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14. ABSTRACT The basic premise is that a legacy part design that was originally optimized for one manufacturing process may either be impossible to produce by another process, or too costly. To re-manufacture a replacement part, the original geometry and the material need to be modified; such modification must be done without violating the inter-facing, functional and structural constraints.							
The Rapid Re-Engineering System (RRES) is envisioned to serve as a bridge between Geometry Extraction							
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REPORT DOCUMENTATION PAGE



LSE Re-Engineering Testbed: Final Report

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Grant# <u>W911NF-05-1-0186</u> May 2009

Outline

- LSE Background
 - Motivation & Broader Impacts for US Army
 - What is Legacy Systems Engineering
- ASU Project Overview
 - Major objectives
 - Status at a glance
 - Collaborations
 - Tech Transfer issues
- Technical Details
 - TechSpec formulation
 - Cost & Manufacturability evaluation
 - Material substitution
 - Assemby feature & load paths extraction (structural function)







LSE BACKGROUND







- The US military owns and operates many complex electromechanical systems, some that were designed 25-50 years ago.
- Continued maintenance requires spare parts but the original manufacturers may no longer be around to provide them.
- In some cases there might not be sufficient technical data available to the Army to allow replacement manufacturing; in other cases, replacement costs may be too high or have large delivery times
- to sustain such legacy systems in a cost effective manner and respond rapidly to demand, a holistic plan is needed
- Past research has produced many clever solutions to specific problems, particularly geometry extraction from legacy parts and automated CAD model re-construction from point clouds or paper drawings and reproduction of copies of the original part.
- The holistic plan must include a high degree of automation (to reduce manpower cost, expertise needed) and high degree of integration between the sub-systems
- to move from academic labs to the real world, such as Army facilities like Mobile Parts Hospitals (MPH), a major shift of strategy is needed







REVERSE ENGINEERING

Producing as close of a replica of the original part as possible. Part specification may come from drawings or physical parts (used or pristine)

RE-ENGINEERING

Selectively change some attributes of the original design, such as materials and geometry not constrained by interfacing requirements, etc. May be necessitated by inability to extract all engineering specs, unavailability of certain manufacturing resources, time/cost constraints, or desire to improve the design

RE-DESIGN

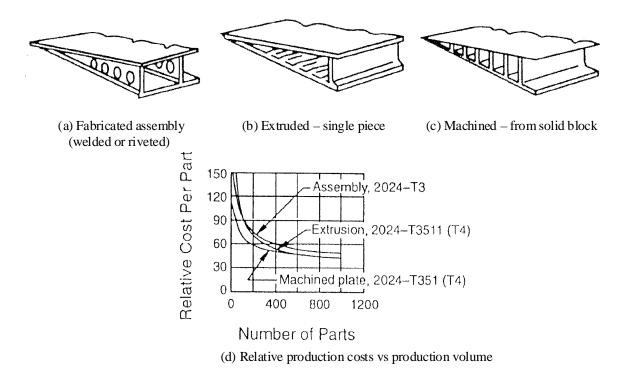
Replace the original part with an equivalent device, if it happens to be a standard device (motor, bearing, gear or gearbox, clutch, brake,etc.) or design a new component based only on the performance requirements and inter-facing constraints.

We refer to all of these collectively as "Legacy Systems Engineering"



Background: Manufacturing feasibility & economics





- A legacy part that was originally optimized for one manufacturing process may either be impossible to produce by another process, or too costly.
- To re-manufacture a replacement part, the original geometry and the material may need to be modified;
- such modification must be done without violating the inter-facing (geometric), functional and structural constraints.





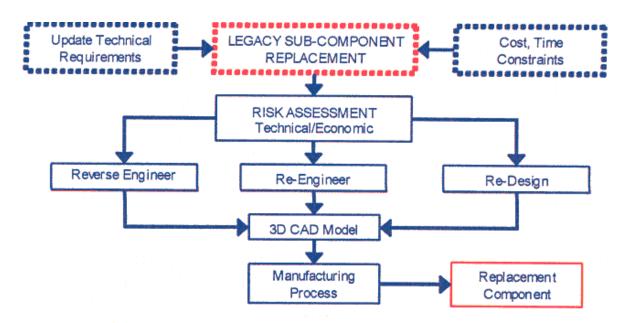
Background: Viability of LSE

- Must consider both technical and economic viability
- Tech Viability requires producibility evaluation that must be based on the manufacturing resources available
- Economic viability must take into account batch size and lead time. Special tooling, dies, molds, fixtures should be avoided, because small batch manufacturing cannot sustain the cost and the also because the lead times are large
- **LSE** must be heavily automated to minimize the cost in small batch production
- The consequences of design changes must be investigated with simulation tools and constraint based design systems; including functional and structural integrity.



Which LSE Strategy is best?





The decision depends on several technical and economic factors

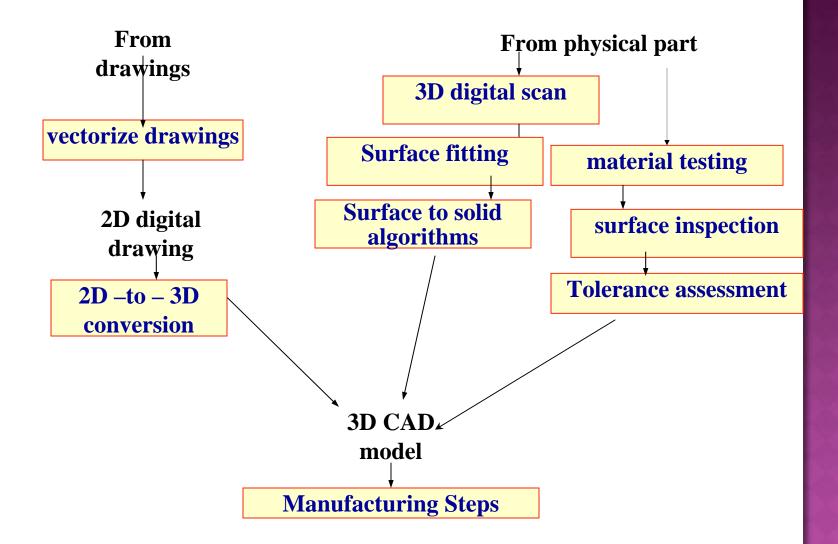
How much information is known about the part?

- What form is the data in? (paper, digital, physical part ...)
- How much will it cost to collect additional info needed?
- Is it a standard or non-standard part?
- What quantities are needed? how quickly? future demand?
 - What is the level of obsolescence of the embedded technology?
 - What is the complexity of the part? Degree of coupling with other subsystems?
 - Do we need and equivalent part or an improved/upgraded one?



Reverse Engineering Technologies

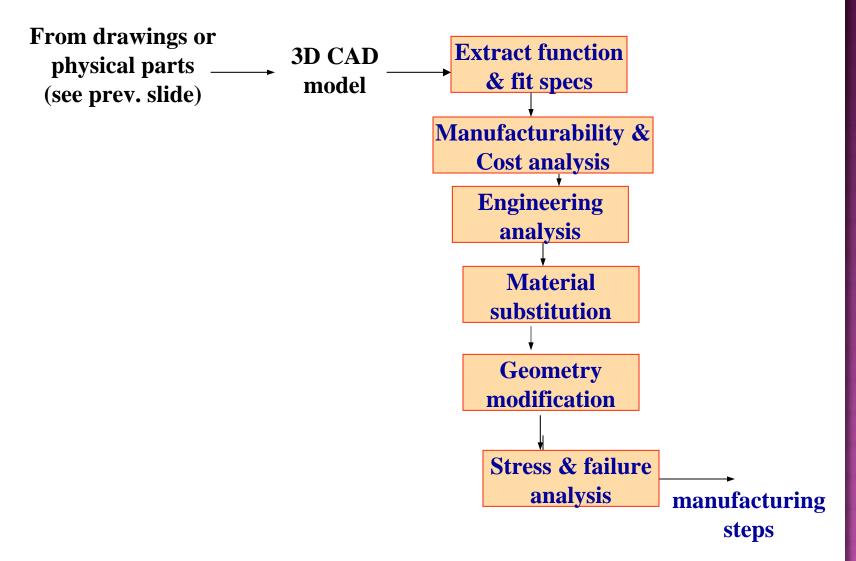






Re-engineering Tasks









ASU PROJECT: OVERVIEW







- Grant W911NF-05-1-0186
 - Holistic Legacy Systems Engineering: Rapid Reengineering System
 - Partial funding, \$125k
 - Start date: 4/15/2005

Addendum 1

- Material substitution pilot study
- **Funding \$18.7k**
- Start date: 2/23/2006

Addendum 2

- Semi automatic extraction of structural function
- Funding, \$13k
- Start date: 2/22/2007

Project end date: 2/14/2009



ASU Projects Particulars



- Develop technologies and tools to analyze and Redesign legacy parts that
- Must
 - cost less
 - take least possible time to re-engineer and manufacture
 - be manufacturable with capabilities available in the field, such as Army MPH
- Must not violate
 - interfacing constraints
 - kinematic constraints
- Must take the loads applied



Cost of Legacy Systems Engineering

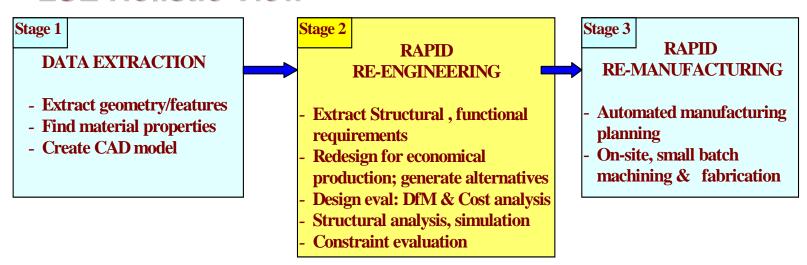


- Costs include:
 - forensic analysis
 - product teardown
 - measurements and test
 - analysis for re-engineering / redesign
- Because of small batch sizes and time (urgency), automation of these tasks is even more critical
- Which tasks can be automated and how?



