars are drawn as thick horizontal or vertical bars as shown in Figure A-B5.

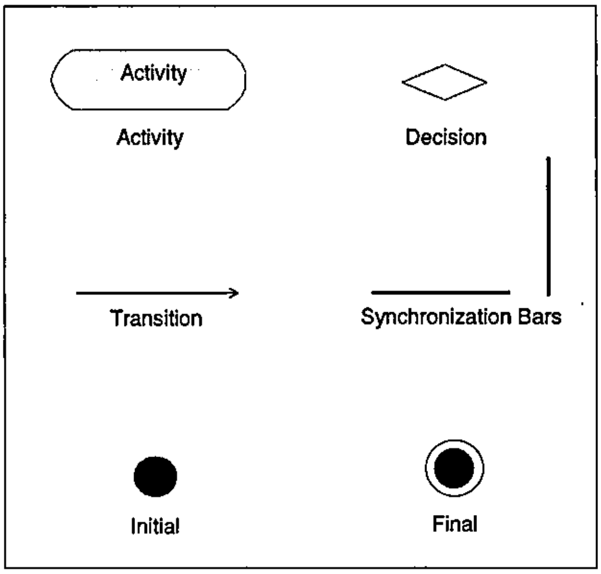


Figure A-B5 – UML Notation for Activity Diagram Elements

An activity represents the performance of some behaviour in the workflow. Transitions are used to show the passing of flow of control from activity to activity. They are typically triggered by the completion of the behavior in the orinating activity. When modelling the workflow of a system it is often necessary to show where the flow of control branches based on a decision point. The transitions from decision point contain a guard condition, which is used to determine which path from the decision point is taken. Decisions along with their guard conditions allow you to show alternate paths through a workflow. In a workflow there are typically soe activities that may be done in parallel.

A synchronizarion bar allows you to specify what activities may be done concurrently. Synchronization bars are also used to show joins in the workflow; that is what activities must complete before processing may continue. A synchronization bar may have many incoming transitions and one outgoing transition or one incoming transition and many outgoing transitions. There are special symbols that are used to show the starting and final activities in a workflow. The starting activity is shown using a solid filled circle and the final activities are shown using bull's eye. Typically, there is one starting activity for the workflow and there may more than one ending activity [Quatrani, 2000]. An example of UML activity diagram is shown in Figure A-B6.

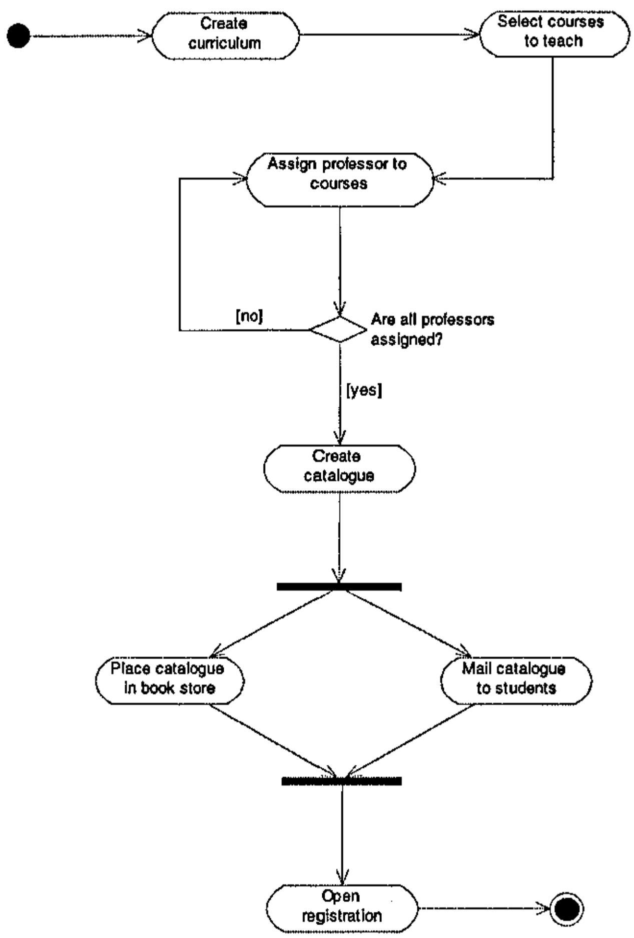


Figure A-B6 – Actvity Diagram Representation

The activity diagrams are sequential routes of actvities in a computational process related with the representation of the dynamic aspects of a system. The activity resulted in some action that gives changes to the state of the system or return of a value. Activity diagrams are generally applied to represent a system workflow between object and operation. Figure A-B6 shows a general example of an activity diagram. The different activities performed by the system are shown in a sequential path of action. Simple arrows represent transitions from one activity state to another. The diamond boxes are defined as sequential branches and different actions are taken depending on the expected output.

