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CAFIXD: A CASE-BASED REASONING FIXTURE DESIGN METHOD. FRAMEWORK AND INDEXING MECHANISMS

Iain M. Boyle

Kevin Rong*

Computer Aided Manufacturing Laboratory,
Worcester Polytechnic Institute,
100 Institute Road, Worcester, MA 01609-2280

David C. Brown

Department of Computer Science,
Worcester Polytechnic Institute,
100 Institute Road, Worcester, MA 01609-2280

ABSTRACT

Fixtures accurately locate and secure a part during machining operations such that the part can be manufactured to design specifications. To reduce design costs associated with fixturing, various computer-aided fixture design (CAFD) methods have been developed through the years to assist the fixture designer. One approach is to use a case-based reasoning (CBR) method where relevant design experience is retrieved from a design library, and adapted to provide a new fixture design solution. Indexing design cases is a critical issue in any CBR approach, and CBR systems can suffer from an inability to distinguish between cases if indexing is inadequate. This paper presents a CAFD methodology, entitled CAFixD, that adopts a rigorous approach to defining indexing attributes in which axiomatic design functional requirement decomposition is adopted. Thus, a design requirement is decomposed in terms of functional requirements, physical solutions are retrieved and adapted for each individual requirement, and the design is then re-constituted to form a complete fixture design. Furthermore, adaptability is used as the basis by which designs are retrieved in place of the normal attribute similarity approach, which can sometimes return a case that is difficult or impossible to fix. This paper presents the CAFixD framework and operation, and discusses in detail the indexing mechanisms used.

Keywords: case-based reasoning, retrieval-by-adaptability, axiomatic design, fixture design

1. INTRODUCTION

A key concern to a manufacturing company is the ability to manufacture high quality products in as short a time as possible. Quick release of a product into the market place, ahead of any competitors, is crucial to securing a higher percentage of the market place. Fixtures play an important role within many manufacturing processes. They accurately locate and secure a workpiece during machining such that the part can be manufactured to design specifications. Thus fixtures have a direct effect upon machining quality, productivity, and the cost of products. A typical fixture unit is illustrated in Figure 1. The workpiece rests on locators that accurately locate the workpiece, and clamps are used to hold the workpiece securely in this position during machining. The typical structure of a fixture consists of a base-plate, to which the clamping and locating units are attached. Locating and clamping units consist of a supporting unit plus either a locator or clamp. Fixtures may contain different numbers and types of clamping and locating units, but units generally always follow this same basic format.

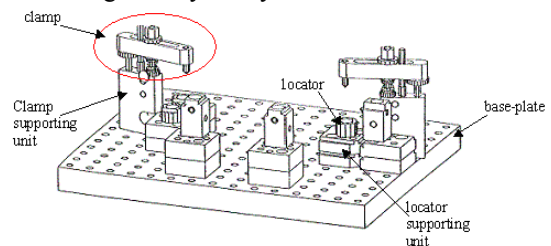


Figure 1: A typical modular fixture

The costs associated with the design and manufacture of fixtures are sizeable, accounting for some 10 – 20% of the total cost of a manufacturing system [Bi & Zhang (2001)]. Various

* email rong@wpi.edu, phone 508-831-6020, fax 508-831-6412

approaches have therefore been pursued with the aim of reducing fixturing costs. One approach has been to develop flexible modular fixture systems that can be used in a variety of different situations. An alternative approach has been to examine options of simplifying and shortening the fixture design process. Various computer-aided fixture design (CAFD) methods employing Artificial Intelligence in Design techniques have been studied through the years to assist the fixture designer.

This paper proposes the CAFixD methodology, a new fixture design method based upon a case-based reasoning (CBR) approach. Initially, various CAFD approaches are critiqued to clarify the need for the development of the CAFixD approach. The CAFixD methodology is then discussed. The overall CAFixD framework is presented with significant emphasis given to describing the employed indexing mechanisms. A worked example of its operation is also provided.

2. LITERATURE REVIEW

Much effort in the CAFD community has concentrated on developing systems that generate optimal fixture configuration layouts. These layouts specify the optimum positions where the fixture should contact the workpiece being machined. Rule-based [Nee & Kumar (1991), Roy et al (1997), Trappey & Liu (1992)] and genetic algorithm [Krishnakumar & Melkote (2000), Wu & Chan (1996)] methods are typical approaches that have been used to develop CAFD systems. However, such systems do not specify the actual physical form the individual units that comprise a fixture should assume. Their output is a list of coordinates stating where the fixture should contact the workpiece. Kumar et al (1999) attempted to conceptually design individual fixture units using a combined genetic algorithm/neural network approach. However, their output was essentially a high level conceptual design of a fixture unit that specified its basic type and the nature of its components. Attempts at designing complete fixture units have been largely based upon geometric approaches [Wu et al (1998), An et al (1999)] where the basic concept is to identify the critical dimension of a particular fixture unit (normally its height) and to then relate all other dimensions of this component through pre-existing mathematical relationships to this critical dimension.

A common feature related to CAFD approaches to date is that they do not consider the complete operational requirements of a fixture, instead focusing on some specific aspect of a fixture, most often the fixture configuration layout. However there remains the need to develop CAFD techniques that incorporate all aspects related to fixture design, as has been recognized by Bi & Zhang (2001). Other requirements may include loading/unloading time, fixture weight, cost, assembly time, and so on. What is still missing from the CAFD field therefore is a system that can fully design a complete fixture, using all of the operational requirements to guide the design process.