LSE Holistic View





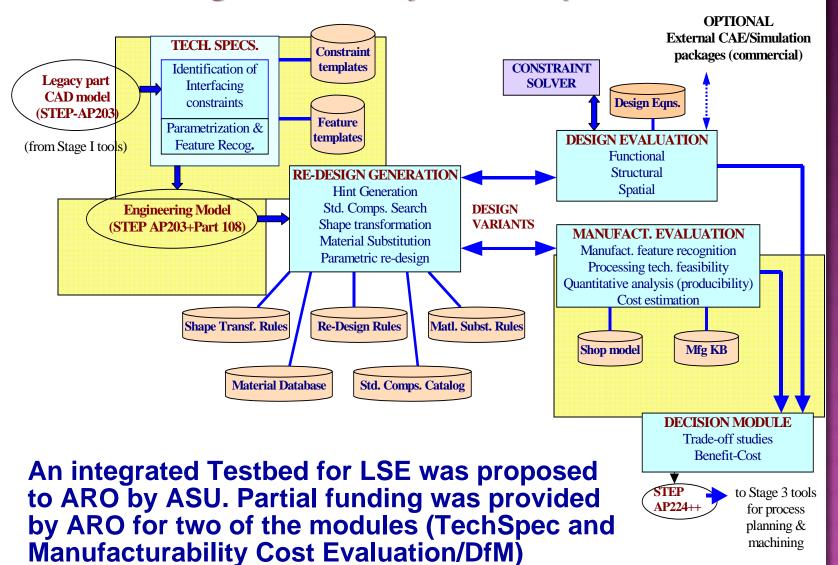
- Prior research in Reverse Engineering has produced
 - (i) Methods for extracting geometric information from legacy parts/drawings;
 - (ii) produce near exact replicas of original parts;
 - (iii) Techniques to automate manufacturing planning tasks.
- Observation: the above tasks are necessary but not sufficient; the technologies in Stage 2 are missing

Our goal is to explore a holistic strategy to make LSE technologies economically viable and technically practical for field deployment.



Integrated LSE System Proposal





Subsequent partial funding for pilot studies of material substitution and function extraction



Project Status at a glance



- Rapid Re-engineering System (RRES)
 - TechSpec Data model: completed
 - TechSpec module: partial implementation done
 - DfM Testbed: completed and adapted to RRES
 - Interfacing TechSpec with DfM: planned
- Material substitution pilot study
 - Database design: done
 - Substitution rules: initial set
 - Material DB population (pilot): proof of concept
- Semi automatic extraction of structural function
 - Theoretical formulation: done
 - Mating feature extraction algorithms: in progress
 - Software implementation: future



Synergistic collaborations



- ASU is also part of a multi-university consortium called VPERC (Virtual Parts Engineering Research Consortium)
- VPERC includes U. Utah, Hampton University and several small businesses (manufacturing shops)
- VPERC also has association with Focus Hope, TARDEC and TACOM
- Each university partner is funded separately by ARO
- U. Utah researchers specialize in digital scanning and surface reconstruction; Hampton has expertise in nondestructive testing techniques for materials, as well as, some imaging methods for assemblies before taking them apart
- ASU expertise is in engineering design, manufacturability evaluation and precision engineering



Project Needs & Tech Transfer



Technical Data Packages

- from our TARDEC contact (T. Wagner) and TARDEC contacts (G. Moeller, T. Richman) we have managed to get only two sets of specs for real legacy parts and assemblies – candidates for LSE
- the project needed more example TDPs of mechanical assemblies or parts, particularly load bearing parts or castings, but this did not happen

Tech Transfer

 we would like to arrange face to face meetings with maintenance shop personnel to solicit their opinion on usability and customizability of the DfM Testbed

Additional RRES modules

 so far ARO has funded only TechSpec and DfM modules; Design Generation and Design Evaluation Modules were left open for future funding





ASU PROJECT: Technical Details



Technical Tasks



- determine technical specification content required for re-engineering (form, fit, function)
- design neutral data model for Tech Specs including kinematic, assembly and spatial constraints
- design constraint management system
- develop a method for extracting kinematic and structural function based on screw theory
- design and implement a customizable DfM and Cost shell, populate with MPH data and integrate with TechSpec
- design a material substitution system: subsdtitution rules, material database, queries
- implement interactive system for extracting technical specifications and constraints
- demonstrate redesign based on manufacturability (pilot)







Geometric data is necessary but not sufficient for reverse engineering. We also need

- material data
- surface quality data
- heat treatment
- surface treatment
- precision data (tolerance information)

Part drawings may have this data, physical parts may not carry this info



What more do we need to know?

What is the function of this part →

Observation

Part geometry (from drawing, physical part) is insufficient to understand function of a part unless it is a standard component

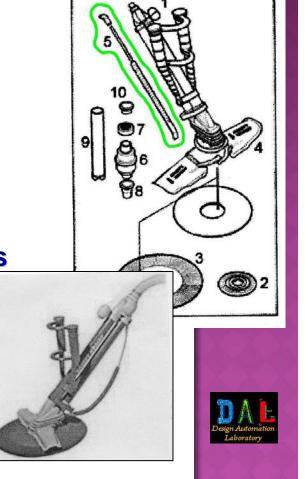
Mechanical parts move, transmit force, transmit/convert/absorb energy, allow/prevent material flow ...

Observation

Viewing the part in relation to other components gives more information, but

- -we need to see it in its operating environment
- -we need to apply technical expertise relevant to that domain

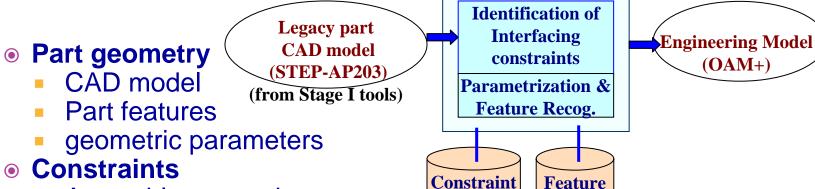
cannot tell by looking at just a picture, drg, or physical part



TechSpec Module



From the the assembly and part models extract:



TECH. SPECS.

templates

templates

- Constraints
 - Assembly constraints
 - Mating regions
 - Shape, size
 - Spatial
 - Kinematic constraints
- Loads
 - External loads
 - Transfer loads
- Supports
- **Material specification, including HT**



Kinematic & Structural function



- To completely characterize the state of the constraint of an assembly
 - state of mobility and constraint needs to be determined separately
 - Screw theory can be used to do this
- Screw theory
 - Determines the specific degrees of instantaneous freedom of mobility and/or directions of instantaneous overconstraint of a given part in the assembly
 - First developed by Sir Robert Ball¹; A simplified approach to analyze assemblies is developed by Whitney²
 - A screw is a way of representing the motions that a rigid body can undergo or of representing the forces and moments exerted on it.
 - Screws representing

 - motion are called twists, $T = [\omega_x, \omega_y, \omega_z, v_x, v_y, v_z]$ forces are called wrenches, $W = [f_x, f_y, f_z, m_x, m_y, m_z]$
 - A twist or wrench matrix has
 - six columns
 - o one to six rows, one for each degree of freedom being described



TechSpec Contents

- 1

Part feature

- Required to support redesign
 - Parametric modification
 - Feature replacement
 - Constraint modification
- Required by assembly feature
- Must be represented using N-Rep definition
 - Existing feature recognizers will be useful

Assembly feature

- Required to store information between part features
- Helps during design validation

Parameters

- Used in part and assembly features
- Allows parametric redesign

Constraints

- Used in part features
- Allows constraint based redesign
- Used for validating design

• Kinematics

- Mobility of parts
- Needed to maintain the kinematic validity
- limits of kinematic motion

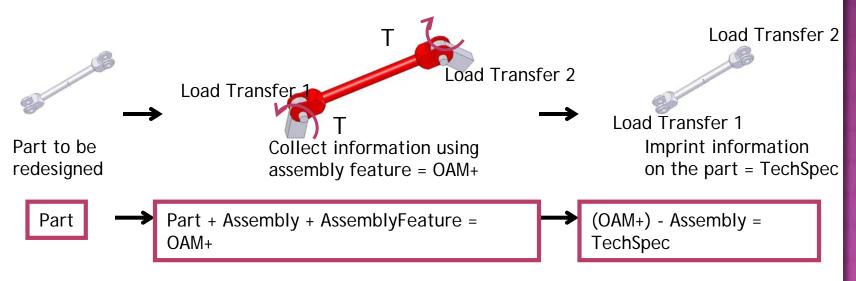
Load paths

Magnitude, direction, location, time historty



TechSpec Input/Output

- Input to TechSpec
 - A representative assembly of redesign part
- TechSpec system needs to
 - Extract interfacing, kinematic constraints
 - Define parameters, kinematic limit
 - Specify loads
- Information are stored in OAM+
- The output is expressed in XNRep schema for redesign