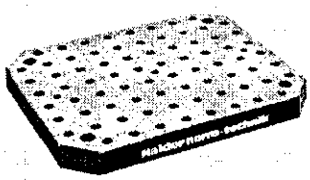
Appendix – C

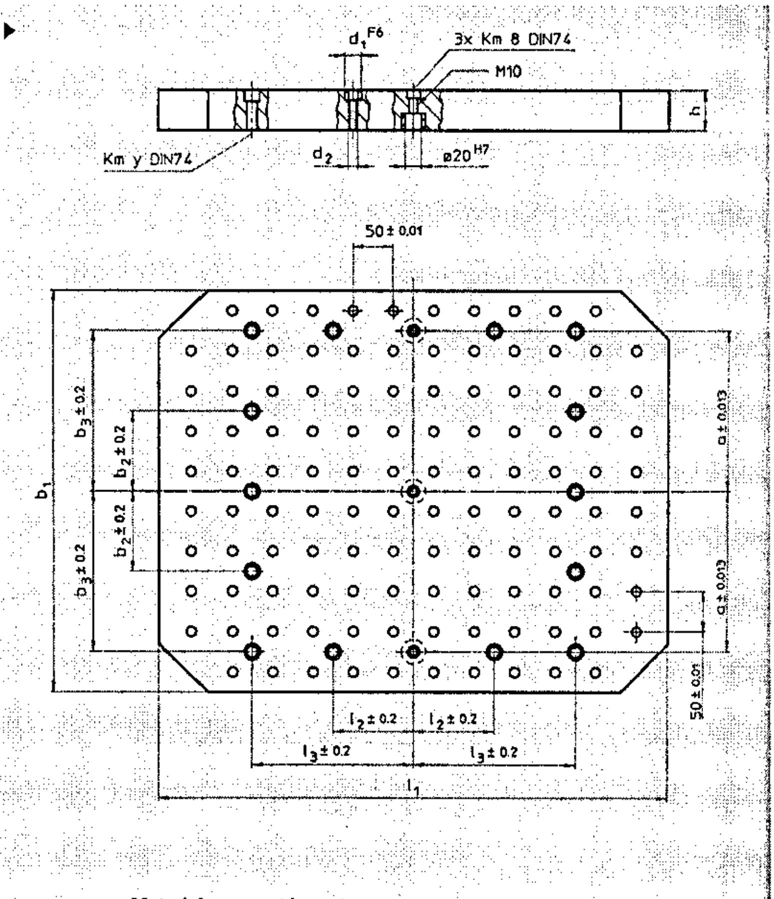
The Modular Fixturing Elements

[Halder's Modular Jig and Fixture Systems, 1994]

▫ PLATE

15 002–16 009
Mounting plate





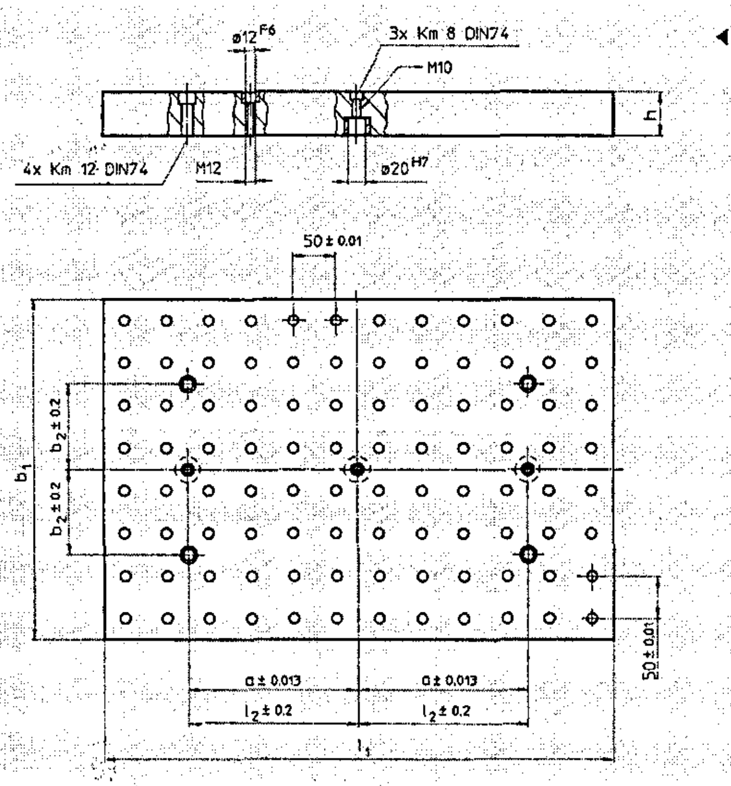
Material: grey cast iron

Cat. No.	$b_1 \times l_1$	h	d_1	d_2	a	b_2	b_3	l_2	l_3	y	Number of hole rows	g
15002	400x 400	40±0,02	12	M 12	150	–	150	–	100	12	8x 8	68000
15003	400x 500	40±0,02	12	M 12	150	–	150	–	200	12	8x10	73000
15004	500x 500	40±0,02	12	M 12	200	100	200	100	200	12	10x10	90000
15005	500x 630	60±0,03	12	M 12	200	100	200	100	200	12	10x12	115000
15006	630x 630	50±0,03	12	M 12	200	–	200	–	200	16	12x12	145000
16006	630x 630	50±0,03	16	M 16	200	–	200	–	200	16	12x12	144000
16007	630x 800	50±0,03	16	M 16	200	–	200	–	300	16	12x16	190000
16008	800x 800	50±0,03	16	M 16	300	100	300	100	300	16	16x16	245000
16009	800x1000	60±0,03	16	M 16	300	100	300	100	400	16	16x20	305000

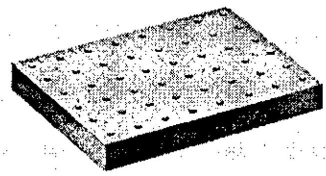
Shape and positioning tolerance
(for all Halder Jig and Fixture Systems)

Positioning tolerance:	0 - 500 mm	±0,01
Parallelism:	on 500 mm	0,01
Angle precision:	on 300 mm	0,01