Case-based reasoning (CBR) has also been used to develop CAFD systems [Bi & Zhang (2001), Kumar & Nee (1995)]. CBR is an example of analogical reasoning – a technique whereby knowledge from similar design experiences is retrieved and adapted to provide a solution for a new design problem. It appears well suited to fixture design because a good

fixture design is largely dependent upon the designer's experience [Kumar & Nee (1995)]. Essentially, there are two main stages to CBR – case recall and case adaptation [Maher & Garza (1997)]. Design case recall is concerned with finding a relevant case within the case library. It subdivides into:

- Indexing – where the features that previous solutions should have relative to the current problem are identified;
- Retrieval – where cases that have all or some of the required features are identified;
- Selection – the retrieved cases are evaluated and then ranked in order of similarity.

Adaptation recognizes the differences between the selected design and the new problem for which a design solution is sought. Once the necessary changes are identified, they are then made. With regard to indexing cases, inseparability is an important issue [McSherry (2002)]. Inseparability occurs when a CBR system is unable to distinguish between two cases: i.e., two cases can have the same values for all attributes, but it is unlikely that both cases will be equally suited to the current design requirement. Inseparability is caused by either having too few indexing attributes or by selecting a poor choice of attributes: i.e., the attributes and/or their values are common to all or many designs and do not distinguish between designs. The indexing approach adopted by many has been to define attributes associated with the design problem. For example Kumar (1995) indexed design cases using attributes that described the workpiece for which a fixture was to be designed, such as machining features, inter-feature relationships, surface information, machining direction and so on. However, there are few guidelines on choosing appropriate indexes, and the norm is for the designer to determine appropriate indexes using his/her experience. Thus, there is a need to develop a formal methodology for determining case indexes that clarify the design requirement.

Many CBR systems base case recall upon attribute similarity: i.e., a nearest neighbor approach using standard weighting techniques [Chang et al (2000), Varma & Roddy (1999), Liao et al (2000)]. However high similarity between cases does not necessarily result in a case that can be easily adapted. Indeed a less similar design case may in fact be more readily adapted in certain design situations (Leake, 1996). Attempts have therefore been made to tie other components of the CBR process more closely to adaptation [Smyth & Keane (1996, 1995), Rosenman (2000)]. For example Smyth & Keane based retrieval directly upon the basis of likely adaptability. They determined what adaptation strategies were required to fix a particular case, and retrieved the design with the most favourable adaptation strategy. However, adaptability-based-retrieval is a computationally expensive approach for two reasons. One, the approach requires the CBR system to determine what changes need to be made to fix a case, to then decide how this change can be achieved (as there may be several means of affecting a change), and to also check how making a change will affect the rest of the design. This is a far more complicated process than merely checking attribute similarity, as it requires the prophetic ability to determine the effect of design decisions. Secondly, the approach can require the navigation of a very large search space leading to control

problems. Thus some method of initially constraining the search space needs to be defined. Keeping the library small is very important in adaptability-based retrieval, which is in contrast to similarity-based retrieval where a large number of similar design cases is desired to improve the likelihood of finding a suitable design solution.

3. DESIGN METHODOLOGY

Section 2 presented a critique of various CAFD approaches. This section summarizes the objectives of the CAFixD methodology, details how these objectives will be met, and subsequently discusses the CAFixD approach. An overview of the CAFixD framework and an in-depth description of the indexing mechanisms used is presented. The retrieval and adaptation processes will be discussed in detail in a future paper.

3.1 CAFixD Objectives.

Based upon the findings of the literature review presented in Section 2, the objectives of CAFixD are:

- To develop a CAFD technique that incorporates a full understanding of the complete operational requirements of a fixture into the design process;
- To use this fuller understanding of the design requirement to generate complete fixture designs that fully detail the physical structure of the locating/clamping units;
- To address the inseparability issue within CBR by developing a formal method for determining the indexing attributes of a design case;
- To develop a retrieval method that is both computationally feasible and has a well-defined control mechanism to restrict control of the search space, and that has the greatest probability of returning a satisfactory design solution;
- To develop a method that can effectively measure adaptability and gauge the effect of potential design decisions.

In order to achieve these objectives:

- The concept of design requirement decomposition is used in which a complete list of functional requirements of the fixture design problem is produced. This accomplishes two goals: one, the functional requirements can be used as a thorough indexing mechanism for design cases thus alleviating the problem of inseparability; two, the thoroughness of this requirement decomposition technique allows the designer to fully define the total operational requirements of a fixture and subsequently use this comprehensive specification to drive and guide the design process;
- Emphasis is given to adaptability-based retrieval to help ensure that a satisfactory design solution is achieved. However, similarity-based retrieval is still used to vet possible design solutions and help constrain the search to prevent control problems arising during navigation of the solution space;
- A data structure entitled the “second layer of the design matrix” is proposed as a means of identifying

the possible adaptations required to fix a design and of gauging the effect of potential design decisions when evaluating designs in terms of their adaptability.

3.2 The CAFixD methodology

Overall, the CAFixD methodology (Figure 2) decomposes the design problem into a series of smaller problems, searches the case base for a solution to each individual problem, and then reconstitutes the individual solutions to form one complete solution. The approach is similar to that adopted by a human designer, who would initially generate a conceptual design solution, and subsequently fill in the details of that solution during a detailed design stage. Thus, CAFixD has two design case libraries. One contains conceptual design solutions and is used during the conceptual design stage, and the second contains detailed designs of individual fixture units and supports the detailed design stage. During retrieval, emphasis is given to evaluating the adaptability of design cases.