TechSpec Data Model development (OAM+)

- Assembly feature is a must
 - Part feature and information between them
- Assembly can be viewed as
 - Parts with some surface contacts
 - Simple
 - Only stores surface contact information
 - Parts with interacting part features (asm. feature)
 - Little more complex
 - Part features must be identified first feature recognizers
 - Can store any information between the part features
 - Very useful for "imprinting"
 - The external part can be discarded after constraint extraction
 - New part can be replaced and constraints can be restored



Parameters - defines a new vraiable

- Between geom. Entities geom. parameter
- Between other params algebraic parameter
- Unlike constraint it does not put limit
- Important for constraint spec. and redesign

Constraints representation

- Enumerated
 - Easy to use
 - Introduction of new constraint will need modification of the model – not flexible
- Generic
 - Any two entities can be taken together and related to each other
 - Very flexible new constraints can be defined and added
 - Can work with user defined constraints and features (NRep)
 - Can be translated to solve by constraint solver



Kinematics representation

- Screw theory is used
- Opens up many possible automations
 - Kinematics extraction from interfacing constraints
 - Simple kinematic validation
 - Assembly hierarchy generation

Load Representation

- Equivalent load on a common mating point
 - Parts contact over a surface, not a point
 - Equivalent load may not represent the actual load correctly
 - Contact load transfer, multiple contacts
 - OAM+ is a model not an application should only store the load
- Actual load and load transfer information
 - The load and its location in redesign part co-ordinate system
 - The load transfer can be determined by the wrench matrix
 - Simple and accurate



- Base entity TSFeatureEntity
 - Points to a geometric surface
 - Features and their relations are defined using surfaces
 - Can be extended to support other entities in future
- Geometry TSPartGeometry
 - Hides the internal geometry from user
 - Any BRep CAD model can be used internally
 - Application (TechSpec) should provide method
 - to traverse the geometry
 - to create references to the surfaces
 - ACIS commercial geometric kernel is used in this research



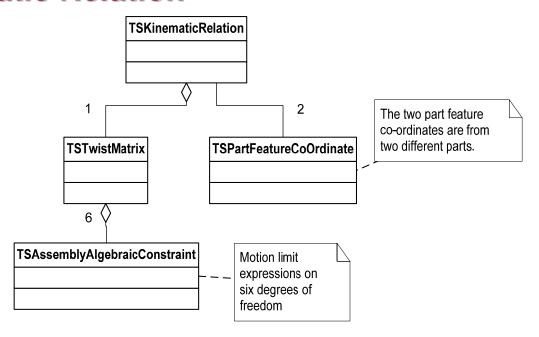


- Material Representation TSMaterial
 - Set of material properties
 - Instead of using an array of numbers any material property can be created and added to the material
 - Flexible can work with any material database (provided that the material property definitions comply)
- Material property TSMaterialProperty
 - From the commercial material property definition
 - Property name
 - Variability (constant/function)
 - Value
 - Unit



Kinematic Relation



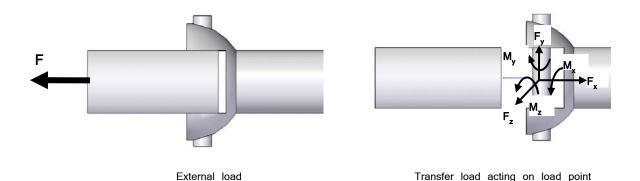


- TSKinematicRelation is composed of a TSTwistMatrix (from Screw Theory) and has two TSPartFeatureCoOrdinates.
- The two part feature co-ordinate systems should come from part features on two different parts
- The twist matrix describes the degrees of freedom in terms of possible angular and linear displacement
- Each DOF is associated with motion limits that are essentially algebraic constraints
- Expressing limits as algebraic expression in terms of part and assembly parameters, instead of a specific limiting value, assures that the limits remain valid when the design is changed.



Transfer Load





- TSTransferLoad is the load transferred between parts in an assembly.
- TransferLoad should be placed on an assembly feature, the common portion of the mating parts in an assembly.
- The concept of LoadPoint is used to specify the transfer load.
- LoadPoint is a point near the common mating position of an assembly feature, where all the loads due to a load transfer can be assumed to be acting
- LoadPoint is a point near the common mating position of an assembly feature, where all the loads due to a load transfer can be assumed to be acting
- One advantage of the notion of load point is it can be imprinted onto the part to be redesigned







- Loads on part
 - External (applied)
 - Internal (stress calculation, needed by simulation app.)
- Force or moment
 - Location function of time x(t), y(t), z(t)
 - Magnitude function of position and time x, y, z, t
- The load vector:

$$F = \begin{bmatrix} F_u \\ F_y \\ H_{uy} \\ M_{yu} \\ M_{yu} \end{bmatrix}$$
 where $F_l = f(x, y, z, t)$

- From the stress equation, its calculation will need:
 - Surface contact present in assembly feature
 - Amount of surface mate
 - Load transfer wrench matrix
- Amount of surface mate
 - Obtained from geometric intersection of mating surface
 - Represented by a list of mating surfaces S_i and their bounding edges E_i: MM = (S_i, E_i)



Loads - 2

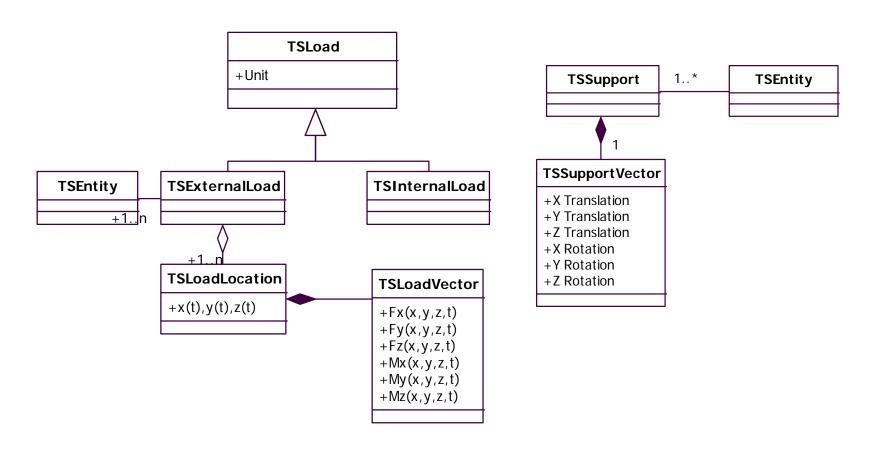
- Static load on an assembly
- The load vector (based on screw theory)
 - $F = [F_1 F_2 F_3 0 0 M_3]^T$
- The location L = (a,b,c)
- Mating Matrix
 - A surface fragment on the pin (redesign part)
 - Two edges bounding it
 - $MM = \{(S_1), (E_1, E_2)\}$
- Load transfer
 - Wrench matrix for pin-hole feature
 - Represents forces/moments experienced by the joint
 - Can be derived from twist matrix
 - For this example

$$W = \begin{bmatrix} F_{y} & 0 & 0 & 0 & 0 & 0 & F_{y} \\ 0 & F_{y} & 0 & 0 & 0 & \alpha F_{y} \\ 0 & 0 & F_{y} & 0 & 0 & 0 \\ 0 & 0 & 0 & M_{y} & 0 & 0 \\ 0 & 0 & 0 & 0 & M_{y} & 0 \end{bmatrix}$$



Load Representation

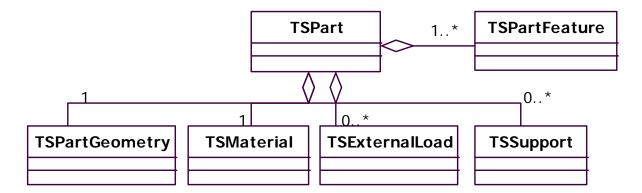
- Structural support
 - On edge, vertex or surface
 - Limits linear or rotational motion
 - For stress analysis
- A vector contains limiting values and their units

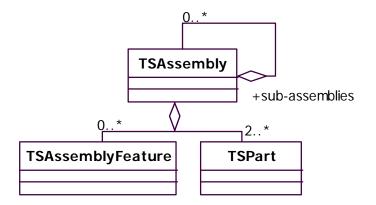




Parts & Assembly Model

- Part can have geometry, material, load and support
- Functional & behavioral attributes and tolerances are excluded as discussed before
- Part features are added for redesign support
- Assembly contains parts, sub-assemblies, assembly features
- Assembly feature contains the relations between part feature