◻ PLATE



15 013–15 015
Mounting plate



Material: grey cast iron

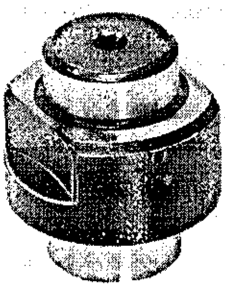
Cat. No.	$b_1 \times l_1$	h	a	l_2	b_2	Number of hole rows	g
15 013	300x400	40±0,02	150	150	100	6x 8	44 500
15 015	400x600	40±0,02	200	200	100	8x12	89 500

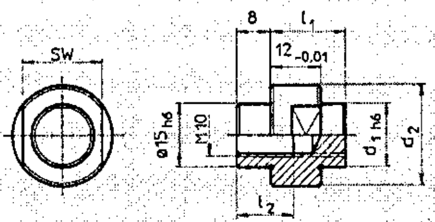
Shape and positioning tolerance
(for all Halder Jig and Fixture Systems)

Positioning tolerance:	0 – 500 mm	±0,01	
Parallelism:	on	500 mm	0,01
Angle precision:	on	300 mm	0,01

▫ LOCATING PIN

11403–11415 Locating pin

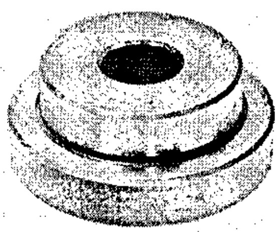


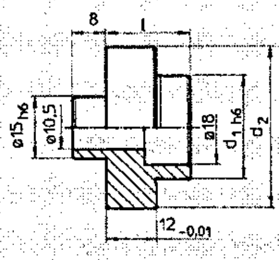


Material: steel **Finish:** case-hardened, ground

Cat. No.	d_1	d_2	l_1	l_2	SW	g
11403	4	19	16	13,5	15	30
11404	5	19	16	13,5	15	30
11405	6	19	16	13,5	15	30
11406	8	19	17	13,5	15	30
11407	10	19	17	13,5	15	30
11408	12	19	18	13,5	15	30
11409	14	24	18	13,5	19	30
11410	15	24	18	Throughgoing thread	19	50
11411	16	24	18	Throughgoing thread	19	50
11412	18	29	19	Throughgoing thread	22	70
11413	20	29	19	Throughgoing thread	22	70
11414	22	34	20	Throughgoing thread	27	100
11415	24	34	20	Throughgoing thread	27	100

11416–11437 Locating pin



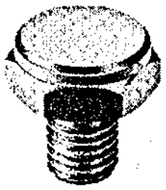


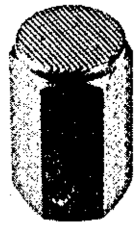
Material: steel **Finish:** case-hardened, ground

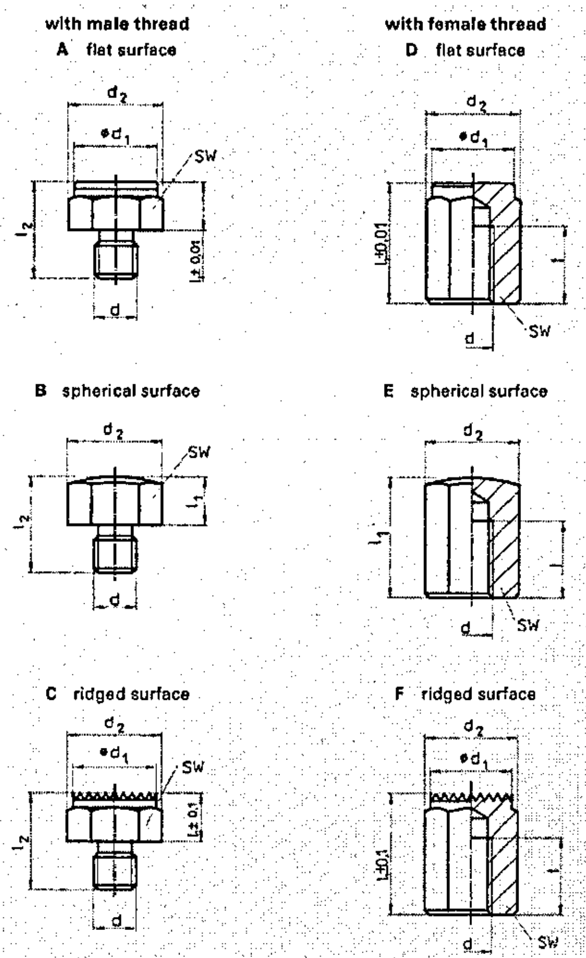
Cat. No.	d_1	d_2	l	g
11416	25	39	20	100
11417	26	39	20	110
11418	28	39	20	110
11419	30	49	22	200
11420	32	49	22	200
11421	34	49	22	200
11422	35	49	22	200
11423	36	49	22	210
11424	38	49	22	230
11425	40	59	24	330
11426	42	59	24	340
11427	44	59	24	350
11428	45	59	24	360
11429	46	59	24	370
11430	48	59	24	380
11431	50	69	26	520
11432	52	69	26	530
11433	54	69	26	550
11434	55	69	26	560
11435	56	69	26	580
11436	58	69	26	600
11437	60	69	26	610