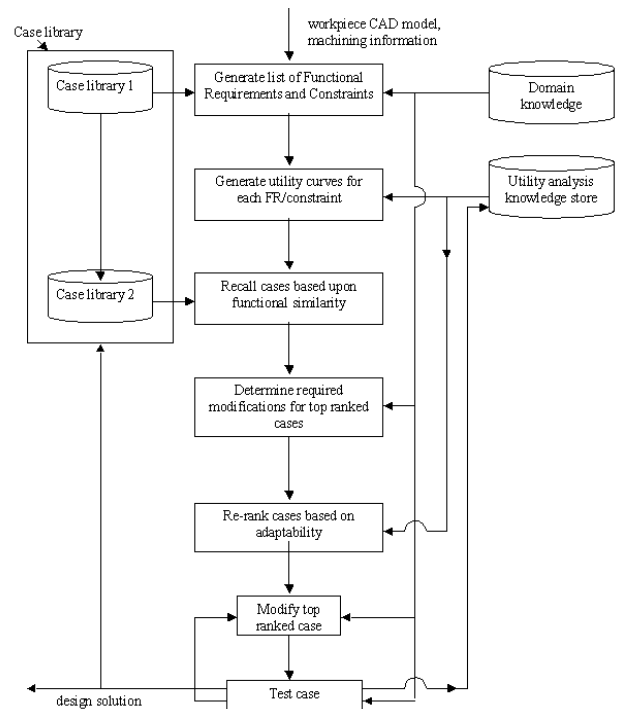


Figure 2: The CAFixD methodology

Initially, a series of design rules select the appropriate conceptual design from case library 1. Workpiece and machining information are then processed to generate a list of functional requirements (FRs) and constraints that the design must satisfy. Utility analysis (Thurston 1991) is then used to guide the decision making process during retrieval from case library 2. Utility analysis is similar to standard linear weighting but is considered a more expressive and accurate method of capturing a designer’s preferences as it allows the designer to state non-linear preferences. Similar to weighting approaches, the output is a figure of merit or utility (U) that represents the relative desirability of a design alternative of several attributes. Thus in CAFixD, for each FR and constraint the designer must record his/her preferences in the form of a utility curve, similar to that presented in Figure 3. These graphs illustrate the utility

of a given attribute based upon its value, thus in Figure 3 a weight of 6 lbs is of considerably greater utility than that of 16 lbs. The method by which these curves are generated is outwith the scope of this paper, but interested readers are directed to Boyle et al (2003) for a description of the process. Using the utility curves and the FR/constraint list, candidate fixture units are retrieved on the basis of functional similarity. Case base 2 contains previous design cases that are indexed by their FRs.

The top ranked cases are then re-evaluated in terms of their adaptability. Specifically, cases are re-evaluated in terms of the design decisions that will have to be made in order to meet the new design situation, and the effect of these changes upon the overall worth of the design is then used as the basis for retrieving the most suitable case. The case that requires the most favorable modifications i.e. the modifications that result in the design of highest utility is then proposed as the most suitable case for modification. The modifications are subsequently executed and the design tested to ensure the FRs are met. The design is also evaluated for possible addition to the case library.

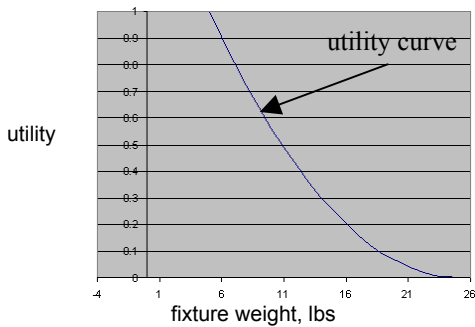


Figure 3: A utility curve

3.2.1 Indexing design cases

Axiomatic design decomposition principles are used to determine the indexing of both design cases and their solutions, as illustrated in Figure 4. Axiomatic design decomposition [Suh (2001)] involves the processing of information across four domains. Mapping occurs between the customer domain, the functional domain, the physical domain, and the process domain. The needs of the customer are listed as customer attributes (CAs) in the customer domain and are subsequently formulated into a set of functional requirements (FRs). A design solution is then created through mapping between the FRs and the design parameters (DPs), which exist in the physical domain. These DPs are mapped into the process variables (PVs). A fundamental aspect of the mapping process is the idea of decomposition. The design process progresses from a higher, abstract level down to a more detailed level. This results in the formation of design hierarchies in the FR, DP, and PV domains.

In fixture design the customer attributes are the workpiece information and machining information. This maps onto a list of FRs that explicitly state the functions that the fixture design must perform. These FRs relate to all desired fixture operational requirements. In addition, constraints may also be included here e.g. fixture cost. The FRs map onto DPs, which are the individual fixture units used to achieve the FRs. The PVs in turn are base design parameters (for example the thickness of a locator) used to achieve the DPs. The significant

difference between this and standard CBR approaches is that the functions of the sought design solution are explicitly stated. Normal CBR approaches map directly from the CAs directly onto the DPs.