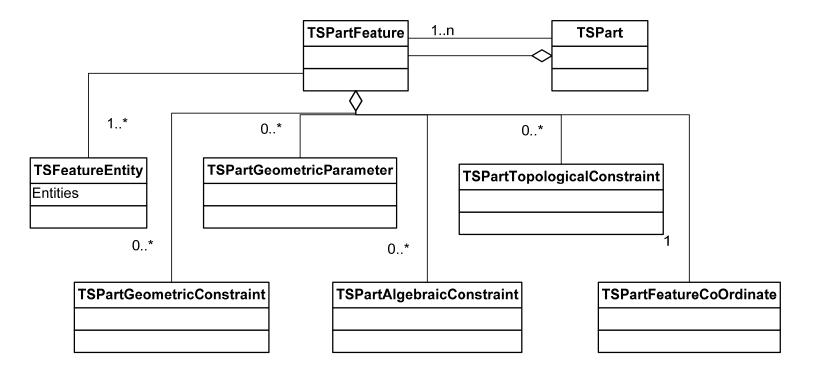








- Features are of two types
 - Part features TSPartFeature
 - Assembly features TSAssemblyFeature
- Part feature
 - Mimics the N-Rep definition: geometry, geometrical relationship, topology, topological relationship, parameters, parametric relationship, location
 - Application independent, user defined





Assembly Features



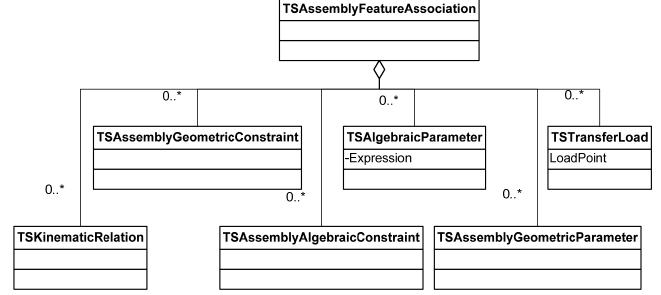
TSAssemblyFeature

TSAssemblyFeatureAssociation

2..*

TSPartFeature

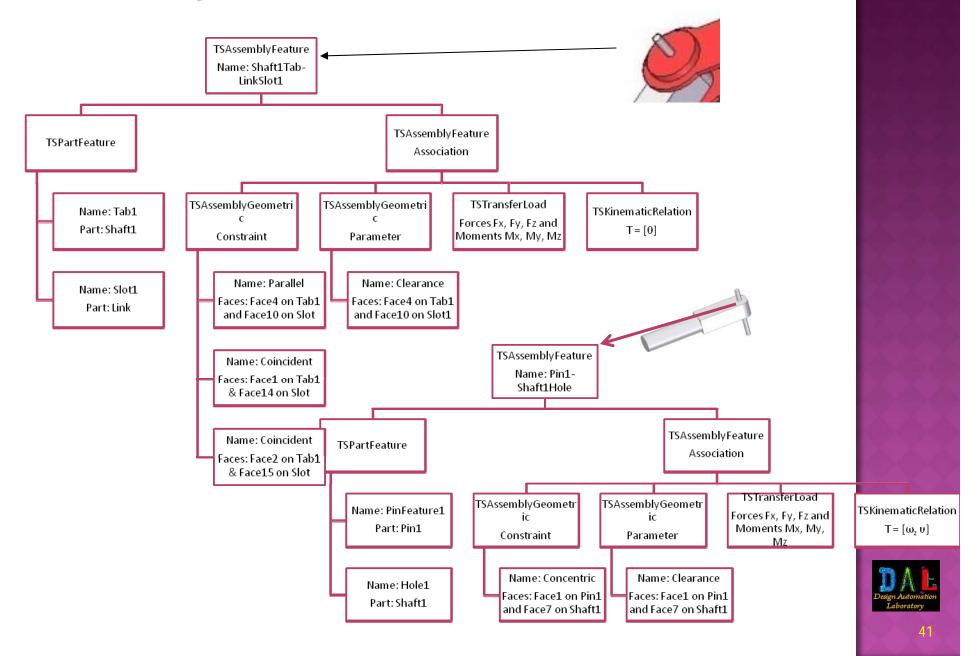
- An equivalent NRep definition for assembly feature
 - Part features
 - Parameters
 - Geometric between geometric entities
 - Parametric between parametric entities
 - Constraints
 - Geometric between geometric entities
 - Algebraic between parametric entities
 - Kinematics
 - Transfer load





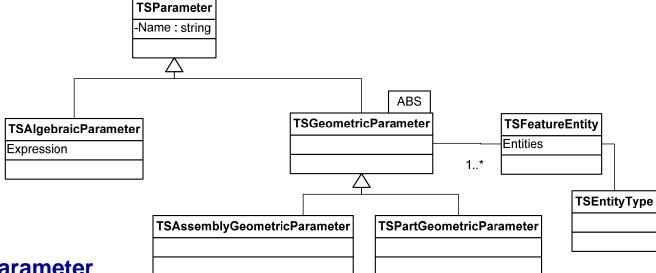
Assembly Feature





Parameter Representation





Geometric parameter

- defined by a geometric entities
- Example: Distance, Radius

TSPartGeometricParameter

- Parametric relation on a part
- Example: Distance between two faces, d = face2 face1

TSAssemblyGeometricParameter

- Parametric relation on two different parts
- Example: Distance between two faces on different parts, d = part2:face1 – part1:face1

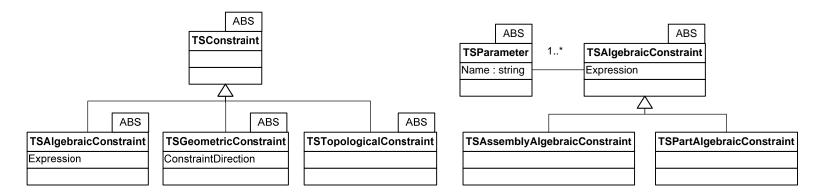
Algebraic parameter

- defined by an algebraic expression
- Example: Clearance between concentric cylinders, c = d2 d1



Algebraic Constraint Representation





Constraint puts

- absolute or relative limit on existing
 - parameters, locations, orientations and size of geometric entities

TSAssemblyAlgebraicConstraint

- Represents assembly algebraic constraints
- Example: Diameters of two pin should be same, d1 == d2

TSPartAlgebraicConstraint

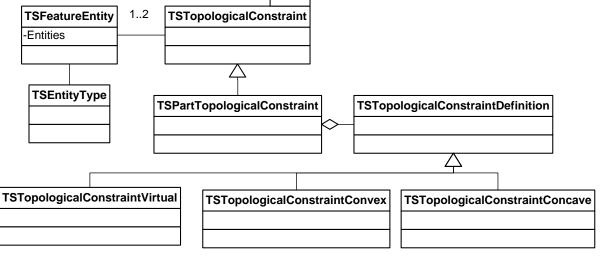
- Represents part algebraic constraints
- Example: Clearance must be less than a value, c <= 0.1mm</p>



Geometric/Topo Constraint Representation



ABS



ConstraintDirection

- indicates geometric constraint direction
- Example: 1-2, 2-1 or none

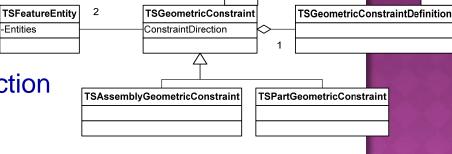
TSGeometricConstriantDefinition

- Represents coincident, concentric etc.
- Example: Distance between two faces should have a minimum value 0.1

-Entities

TSTopologicalConstraintDefinition

Represents virtual, convex and concave constraints



ABS



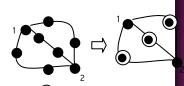


- Kinematic constraints extraction from surface contact
 - Define "basic surfaces" plane, cylinder, sphere
 - Define possible contacts plane-plane, plane-cylinder
 - Derive screw for these contacts
 - Build screw matrix of any feature by combining the screw matrix of the basic surface contacts
- Simple validation of mobility
 - Screw matrix in conjunction with network analysis
 - Finds degrees of freedom a part has wrt. other parts
 - Can be used for quick check on kinematic mobility



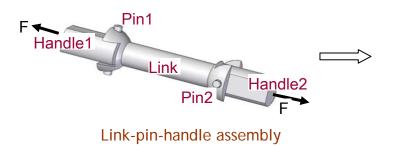
Automated Assembly Hierarchy Generation

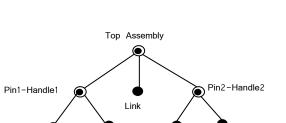
- Based on kinematic hint
- Relative effect the redesign part has in the assembly
 - If root of the assembly effect sub-ordinate parts
 - If not root other parts may not be effected
 - Note surface contacts should be taken care of
- Rule based enhanced liaison graph decomposition



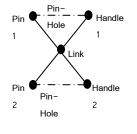




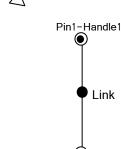




Handle2







Pin2-Handle2

Kinematic rule A applied

Linear liaison rule applied

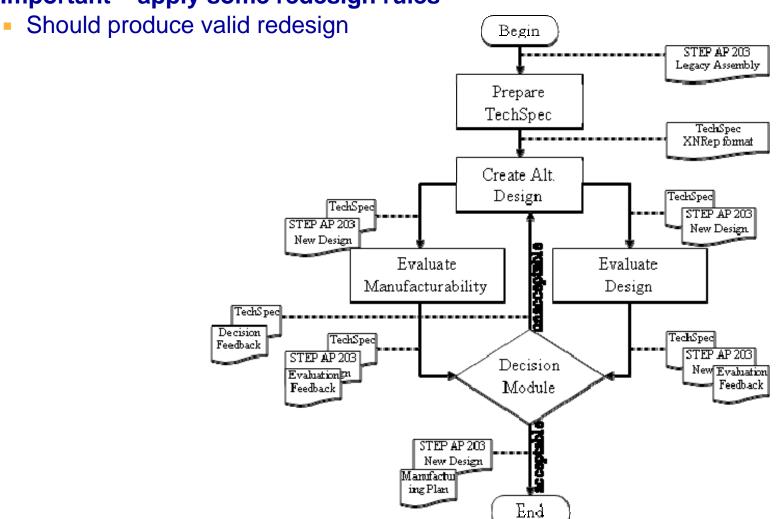
Handle1



Iterative ReDesign

- Iterative redesign contains the five components of rapid reengineering system
- More redesign iteration = more time