□ SCREWED REST BUTTON

2269.
Screwed rest button
HWN 269





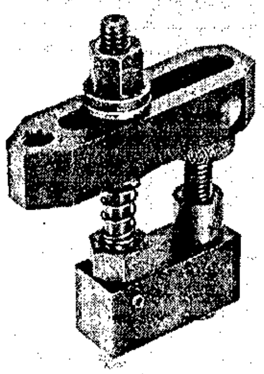


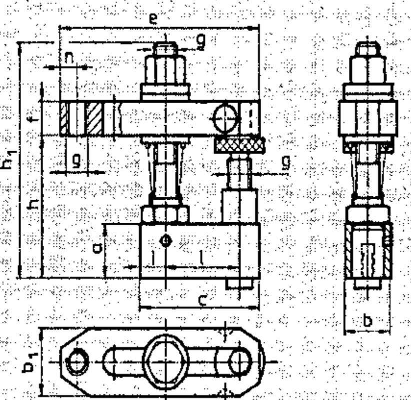
Material: free-cutting steel

Cat. No.			l_1	d	d_1	d_2	l_2	t	SW	g	System
A	B	C			Type A, B, C						
2269.021	.121	.221	10	M 8	17	19,4	20		17	24	V-40
.001	.101	.201	10	M12	22	25,2	26	–	22	40	V-70/L-12
.002	.102	.202	15	M12	22	25,2	31	–	22	56	V-70/L-12
.042	.142	.242	15	M16	30	30	50	–	30	130	L-16
.043	.143	.243	20	M16	30	30	55	–	30	155	L-16
D	E	F			Type D, E, F						
.321	.421	.621	15	M 8	17	19,4	–	6	17	23	V-40
.323	.423	.623	25	M 8	17	19,4	–	16	17	40	V-40
.301	.401	.501	20	M12	22	25,2	–	10	22	52	V-70/L-12
.302	.402	.502	25	M12	22	25,2	–	15	22	65	V-70/L-12
.303	.403	.503	30	M12	22	25,2	–	20	22	77	V-70/L-12
.304	.404	.504	40	M12	22	25,2	–	25	22	105	V-70/L-12
.305	.405	.505	50	M12	22	25,2	–	25	22	135	V-70/L-12
.343	.443	.543	30	M16	30	30	–	20	30	140	L-16
.345	.445	.545	50	M16	30	30	–	25	30	250	L-16

❑ CLAMP ELEMENT

2370.
Clamp element
HWN 2370





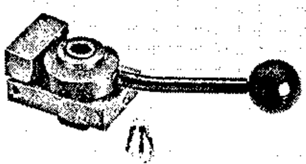
Material: steel

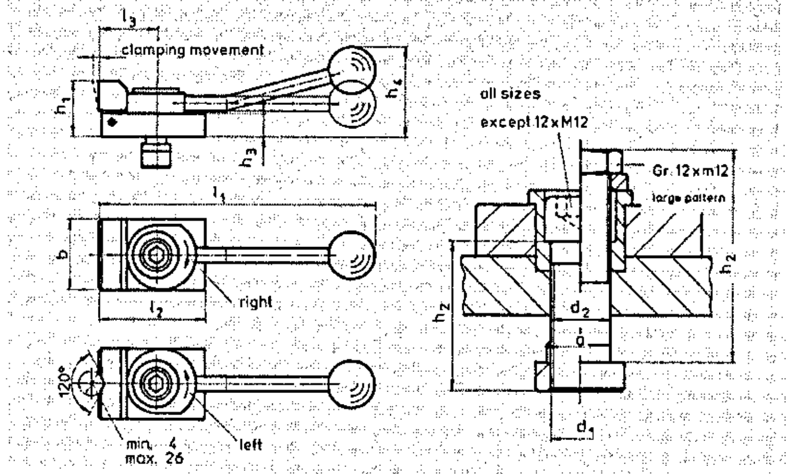
Cat. No.	axbxc	b_1	e	f	g	h	h_1	i	l	n	g	System
2370.012	25x25x65	30	110	20	M12	48-78	112	12,5	40	10	800	V-70/L-12
2370.016	30x30x78	40	142	30	M16	60-96	145	14	50	13	1650	L-16

▫ DOWN HOLD CLAMP

2321. Down-hold clamp HWN 321

▶ AER with cranked clamping lever and flat clamping jaw clamping to the right
AEL with cranked clamping lever and flat clamping jaw clamping to the left
APR with cranked clamping lever and V-clamping to the right
APL with cranked clamping lever and V-clamping to the left
BE with straight clamping lever and flat clamping jaw
BP with straight clamping lever and V-clamping jaw



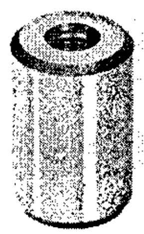


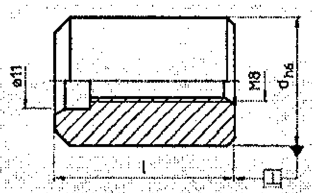
Material: steel

Cat. No. Type AER	AEL	APR	APL	BE	BP	Slot size a	d_1	d_2	b	h_1	h_2	h_3	h_4	l_1	l_2	l_3	s	g	System
small pattern (clamping force horizontal up to 3500 N)																			
2321.101	.105	.102	.106	.103	.104	10	M 8	8,4	32	20	30	8	40	132	50	32	3	220	V-40
.141	.145	.142	.146	.143	.144	14	M 8	8,4	32	20	30	8	40	132	50	32	3	220	V-70
large pattern (clamping force horizontal up to 7000 N)																			
.341	.345	.342	.346	.343	.344	14	M12	12,5	48	38	40	16	62	190	72	40	4	870	V-70/L-12

▫ CENTERING BOLT

2311.
Centering bolt
HWN 312

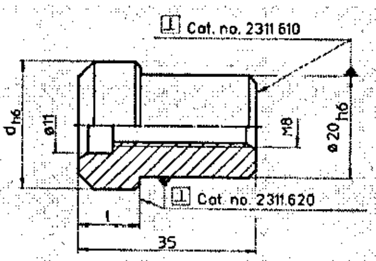




Material: 16 MnCr5

Cat. No.	d	l	g	System
2311.610	20	31	70	V-40/V-70/L-12/L-16
.620	25	35	120	V-70
.530	50	31	460	V-40/V-70
.540	50	45	670	V-70