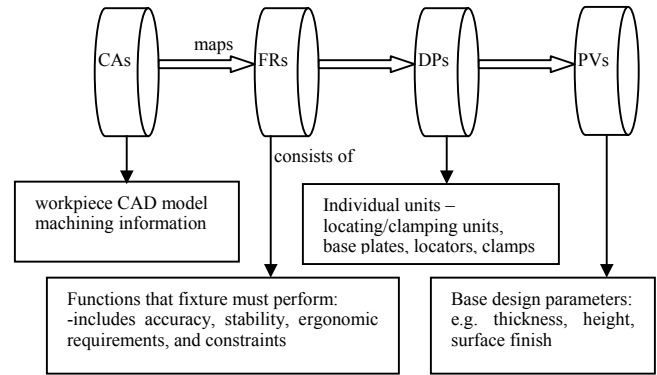


Figure 4: Axiomatic domains applied to fixture design

3.2.2 The Design Case Libraries

The high-level design of the case library is presented in Figure 5. The case base consists of two libraries. Case library 1 is related to fixture planning. It stores conceptual fixture designs largely in terms of their locating principles. The second case base holds the individual units that constitute the fixture design. Examples include locator support units or clamp types. The approach adopted is to navigate through case library 1 to retrieve a conceptual design, before proceeding to the second case library to retrieve appropriate fixture units. Thus, the output from case library 1 constrains the search through case library 2 as only units that can be used in the retrieved locating principle are considered as potential solutions.

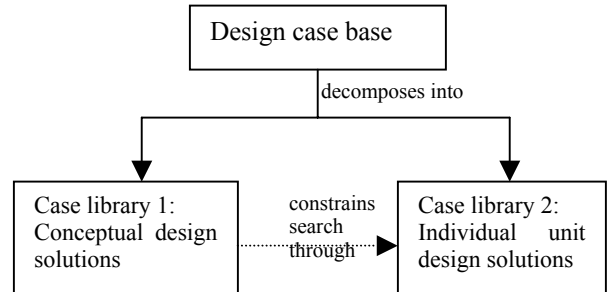


Figure 5: The Design Case Base

3.2.2.1 Case Library 1

The structure of case library 1 is presented in Figure 6. It contains cases that are conceptual in nature i.e. they contain information relating to locating principles in terms of locating methods and locating point distributions. There are 3 basic locating methods: plane, pin-hole, and external profile locating. For each method, there are subsequent decompositions and refinements of the root locating method. For example, plane locating (3-2-1) has seven variations (Figure 7). The third variation is locating with six individual points of location where three locators provide primary location, two provide secondary location, and one provides tertiary location. The primary points all act in the same direction but can act on different planar surfaces, as can be the case with the secondary locating points.

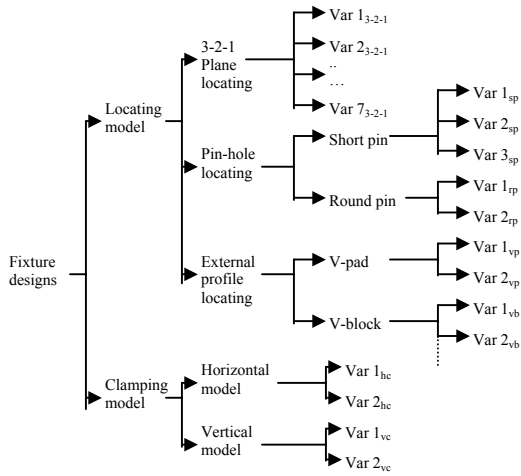


Figure 6: Case Library 1 - Conceptual Design Solutions

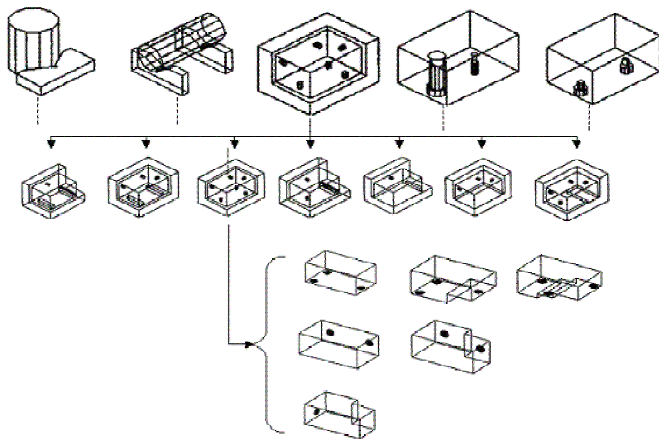


Figure 7: Decomposition of 3-2-1 Locating Solutions

Once the conceptual design has been found in case library 1, the search for a design solution can proceed to the second case library, where appropriate individual fixture units can be retrieved for modification. To each leaf of case library 1 are attached skeleton FR sets.

3.2.2.2 FR decomposition

Skeleton FR sets can be generated for each of the design cases in case library 1. A partial decomposition of the format of a design requirement for a simple 3-2-1 locating scheme is presented in Figure 8.