Important – apply some redesign rules

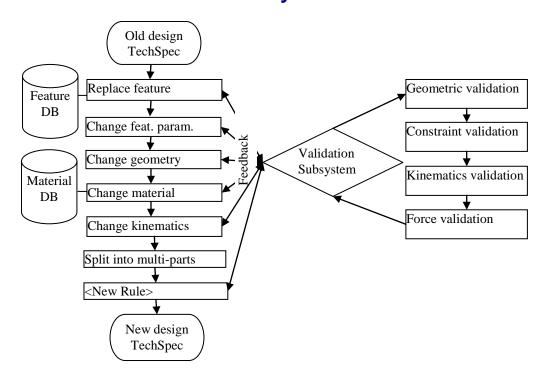






ReDesign Rules

- Two approaches
 - Complete redesign then validate
 - Incremental redsign and immediate validation
- Second approach is better
 - Eliminates iteration
 - Produces valid redesign
 - Problem: the validation may take time

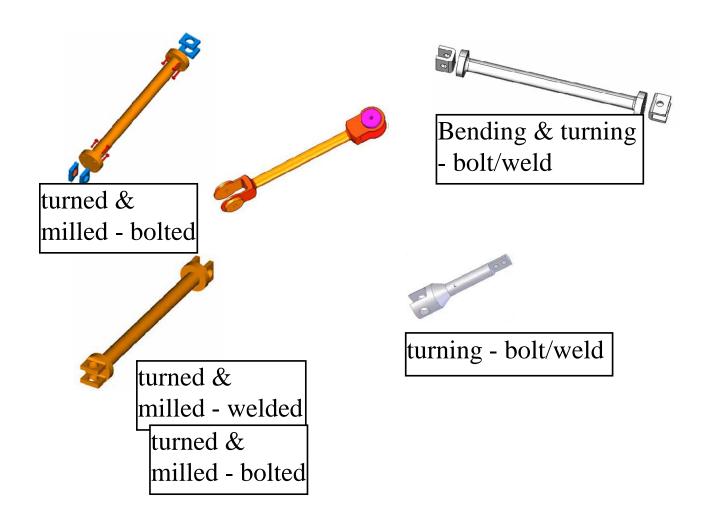






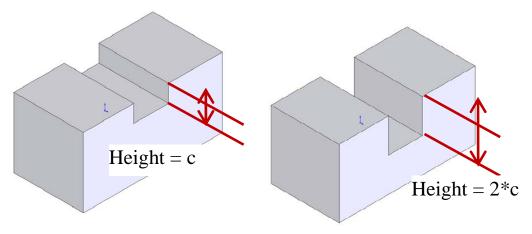
ReDesign Rule Example: Break into multiple parts

- Can simplify manufacturing process
- Non-working simpler sub-component can be replaced faster
- Validation is not possible redesign is targeted for assembly





ReDesign Rule: Parameter change





- Requires 3D constraint validation
 - Does not have the history
 - Can not rollback to 2D sketch and update
- Redesign and validation
 - User triggers the procedure by specifying the parameter edit request
 - A list of available parameters is presented to the user
 - User selects the parameter and types in the new value
 - Constraint solver is called for new value of the parameter
 - Design changes from the new constraints set are applied





Implementation

Process Flow

1. Part Feature specification

Specify part feature definition by means of Nrep language. This part feature definition can come from application like Nrep Feature Tutor.

Assembly Feature specification

Combine two or more part features into assembly features. Fill in assembly feature information in OAM+

3. Loading Assembly and Parts
Load the part. Create one or more TSPart and TSAssembly instances and fill into
OAM+.

4. Part and Assembly feature recognition

Call external or internal feature recognizer and get the instances of part features.

Create TSPartFeatures instances from it and insert into OAM+. Also provide an assembly feature recognizer interface/feel for specifying the assembly feature instances consisting the part feature already obtained. Insert these

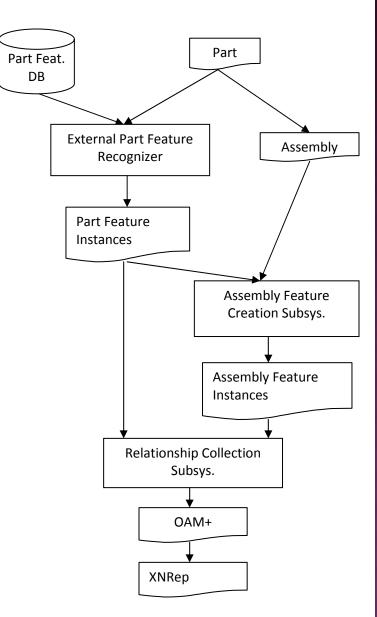
TSAssemblyFeatures into OAM+.

 Constraints and load specification
 Provide an interface for specifying constraint and loads. Create several subclasses of TSConstraint and add them into OAM+.

6. Validate constraints
Call external library such as DCM for the constraint validation.

7. Produce TechSpec
The procedure to produce TechSpec from OAM+ is yet to be defined.

Module interaction



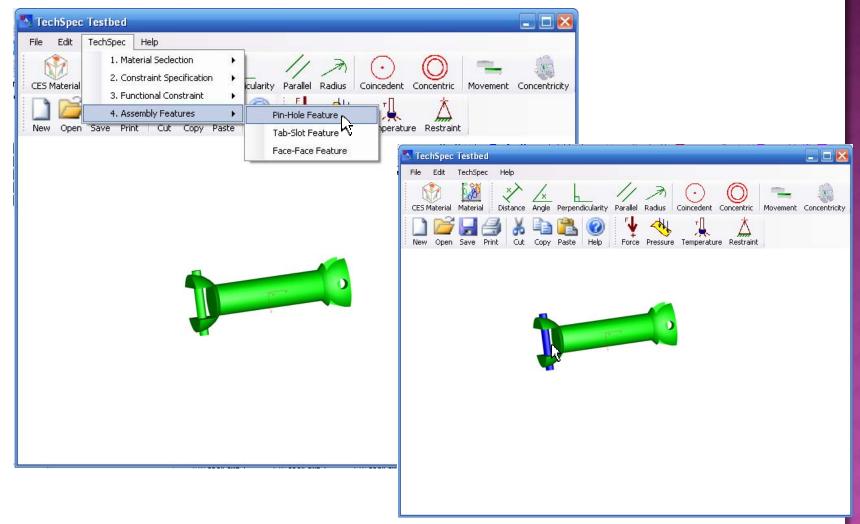




TechSpec Demo System











Part Feature Definition

- Before attempting to go into detail with assembly features, it is important to understand the basics that are involved in assembly features.
- Assembly features primarily depend on individual part features and the relationships between these part features.
- Before an assembly feature can be created, individual part features must be identified and recognized.
- Because of the lack of good part feature recognizers, interactive user-defined feature recognizers were created in ASU's Design Automation Lab (DAL) to fulfill the needs of its user.
- Currently have <u>prismatic</u> and <u>turning feature</u> recognizers.





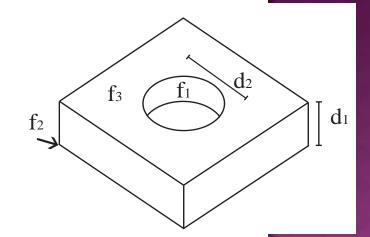
Part Feature Definition

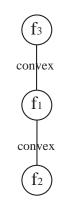
- The following part feature template defines a part feature:
 - Topology (real and virtual faces)
 - Topological Relationships (edge convexity relation)
 - Geometry (face types: planar, cylindrical, etc.)
 - Geometric Relationships (parallel, perpendicular, coaxial, etc.)
 - Parameters (typically dimensions defined by geometric relations or attributes)
 - Parametric Relationships (derived parameters or constraints on parameter values)





- Example of Part Feature Definition
 - Part Feature template for Round Hole:
 - Topology
 - Real Face: "side" f1
 - Virtual Faces: "Vbottom" f2, "Vtop" f3
 - Topological Relationships
 - Edge "convex": f1 & f2; f1 & f3
 - Geometry
 - Planar faces: "Vbottom" f2, "Vtop" f3
 - Cylindrical face: "side" f1
 - Geometric Relationships
 - Constraint "parallel": f2 & f3
 - Constraint "perpendicular": f1 & f2
 - Parameters
 - Parameter "hole_depth": d1 = distance (f2, f3)
 - Parameter "hole_dia": d2