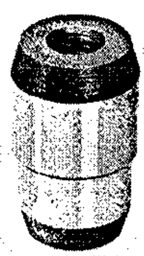
▫ CENTERING BOLT



Material: 16 MnCr5

Cat. No.	d	l	g	System
2311.610	25	12	80	L-12/L-16
.620	50	20	330	L-12/L-16

2311.
Centering bolt
HWN 312



Appendix – D Journal Paper

ELSEVIER

Journal of Materials Processing Technology 76 (1998) 29–35

Journal of Materials Processing Technology

Information models in an integrated fixture decision support tool

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Abstract

An important part of modern design and manufacture is to ensure that effective manufacturing decisions are made as early as possible in the product introduction process. The software tools which can support the broad decision making needs of engineers require further research. A potentially effective approach in this area is the use of information models, which can provide information support to a range of applications, in an integrated CAD/CAM environment. The key problem discussed is the structure of information models to support the interactions between fixture design, process planning and product design. A software support environment is described which consists of three key areas; product information, manufacturing capability information and a set of fixturing decision support applications. The issues related to the data structures required for product and manufacturing capability models are discussed and potential object-oriented solutions are proposed. A selected prismatic workpiece has been used, in conjunction with a variety of fixture types and machine tools, to illustrate the approach taken.

Keywords: Information models; Decision support tool; Fixture design

1. Introduction

In order to ensure effective decisions are made at each stage in the design and manufacture process, it is considered important that software tools should provide sufficient information to support the decision making of design and manufacturing engineers. Fixturing support systems therefore, need to provide information that will support all the activities in design and manufacture which may require fixturing inputs.

Research investigations into fixture support systems can be classified broadly into four categories based on the techniques used; artificial intelligence, CAD tools, group technology and optimisation for fixture configuration. Markus et al. [1] produced one of the first fixture design systems to make use of artificial intelligence while CAD/CAM techniques have been used in a knowledge-based fixturing system developed by Miller and Hannam [2]. The first fixturing system developed using group technology was researched by Jiang et al. [3], while Trappey and Liu [4] developed a work-holding verification system modelled as a quadratic optimisation problem. Each of these pieces of research are useful to their own area but, there is a need for the provision of a general source of information to support decision making. This paper shows how information models can be structured to provide fixturing information to support decision making across product design, process planning and fixture design.

Research investigations into fixture design systems can be classified from the point of view of their degree of automation; namely interactive, semi-automated and fully automated. Interactive fixture design is a process where a computer is used to aid the designer by displaying the appropriate fixture elements based on his knowledge. The correct position of the fixture elements is decided by the designer in arriving at the final fixture configuration. A system can be said to be semi-automated if it does not require full knowledge or expertise from the a designer while arriving at appropriate locating, clamping and supporting faces, points and elements. Ingrand and Latombe [5] developed a semi-automated system incorporating the expertise of a designer into the fixture design system. The determination of appropriate faces for locating, clamping and supporting can be decided automatically [1]. Neverthe-

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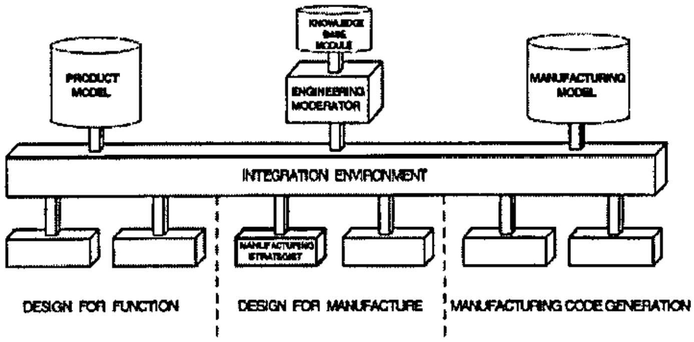

Fig. 1. The MOSES architecture (Loughbrough and Leeds Universities Research Project, 1994, [8]).

less, the selection of appropriate points and elements for building a fixture still depends on the user's expertise and knowledge. An automated system is one which obtains information directly from a CAD model and makes use of the knowledge-base to decide on the appropriate fixturing points and fixturing elements. Design parameters such as orientation, stability, deflection due to cutting forces, set-ups, tolerance relationships, assembly and interference must be considered while designing a fixture. Expert systems together with a good knowledge representation scheme were generally used in arriving at a fixture design [6].

While these various pieces of work have provided some progress towards improved fixture design systems, they have tackled only one particular issue which is automated fixture configuration. The authors agree with Hargrove and Kusiak [7] that there are some areas worthy of investigation. In particular:

- The integration of computer aided fixture design systems with other computer aided engineering (CAE) tools will be one of the most important factors making for effectiveness and acceptance in manufacturing.
- More multi-functional automated systems can be expected throughout the 1990s, which should be initiated by information models that describe the integration of shared databases.

This work presented in this paper aims to provide better support for design and manufacturing engineers through the definition of information models and an integrated fixture decision support tool environment. It proposes a strategist that will act as a fixturing expert making use of both product model information and manufacturing capability model information.

2. Fixturing within information supported CAD/CAM

The main requirement of information supported CAD/CAM is to provide reliable information which can be utilized as a support for high quality decision making during the design and manufacture of a product. The present enabling technologies in CAE allow the development of an integrated system and framework to exploit product and manufacturing information models in concurrent engineering.