FRs are grouped into three main categories. One group deals with the locating accuracy requirements, the second with the stability requirements of the fixture, and the third deals with ergonomic issues related to fixturing. The first two groups are the simplest to handle in terms of automating their generation. The locating principle determines the number of units in the fixture design. As there are six units associated with variation 3 of 3-2-1 locating, there are therefore 6 FRs relating to the accuracy of the locating units (FR_{1,2}), 6 FRs relating to the clamping forces required to hold the workpiece against the locators (FR_{2,1,1}), and 12 FRs relating to the stiffness of the 6 locating and 6 clamping units (FR_{2,1,2}). A tolerance analysis of the workpiece is performed to determine the performance

values of the locating accuracy FRs. Similarly, a simple force analysis of the machining forces allows the performance values for the stability FRs to be defined. The significant problem is related to the third group of FRs, which are related to ergonomic considerations. These FRs include design requirements such as chip shedding, error proofing, workpiece surface protection at the locator/workpiece interface, and assisting tool positioning during machining. These need to be user specified and are created interactively with the designer.

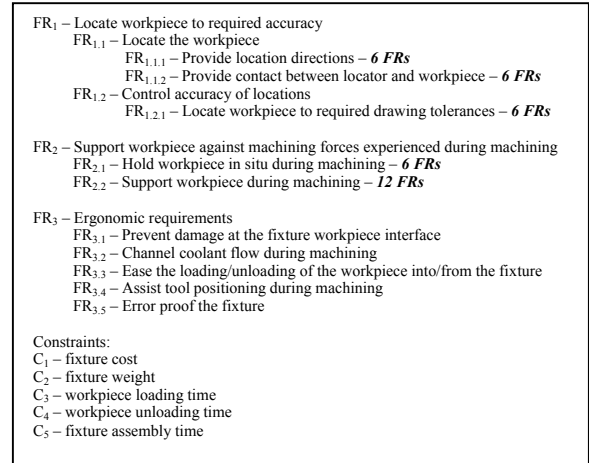


Figure 8: A partial FR decomposition

3.2.2.3 Case Library 2

The second case base contains information relating to individual fixture units i.e. information relating to an individual clamping or locating unit, and where it can be used. Figure 9 presents a partial breakdown of the case library, which contains locating units, clamping units, locator types, and fixture base types that can be combined to create a complete fixture for a workpiece.

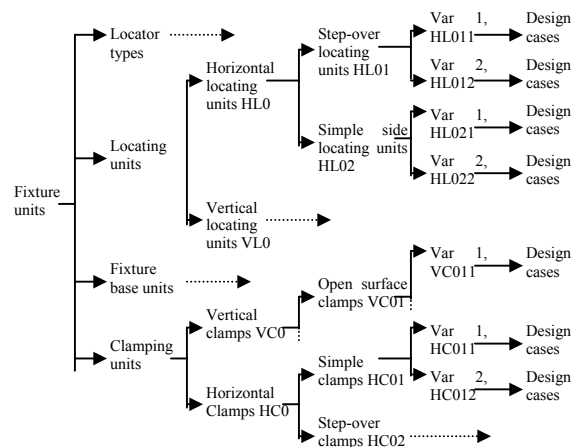


Figure 9: The Decomposition of Case Library 2

Each step down the hierarchy represents a refinement of the unit design. For example, locators can be split up into two types – horizontal locators and vertical locators depending upon the direction of support they provide. Horizontal locators can be subsequently decomposed into two possible types, designated as HL01 (a requirement for step over locating units)

and HL02 (a requirement for simple locating units). HL01 represents the situation where there is another face existing below and which extends beyond the locating face, and HL02 the situation where there is a face above or no face above the locating plane. Each of these locating situations require different types of locating units. For example, HL01 requires the use of L-shaped locating units, whereas HL02 allows tower side locating units or also possibly L-shaped locator units to be used as illustrated in Figure 10.

To each leaf of the case base are attached previous instances of locating and clamping units together with the functional requirements that the unit is used to achieve. Also linked are the relevant PVs.

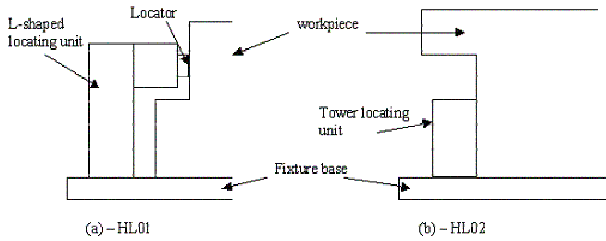


Figure 10: The Two Types of Horizontal Locators

3.2.2.4 Indexing Design Cases – An Example

In this section, a fixture design for a caliper will be used to illustrate how cases are stored in the case library. Figure 11 illustrates the caliper workpiece and its corresponding fixture design. Figure 12 details the locating points.

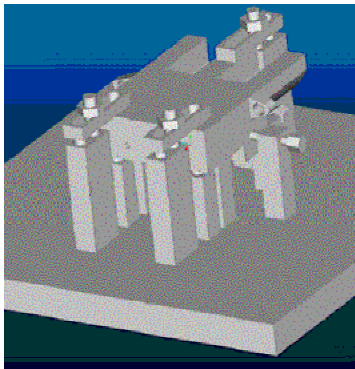


Figure 11: The fixture for a caliper

The fixture has a 3-2-1 locating principle, where two of the primary locators (P1 and P2) act on the same planar surface on the bottom surface of the caliper, whilst the remaining primary locator (P3) acts on a different surface. Three strap clamps are used to clamp the caliper against the primary locators, whilst simple screw clamps are used to provide secondary and tertiary clamping. The secondary clamps sit entirely underneath the caliper.