Assembly Feature Definition

- The next step is to create an assembly feature template similarly to that for part feature recognition.
- The following template defines an assembly feature:
 - Part features that constitute the assembly feature
 - Assembly Parameter Definition
 - Geometric parameter defined by two geometric entities directly
 - Algebraic parameter defined by other parameters
 - Constraints / Relations
 - Geometric constraint between two geometric entities
 - Algebraic constraint between parameters
 - Kinematic Relation DoFs and motion limits
 - Structural Relations: load point, component directions and magnitude, time functions



Examples of Assembly Features

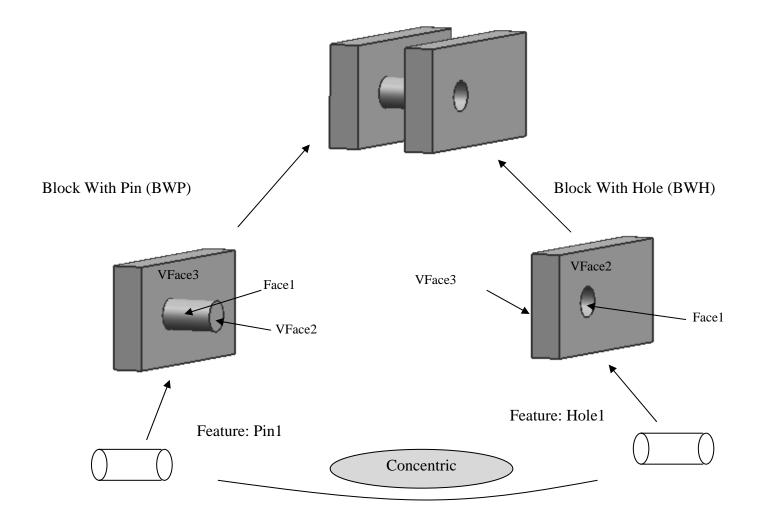
Assembly Featrue	Mating Relations and Constraints
Round Pin and Hole	Pin top face against hole bottom face OR pin virtual face against hole virtual face Pin side face relations of the form:
Prismatic Pin and Hole	Pin top face against hole bottom face OR pin virtual face against hole virtual face Pin 4 side face relations of the form:
Spherical Joint	Ball face against socket face Ball face relations of the form: Against with clearance Diameter of ball face <= diameter slot face



- Example of Assembly Feature Definition (Pin and Hole)
 - Part features:
 - o Pin: "Pin1"
 - Hole: "Hole1"
 - Assembly Parameter Definition
 - Geometric
 - Eccentricity = distance between pin axis and hole axis
 - Algebraic
 - Clearance = hole_dia pin_dia
 - Constraints / Relations
 - Geometric
 - Concentric: Face1 on BWP & Face1 on BWH
 - Against with clearance: Face1 on BWP & Face1 on BWH
 - Against: VFace3 on BWP & VFace3 on BWH
 - Algebraic
 - pin_dia < hole_dia
 - pin_length ≤ hole_depth

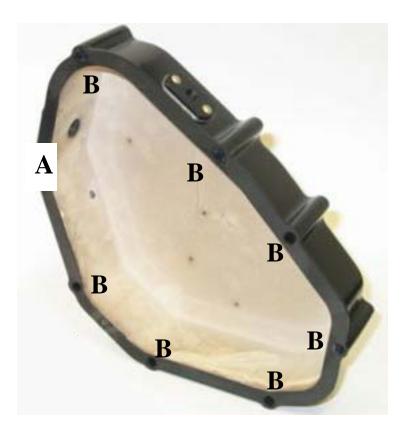








- Legacy Part Specimens
 - Plane to Plane (A)
 - Round Pin and Hole (B)
 - Spherical Joints (C)









- Step One: Data Collection
 - Determine the current material and gather necessary information associated with the existing part that is to be redesigned and its material.
 - Part material
 - Exact or partial knowledge
 - Failure mode (how the current part failed)
 - Part function
 - Loads (type, magnitude, direction)
 - Criticality of part (consequences of failure)
 - Manufacturing process (casting, machining, injection molding)
 - Part surface quality
 - Heat treatment process
 - Environment (temperature, chemical, etc)
 - Overall size





Step Two: Data Analysis

- Based on the gathered information in step one, critical properties can be obtained and populated.
- Specific rules can be used to determine the critical properties of a part based on material type, manufacturing processes, part function, failure modes, etc.
- In most cases, modes of failure can be used to identify critical properties of a given part.
- In some cases, the user may not be able to determine the failure mode.
 - Failure mode can be determined by part usage or common failure modes associated with certain types of parts.
- Critical properties can be identified based on the mode or modes of failure.





- Step Three: Determine Goals and Constraints
 - This step involves setting up material filters to find equivalent materials.
 - In this step, the user will have more control by inputting what materials are currently available for substitution.
 - Whether it is bar, sheet, or plate stock, pellets, etc.
 - The user also will be able to input available manufacturing processes.
 - Such as casting, machining, and injection molding.
 - Important pieces of data are to be determined, calculated, and stored.
 - Such as material indices of key properties (important ratios such as $S_v^{2/3}/p$, E/p, etc).
 - These values will be used later in the process to filter the available materials down to a group of candidate materials.



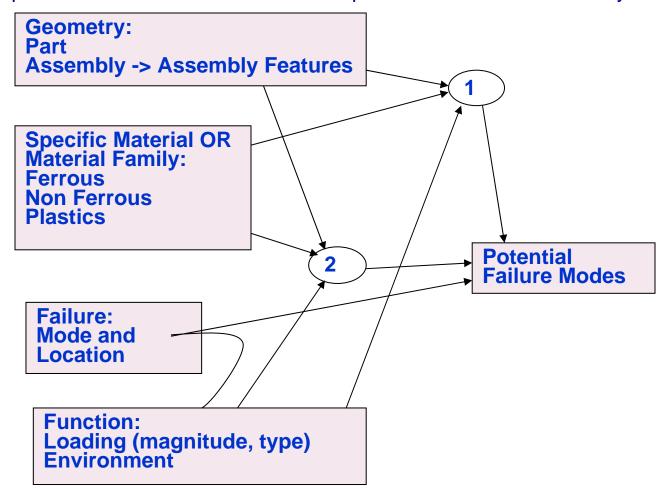


- Step Four: Identification of Candidate Materials
 - This step is where the relevant material properties data, for the current and candidate materials, are gathered and stored based on the information from the previous steps. These may be
 - Physical properties (density, ductility, etc)
 - Mechanical properties (strength, hardness, toughness, etc)
 - Electrical properties (conductivity, permittivity, etc)
 - Thermal properties (thermal conductivity, thermal diffusivity, specific heat, etc)
 - Environmental properties
- It is important to note that typical properties will be used.



MatSub Logic

- The first scenario (labeled 1) is when the user knows geometry, material, and function.
- geometry can be used to obtain assembly features.
 function can be used to determine potential failure modes.
 The second scenario (labeled 2) is when the user knows geometry, material, and how it failed
 - the input failure mode can be stored as a possible failure mode directly.





MatSub Logic

indices.

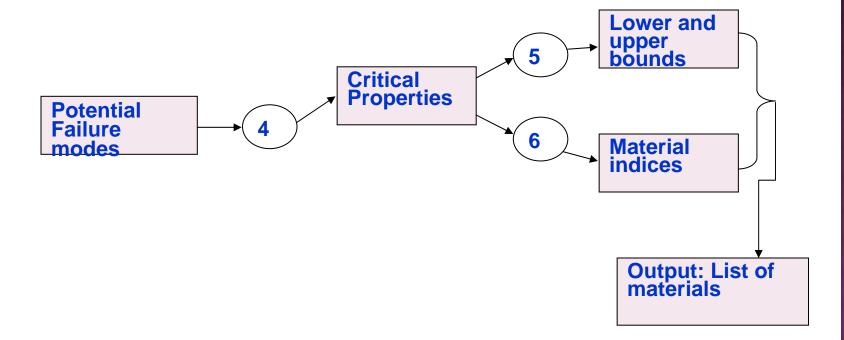
Once potential failure modes are discovered, it is necessary to determine the critical properties, lower and upper bounds and material

Step 4 is simply a table lookup; Given a failure mode, there are

corresponding critical properties that are related to that failure mode.

Step 5 is based on the inputted information thus far, the bounds and material indices can be calculated using structural equations.

From there the candidate materials can be obtained.