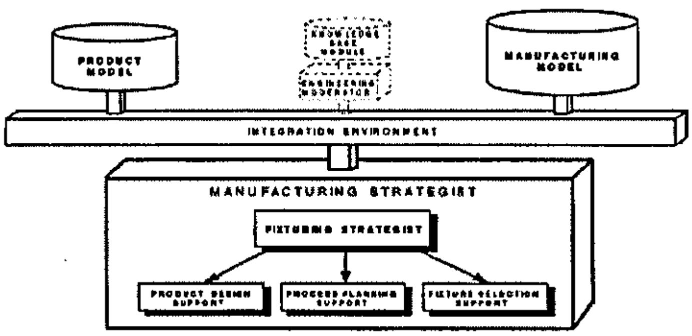

Fig. 2. Fixturing within the MOSES concept.

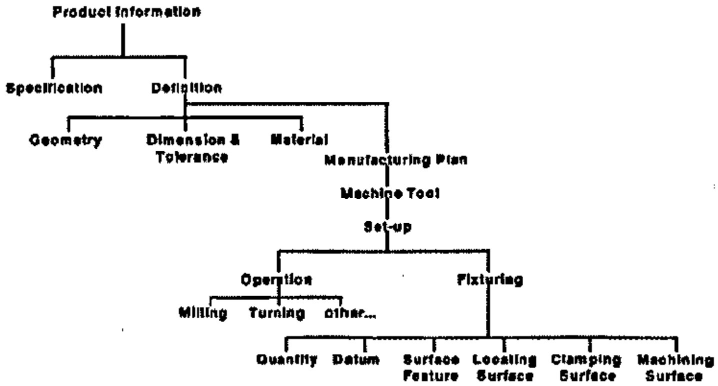

Fig. 3. Product data structure.

The model oriented simultaneous engineering (MOSES) [8] architecture as shown in Fig. 1, was explored as a joint undertaking between Loughborough and Leeds universities and was funded by the EPSRC. The specification of the research into MOSES focused on a computer based system that provides product and manufacturing information, enables decision support based on these information sources and is coordinated in a manner that makes it suitable for operation in a simultaneous engineering environment [9].

The product model captures the information related to a product throughout its life cycle. The manufacturing model describes and captures the information about the manufacturing facility and capabilities at different levels of abstraction [10]. These information models are implemented as object-oriented databases. The engineering moderator is a specialist manager or coordinating program whose role is to drive concurrency within the MOSES system. It can provide excellent support for individual team members or groups working from particular design perspectives. Strategist applications are specialist expert applications which assist users of the CAE system to evaluate, modify and extend the product design criteria which are closely allied to particular design perspectives. An integration environment is required to enable these elements to work together even though they may be distributed over many computing platforms, probably located at several sites. It must also provide support for interactions and communication between applications [11].

This approach is being applied in the case of fixturing. Fixturing requires information about the machine tool, the machining process, cutting tool, fixturing process and fixtures. This information forms a part of the manufacturing model that can be accessed by the fixturing strategist. The fixturing strategist supports three activities namely; product design, process planning and fixture selection. Fig. 2 shows a view of the fixturing strategist structured in the MOSES concept.

The research issues being pursued in this work are:

- What information is needed in the product and manufacturing model and how should be structured?
- How should fixture selection, process planning and product design support applications interact with these information models?

This paper focuses on the first of these two issues, providing a view of the information structures required and how they can be used.

3. Information structures to provide fixturing support

3.1. Product model structures

Product modelling is accepted as an important part of data exchange (STEP) and data sharing in integrated environments. A product model can be considered to be a computer representation of a product which should hold a complete depiction of the information concerning a product. The product model therefore becomes a source and repository for information for all applications and allows information to be shared between the users and software components of the CAE system. When we consider the fixturing process in terms of product model data there are two questions to be answered. What product information should be stored in the product model? What should be the structure of this information?

At this stage, we have defined the product information requirements for fixturing by extending the general data structures defined by Young and Bell [12] to include fixturing. An initial structure of product information is shown in Fig. 3. The figure shows a product specification and product definition which are to be stored in the product model. The specification describes the requirement which the product must achieve. The product definition describes the ways in which the

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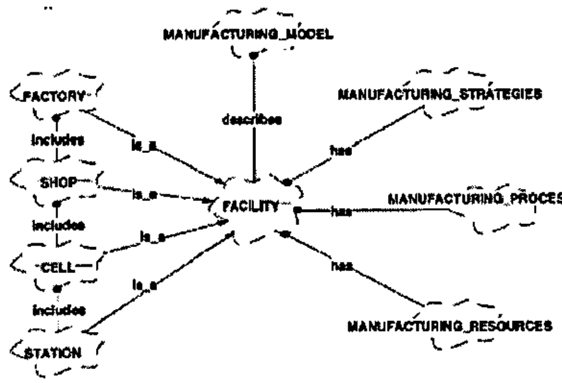

Fig. 4. Object-oriented representation of manufacturing model using Booch notation [13].

specification may be achieved and includes the product geometry, dimension and material and also captures the manufacturing plans, machine tool and set-up, defining operation and fixturing information.

3.2. *Manufacturing model structures*

The manufacturing model describes and captures the information about the manufacturing situation of a company in terms of its manufacturing facility and capabilities at different levels of abstraction [13]. Three entities can be regarded to be basic elements in the definition of any manufacturing environment: resources, processes and strategies. The relations and interaction among them defines the manufacturing environment of a company. Manufacturing resources are all the physical elements within a facility that enable product manufacture, e.g. production machinery, production tools, etc. A description of the resources based on their physical properties and functional composition allows the capture of their capabilities. Being able to represent resource capability enables the support of design decisions, e.g. design for manufacture and manufacturing functions, process planning. Manufacturing processes are those processes carried out in a facility in order to produce a product. Strategies are decisions made on the use and the organisation of resources and processes. The manufacturing model as shown in Fig. 4 has been structured into four levels based on a de-facto standard (i.e. factory, shop, cell, station) and modelled in Booch [14], implemented in an object-oriented database. These levels of abstraction provide manufacturing information for all hierarchical and functional activities within a manufacturing enterprise.