3.2.2.4.1 Storing the Design in Case Library 1

The design is a 3-2-1 fixture design. The two secondary locators act on the same planar surfaces, but only two of the primary locators act on the same planar surface. The third acts on a different surface. Thus, navigating through case library 1, the design is a 3-2-1 plane locating design of type Variation 3. The primary locators are split, hence the designation of the

primary location scheme as $XSplit1_{Var3,3-2-1}$ in the decomposition of case library 1 presented in Figure 13. The two secondary locators (S1 and S2) act on the same surface, thus their designation as $YSplit0_{Var3,3-2-1}$. The tertiary location (T1) is indexed as $Zsplit0_{Var3,3-2-1}$.

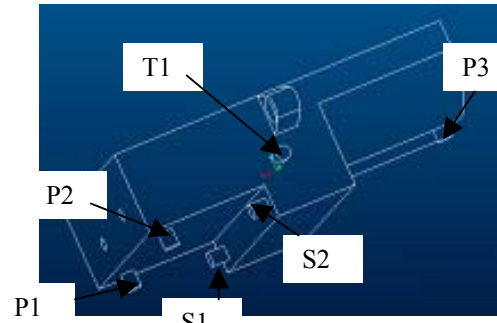


Figure 12: Caliper locating points

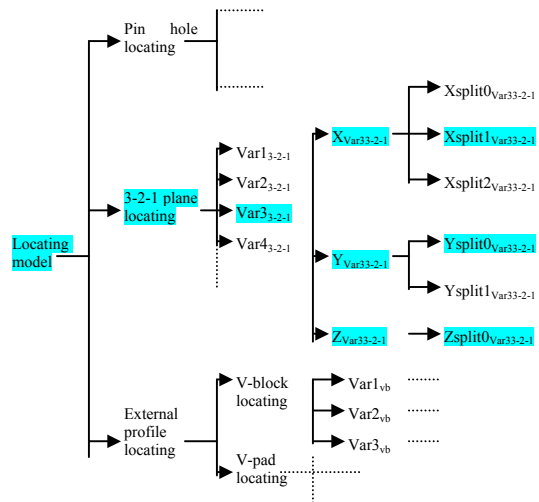


Figure 13: The Decomposition of Case Library 1

3.2.2.4.2 Storing the Design in Case Library 2

Case library 2 contains the designs of the individual units that constitute the complete fixture design. This section illustrates the manner in which these individual units are stored in the case library using one of the primary clamping units (Figure 14) as an example. The clamp consists of the clamping support unit, the fixture base, the clamp arm, the nut/screw assembly, and the mounting pin for the arm. Within case library 2, it is denoted as a vertical clamping unit, type 01, variation 1 i.e. VC01Var1.

The unit has two FRs associated with it, the first of which states the clamping force requirement the clamp must achieve:

- FR2.1.1.1 – Provide clamping force of 100 lbs against locator P1
- DP2.1.1.1 – Clamping force unit providing 100 lbs
- PV2.1.1.1 - Nut/screw tension

The clamp must provide a clamping force of 100 lbs, thus the required DP is simply a clamping unit providing 100 lbs of force. This is achieved through the PV, which is the tension in the nut/screw assembly.

The second FR is related to stability:

FR2.1.2.1 – Control w/piece translation to less than 0.002in (+ve Z direction) at loc P1 under 100 lbs
 DP2.1.2.1 – Clamp C1 stiffness of 16.67E6 lb/in²
 PVs are: Unit A dimensions (width, thickness)
 Base plate dimensions (thickness)
 Unit B dimensions (width, thickness)
 Material properties of base plate
 Material properties of main units

The FR requires that the clamping unit be capable of withstanding a force of 100 lbs acting against it such that displacement of the clamp surface is restricted to less than 0.002 in. The corresponding DP is the clamping stiffness, which can be achieved through multiple PVs related to the physical and geometrical properties of the individual entities that comprise the clamping unit.

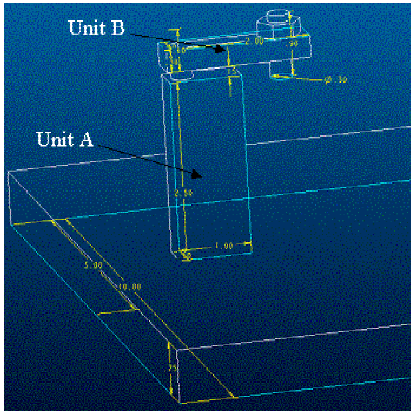


Figure 14: A Primary Clamping Unit

3.2.3 Storing the Relationships Between the FRs, DPs, and PVs

During retrieval and adaptation, the relationships connecting the FRs, DPs, and PVs must be known. Axiomatic design uses a matrix to store the relationship between the FR and DP domains and a second matrix for the DP and PV domains. The CAFixD approach however advocates a format entitled the second layer that explicitly shows the relationship between the FRs, DPs, and PVs in a single representation whilst simultaneously highlighting the effect that different types of constraints have on the design solution.

Figure 15 presents this second layer. The second layer illustrates how the PVs, DPs and FRs are related. Thus, PV_{2.17} has an effect on DP_{2.7} determined by the relationship RelDP_{2.7.1}. DP_{2.7} then acts as the input to RelFR_{2.7.1}, which controls the level of FR_{2.7}. However, DP_{2.7} can also be controlled by PVs 2.18 and 2.19 through their respective relationships RelDPs 2.7.2 and 2.7.3. The second layer also illustrates clearly the roles of the constraints. Two types of constraints exist. Local constraints exist on the PVs. For example C10 and C11 are local constraints that limit the value a PV can have. Thus, if PV_{2.19} is a thickness, C10 will be the minimum allowed thickness and C11 the maximum. These local constraints act upon the PVs.