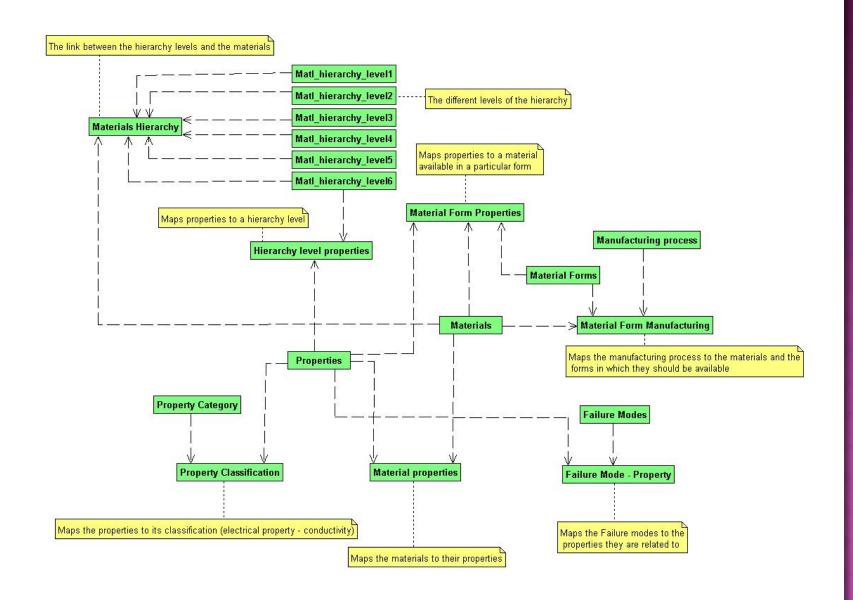






MatSub database contents







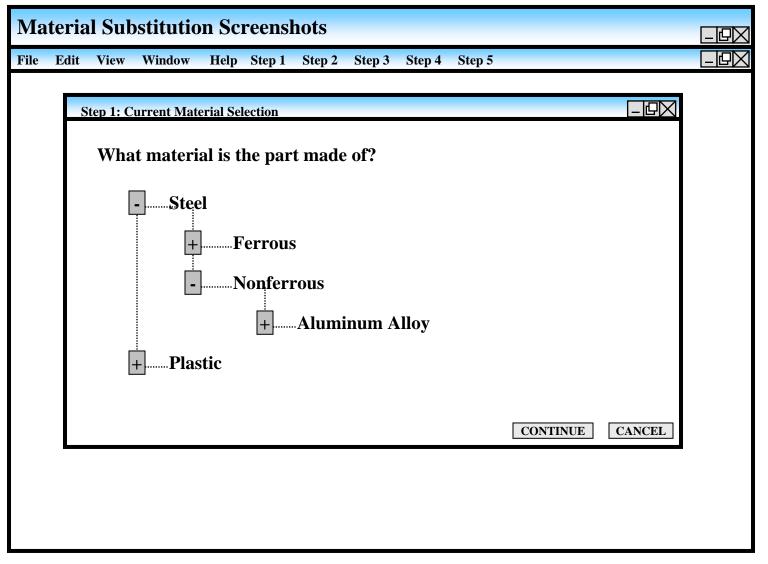


- Step Five: Detailed Analysis and Selection
 - Some drawbacks exist with using Ashby charts.
 - Property ratios cannot be determine for combined loads and/or combined stress.
 - Only 2 properties, or at most 3, are considered at a time.
 - Because of these limitations, a similar technique, with some adjustments, will be used.



Material Substitution Architecture





Initially the user chooses from steel or plastic. Then the user is able to narrow down the field to the next level of material type. Where the user stops, that is where either a specific material is chosen, if the user knows exactly what material it is, or average values are used.







M	Material Substitution Screenshots													
File	Edit	View	Window	Help	Step 1	Step 2	Step 3	Step 4	Step 5					
File	Step 2: User Input How did the part fail? Wear What is the part's function? Transfer Movement How critical is the part?								How did you cone to this conclusion? Inspection ✓ How did you cone to this conclusion? Inspection ✓ On a scale from 1 to 100, how confident is your submission?					
]	High How w	as the pa	art ma	anufac ▼	tured?	•			rom 1 t your st		sion?	CANCEL	4

A series of questions are asked to the user (not all questions are shown). Some circumstances may need the user to enter a confidence level and others it may be better to find out how the user came up with the answer.







Material Substitution Screenshots											
File	Edit	View	Window	Help	Step 1	Step 2	Step 3	Step 4	Step 5	[_	X
	I	How m 2 Load ty	nany loac	ls are	there M				-		
	[ype? cale fron ent is you	_ 1 1 to	100, h		de? ▼		Load direction? X ▼ CONTINUE CA	ANCEL	

User enters number of loads. Corresponding number of load entries are populated. Will need to find a way so that the load direction is standard on all of the parts. After this step, critical properties are assigned based on user input.







M	Material Substitution Screenshots											
File	Edit	View	Window	Help	Step 1	Step 2	Step 3	Step 4	Step 5		_	
	Step 3:	Manuf	acturing Pro	cesses								
			7									
	1	What	t manu	fact	uring	g pro	cesses	sare	available	?		
			Casting			, 1						
			8									
		\mathbf{X}	Machining	<u> </u>								
			Injection N	<u> Ioldin</u>	g							
		7	None									
			TOILE									
										CONTINUE	CANCEL	

After this step, material property values are obtained.





\mathbf{M}	aterial Substitution Screenshots		
File	e Edit View Window Help Step 1 Step 2	Step 3 Step 4 Step 5	
	Step 4: Summary		
	Sumn	nary	
	Current Part		
	Material	Aluminum Alloy	
	Part Failure	Wear	
	Part Function	Transfer Movement	
	Part Criticality	High	
	Manufactured	Casting	
	Loads	Point, 100, Z	
		Point, 100, X	
	Redesigned Part		
	Available Manufacturing	Casting	
		Machining	
	Available Materials	Bar Stock	
		Plate Stock	
		OBTAIN MATERIAL SUBSTITIUTION CANCEL	

A Summary of input information.





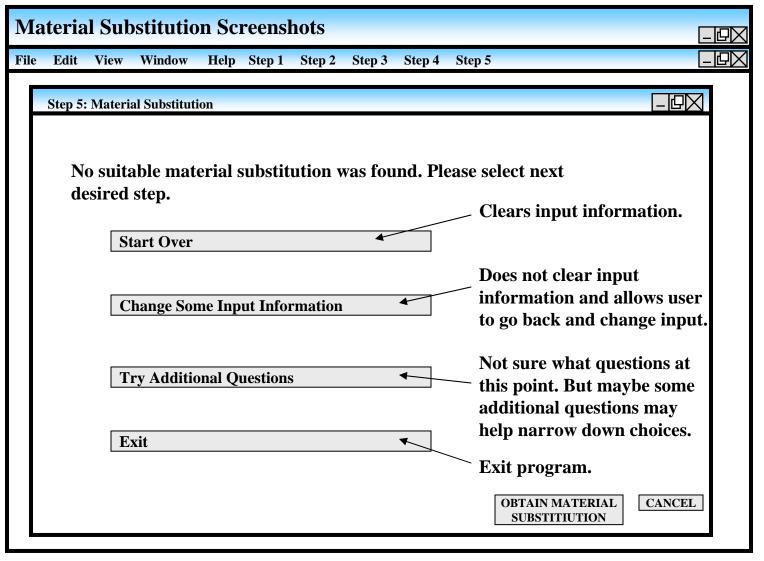


M	ateria	l Sub	stitutio	n Sci	reensl	hots					_	
File	Edit	View	Window	Help	Step 1	Step 2	Step 3	Step 4	Step 5	5	_	
			al Substituti				Di					
		e poss	sibilities.					_		row down the search.		
			errous onferrous									
			hermoset	Plastic	s							
		T	hermoplas	stic								
										OBTAIN MATI	CANCEL	

If there are too many materials to choose from, based on user's input, user is required to help narrow down the choices based on family of materials.



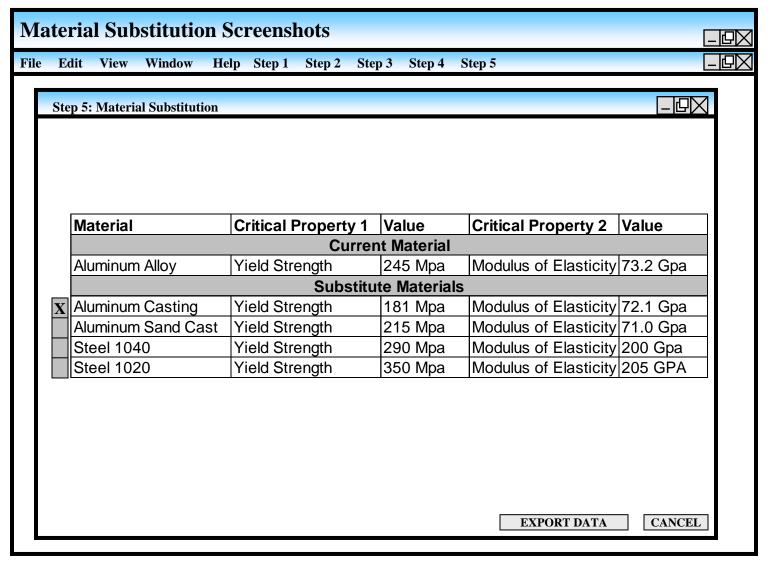




Or if the program is unable to find a suitable material based on user input, the user is needed to either repeat the process, change some of the input information, or be asked additional questions. Starting over would be the least desirable.







After any iterations are completed and some or a material is narrowed down, the user is able to see some of the criteria by which a substitution is made. The user is able to choose which material to substitute.