The fixturing process cannot be considered independently of the machining process. Thus, any representation of information related to fixturing must also be relate to machining. In a similar way fixturing resources also relate to machining resources in terms of the machine tool and cutting tool being used. An examination of the requirements for fixturing a product and the identification of the key aspects of related manufacturing information led to the general structure illustrated in Fig. 5. This shows a general view of manufacturing information for fixturing with an initial view of how it should be structured in a manufacturing model.

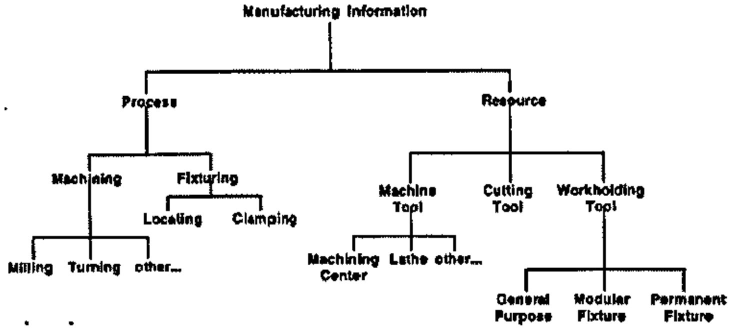

Fig. 5. Manufacturing data structure.

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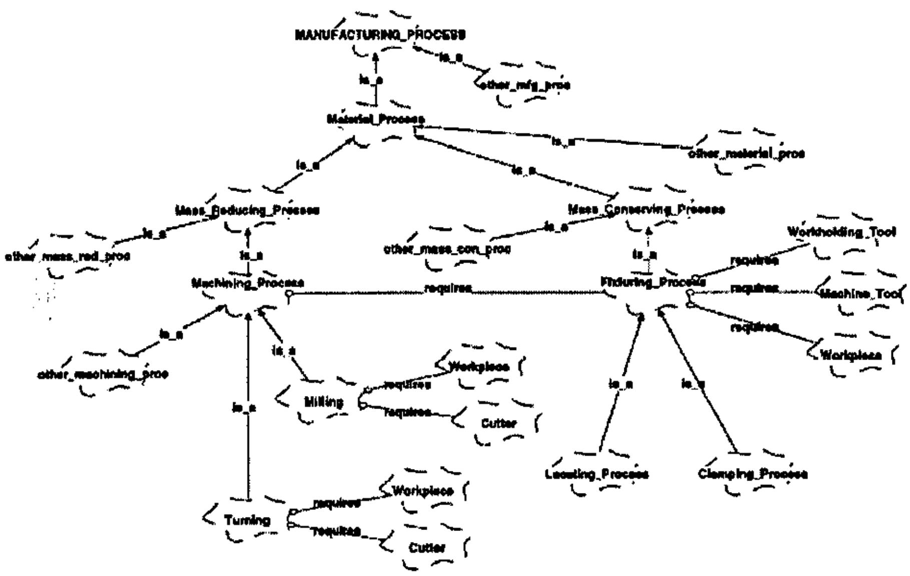


Fig. 6. Class diagram for manufacturing processes using Booch notation.

3.3. Object-oriented design by Booch method

To have a successful implemented software system, it is important to have a good understanding of the design of the information as well the interactions between the system's models. The Booch object-oriented design method has been employed to describe the information classes and their relationships. This provides a suitable depiction of the manufacturing information structures and their relationships at different levels of abstraction.

In defining a representation of the fixturing process as a manufacturing process, we must recognise that it is a different type of process from machining. It's not a mass reducing process like machining but it is related to machining as machining requires a fixturing process to be used before it can itself be performed. The fixturing process involves a number of sub-processes, these being, locating a workpiece and clamping a workpiece. Fig. 6 illustrates the class diagram for manufacturing processes showing in particular the structures for mass reducing processes and mass conserving processes as well as illustrating the relationships between machining and fixturing. It also clearly shows the relationship between both machining and fixturing processes and the resources required to achieve them.

These resources can also be captured with the manufacturing resource class structure as shown in Fig. 7. This illustrates the different manufacturing resources such as production machinery and production tools which can be represented and their relations are defined. By defining these interrelationships, it is possible to define how machine tools use cutting tools and work-holding tools in order to perform particular machining operations.

4. Populating information models to provide fixturing information

This section describes how the data models can be populated with information and provides a simple example of how that information can be used with respect to a particular workpiece to identify possible work-holding methods. Fig. 8 illustrates the production resources part of the model being populated with example work-holding tools. The class diagram for work-holding-tool, which shows a general-purpose-fixture as a sub-class of work-holding-tool, leads to devices such as a chuck and vice. Also, modular-fixture is a sub-class of the work-holding-tool which leads to the representation of a variety of standard off-the-shelf tooling such as tooling plates, cubes, locating, clamping, supporting elements and similar components.