Global constraints pertain to the fixture design as a whole and include items such as total cost, weight etc. The PVs may or may not have an effect on these constraints, but these are

limits on the fixture design as a whole. For example, altering PV_{2.19} will increase cost (C1), but there is no limit on the cost of the thickness change itself. It may be possible to offset the increased cost of the thickness change elsewhere in the design. In this way, the second layer allows the designer to gauge the global effect of local decisions.

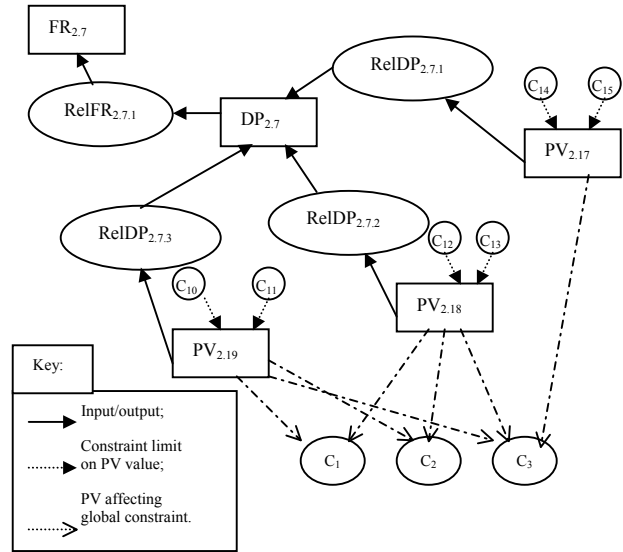


Figure 15: The Second Layer of the Design Matrix

3.3 Retrieving Design Cases

Retrieval occurs in two stages, the first of which is a vetting operation based upon functional similarity. The FR performance values of stored design cases are compared with those of the current design requirement, and the utility of each stored design case is obtained from the utility curves that the designer has previously specified for each FR. The design cases with the highest utility values are then proposed for further consideration on the basis of their adaptability.

When assessing candidate cases on the basis of adaptability, the necessary change that must be made to a PV to achieve an FR is determined using the second layer. In Figure 16 for example, it has been determined that to meet FR_{2.7}, a case in the case base must have its DP (DP_{2.7}) value altered. There are various PVs by which this DP can be altered by the required amount. These include PV_{2.17}, PV_{2.18}, and PV_{2.19}. The objective is to determine which of these PVs is the most desirable one with which to control the DP.

Consider PV_{2.17}. To achieve the required DP level, the change in PV_{2.17} (the thickness of a locator for example) is an increase of 1 in. The relationship between this PV and the global constraints on the fixture design are known. The utility curve states the worth of this constraint to the design based upon the value of this attribute. In this instance the attribute is the weight of the fixture (C3), and the resultant increase in weight of the fixture can be determined. The worth of this increase in weight can then be determined using the utility curve and the worth of the design change to the design as a whole can be calculated. This can be repeated for all possible design changes (PVs 2.17, 2.18 and 2.19) and the associated utility value recorded. The most desirable design change can then be selected (in this instance PV_{2.17} since it has the least negative impact).

secondary and tertiary clamping. The secondary locators and clamps sit entirely underneath the caliper.

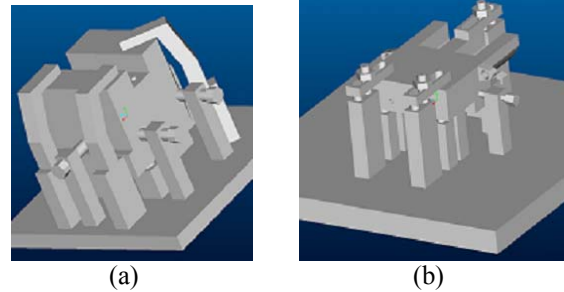


Figure 18: The two complete fixture designs

Retrieval occurs in two stages. Initially, retrieval is performed on the basis of functional similarity i.e. how similar are the FRs of the stored design cases to the current design requirement. The utility curves are used to determine the worth of each design case on the basis of its FR value. The worth of a complete fixture design can be obtained by combining the utility values for each FR of that design. This stage is essentially a vetting process. The most functionally similar cases are then re-ranked on the basis of their adaptability, as described in Section 3.3. The results from the study are presented in Table 1.

FR ₁ – Locate workpiece to required accuracy
FR _{1,1} – Locate the workpiece
FR _{1,1,1} – Provide location directions – 6 FRs
FR _{1,1,2} – Provide contact between locator and workpiece – 6 FRs
FR _{1,2} – Control accuracy of location
FR _{1,2,1} – Locate workpiece to required drawing tolerances – 6 FRs
FR ₂ – Support workpiece against machining forces experienced during machining
FR _{2,1} – Hold workpiece in situ during machining – 6 FRs
FR _{2,2} – Support workpiece during machining – 12 FRs
Constraints:
C ₁ – fixture weight not to exceed 15 lbs
C ₂ – fixture cost not to exceed \$110
C ₅ – fixture assembly time not to exceed 15 mins

Figure 19: The FR set for the new design

	Complete		Synthesized	
	Design 1	Design 2	Design 3	Design 4
Overall utility (similarity)	0.898	0.925	0.939	0.898
Overall utility (adaptability)	0.62	0.524	0.602	0.64

Table 1: Results for the two retrieval methods

The methodology would normally generate designs by searching for the most appropriate design solution (individual fixture units) for each FR before combining them to form one complete fixture design. Designs 3 and 4 represent the results of the standard approach of the method. For the purposes of comparison however, the two complete fixture designs presented in Figure 18 were each considered as a whole during retrieval (i.e., they were not decomposed such that the best parts of each design could be assembled to form a new design). Fixture Design 3 is a synthesized design found by combining the most functionally similar units of fixture designs 1 and 2. Fixture design 4 represents a complete design that was compiled from individual units that each had the highest utility

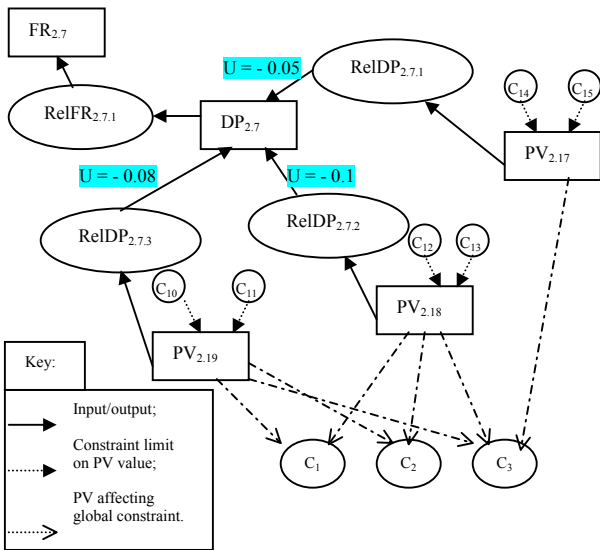


Figure 16: The second layer of the design matrix

4. WORKED EXAMPLE

A worked example has been conducted in which a fixture was generated for the part shown in Figure 17. Features to be machined are the two channels and the hole. Initially, the appropriate conceptual design is retrieved from case library 1 based upon the workpiece geometry. Standard fixture design rules support this process, and for this workpiece a standard 3-2-1 locating model is retrieved along with its skeleton FR set defining the tolerance and force stability FRs.

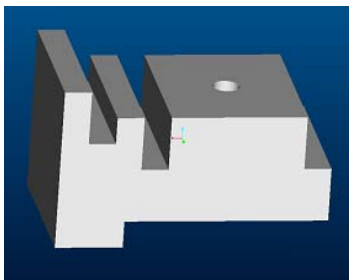


Figure 17: The workpiece

Upon generation of the list of functional requirements, the designer defines his/her design preferences in the form of utility curves for each FR and constraint. Case library 2 contains all of the individual fixture units of the two complete fixture designs presented in Figure 18. Fixture design 1 is presented in Figure 18a. It is a simple 3-2-1 locating principle fixture with three identical primary locators acting on the bottom surface of the workpiece. Three hydraulic clamps perform primary clamping. Two identical screw clamps perform the secondary clamping requirements and act against two secondary locators that both act upon the same surface and are identical. A step-over side locator provides tertiary location, and a screw clamp provides tertiary clamping. Fixture design 2 (Figure 18b) is a fixture that holds a caliper in place during machining. The fixture has a 3-2-1 locating principle, where two of the primary locators act on the same planar surface underneath the caliper, whilst the remaining primary locator acts on a different surface. Three strap clamps are used to clamp the caliper against the primary locators, whilst simple screw clamps are used to provide

in terms of adaptability. This new synthesized case was the best case in terms of retrieval by adaptability. Figure 20 presents fixture design 4.

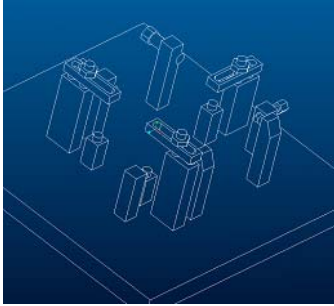


Figure 20: The new design solution

5. CONCLUSIONS AND FUTURE WORK

This paper has presented the CAFixD methodology to support the fixture design process. It seeks to address three main issues. One is that it considers the complete operational requirements of a fixturing problem. Secondly, the approach adopts a rigorous indexing technique in an effort to prevent the problem of inseparability. Thirdly it uses adaptability to guide retrieval by choosing those cases whose adaptation will have the most desirable effect upon the overall design solution, whilst still using traditional attribute similarity to constrain the search space to prevent control problems.

Currently a software implementation of the CAFixD method is being developed as a stand-alone system that communicates with other CAD/CAM packages as and when it needs to pass or receive information from external sources. The purpose of CAFixD is to process this information, use it to generate a fixture design, and then pass on the details of this fixture design to a CAD package that will create the fixture design drawings. System development is currently focusing on two main areas. The first is that the decomposition-reconstitution approach results in the dynamic creation of constraints during the adaptation stage and these constraint effects must be incorporated into the evaluation of design adaptability. A simple example of this constraint generation is that checks must be performed to ensure that individual units are compatible with each other and can be combined to form a complete fixture. A second issue is the learning mechanism. This is a key area of development. Due to the high levels of computation involved in CAFixD, work is ongoing to develop strict criteria for managing the growth of the case base.

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