Fig. 9 illustrates the representation of the fixturing process; in particular the locating process and the clamping process. It is important to note that the representations captured here are generally applicable processes, without regard to particular workpieces. Locating is the process of positioning the workpiece relative to the fixture and guiding the fixture relative to the

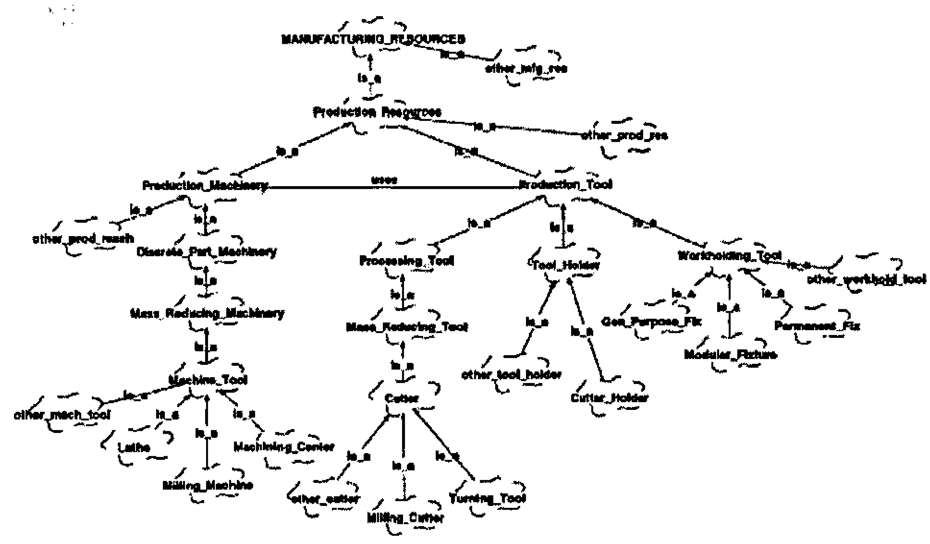


Fig. 7. Class diagram for manufacturing resources using Booch notation.

cutting tool. Locating the workpiece to the fixture is done with locators and guiding the fixture to the cutting tool is done by guiding devices, such as feeler gages. Clamping is the process of holding the position of the workpiece in the fixture. The primary devices used for holding a workpiece are clamps which function by holding the workpiece against its locator and preventing movement of the workpiece during machining.

If we take a particular workpiece as shown in Fig. 10 and apply this fixturing process model, we can identify the specific locating and clamping processes which can be used and select appropriate resources from the model. This provides an integrated route to offering information which can be used to support product design, process planning or the selection of appropriate fixturing elements.

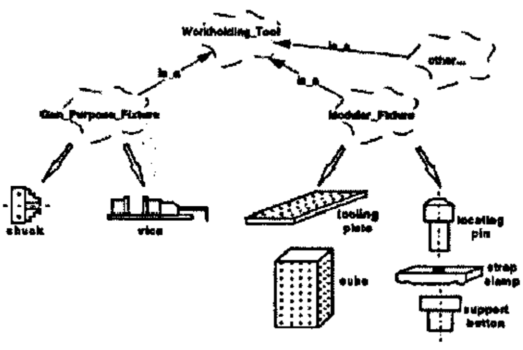


Fig. 8. Populating production resources with particular work-holding tools.

5. Conclusions

In this research a new approach has been presented which has proposed a fixturing strategist within information supported CAD/CAM. The rationale behind this approach is to provide better support for design and manufacturing engineers through the use of information models within an integrated fixture decision support environment. The following contributions have been made in this work:

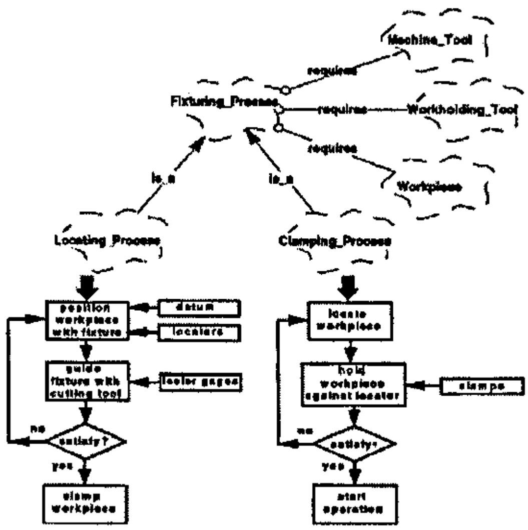
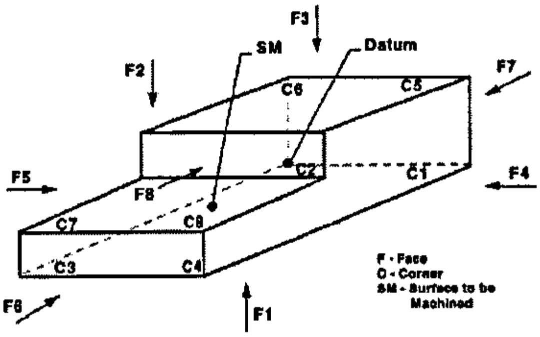


Fig. 9. Fixturing processes within the data structure.



Locating Process	Clamping Process	Workholding Tool
Datum at C2 (F1, F5 & F7)		
Combination # 1 locate F1, F4 & F5	clamp on F4 & F5	Vice
Combination # 2 create a hole on center of F3 and locate at the center of the hole & F1, then place stops on F4 & F5	clamp on F3	tooling plate, locating pin & support pins

Fig. 10. Prismatic workpiece.

- The fixturing information structures needed within product and manufacturing models have been identified.
- An object-oriented method has been used to illustrate how the information model can be applied to a particular workpiece to select possible locating and clamping processes in conjunction with the appropriate available resources.

The authors will pursue further work to explore how fixture selection, process planning and product design support applications should interact with these information models to provide fixturing information to support decision making across these processes.

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