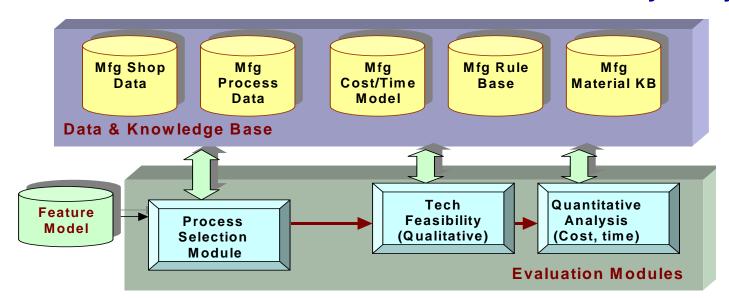
Materia	al Substitution S	creensh	ots			
File Edit	View Window Hel	p Step 1	Step 2 Step 3 St	tep 4 Step 5		
Final	Review					
		Sumr	mary			
	Current Part					
	Material		Aluminum Allo	y		
	Part Failure		Wear			
	Part Function		Transfer Move	ement		
	Part Criticality		High			
	Manufactured		Casting			
	Loads		Point, 100, Z			
			Point, 100, X			
	Redesigned Part		lo «		1	
	Available Manufactur	ing	Casting			
	Available Materials		Machining		_	
	Available Materials		Bar Stock Plate Stock		_	
	Chosen Material		Triale Stock			
	Aluminum Casting	Yield S	trength	181 Mpa	1	
			s of Elasticity	72.1 Gpa		
			e Tensile Streng			
			Strength	290 Mpa		
			s Ratio	0.33	GAND	TOWN TO SERVICE STATE OF THE S
		•	SAVE	EXIT		

When export data button is pressed, a summary screen appears with information for printing. User is also allowed to save info to desired location as a text file.



Customizable DfM module

 DFM Advisor, previously developed in the DAL, offers a robust and customizable framework for manufacturability analysis.

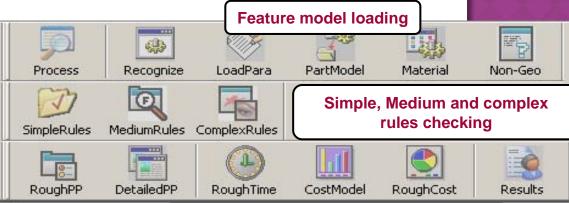


•The DFM Advisor is linked to several databases :

- -Resources,
- -Rules,
- -Features,
- -Manufacturing processes

-....

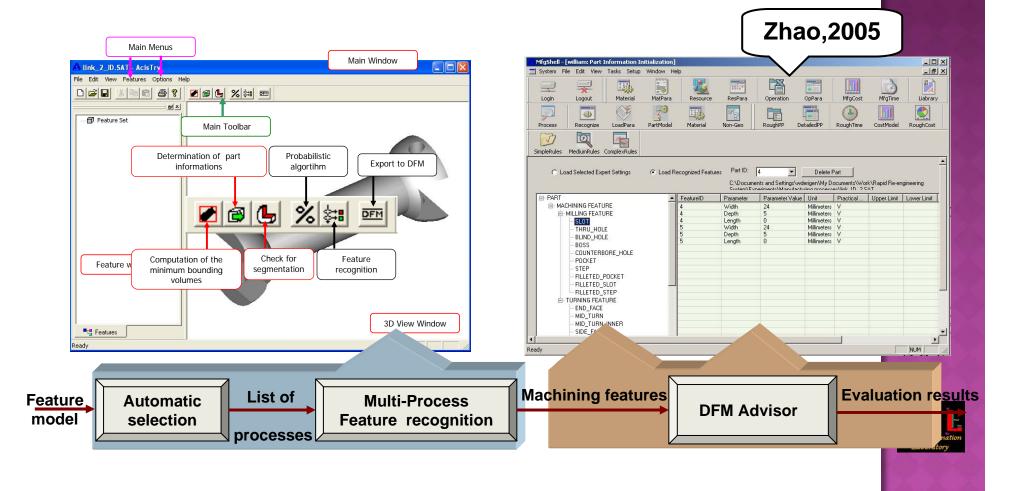
•Each of these databases could be customized by an expert



Process Planing and cost-time evaluation

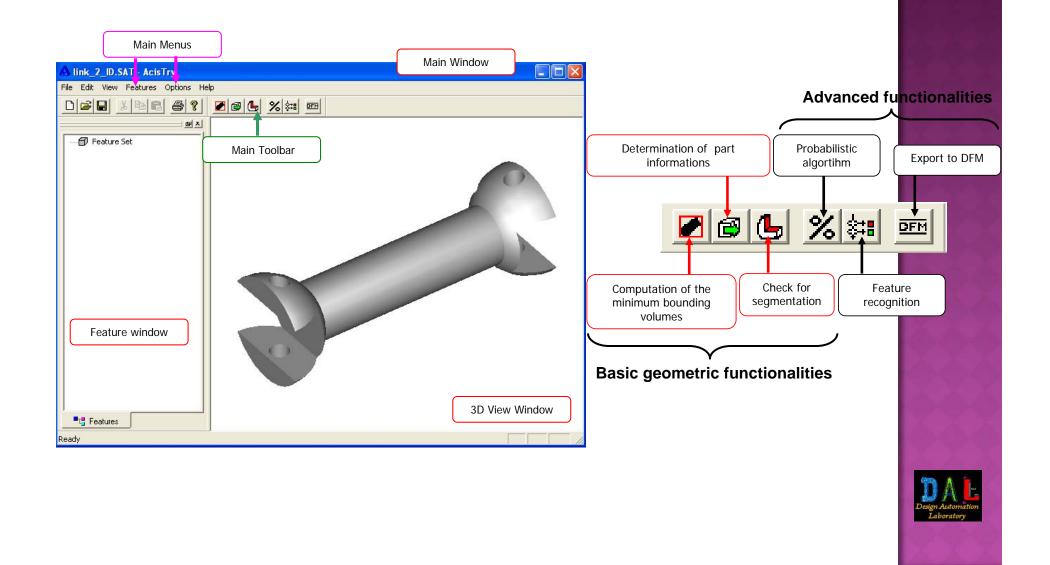
New developments

• An application has been coupled with the DFM Advisor for analyzing geometric characteristics of a part, classifying it (turned, milled, mill-turn, sheet metal), making a preliminary process selection, selecting the appropriate set of feature recognizers, and exporting the features and parameters to DfM.



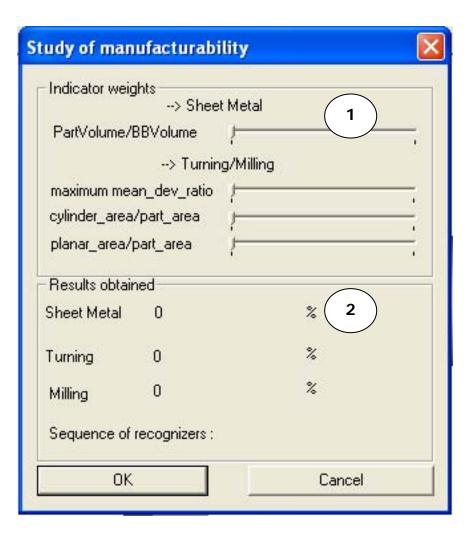
DfM Demo System

 Main interface. The following will describe the advanced functionalities



"Probabilistic" Process selection





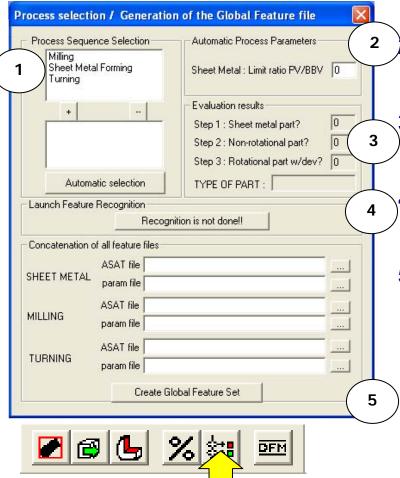


- 1 Indicator weights: the weights of each indicator taken into account into the evaluation process. The sliders provide a simple way to experiment and fine tune the value of the weights
- 2 Resuts obtained: the probability that the part can be manufactured by this process/ the percentage of the part features manufacturable by a process



Preliminary process selection and feature generation





1 – Process sequence selection: the available processes to be selected (manual or automatic). The order of the selected processes determines their priority

2 – Automatic process parameters: the parameters needed for automatic selection

3 – Evaluation results: the results of the evaluation steps and the type of the part

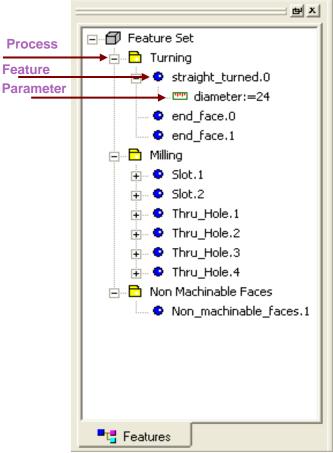
4 – Launch feature recognition: launches each needed feature recognizer in order

5 – Concatenation of all feature files:
After the recognition phase, each selected process has its ASAT and PARAM file. The conjugation of these two files provides all the information about the recognized features related to this process. The file paths are entered into this form to create the global feature set.



Feature viewing & editing

Interface for



- Classification of features: a tree structure organized in a way that each feature belongs to a generic manufacturing process; the feature parameters represented as leaves of the tree.
 - Editing of the feature parameters: due to some complex topological situation, a recognizer may not be able to determine one parameter value. To overcome this limitation, a modification dialog is available.
 - Detection of non-machinable faces: once the global feature set is created, some of the faces of the geometric model could be not associated with any feature. This event could result from:
 - A manufacturability problem (the process can not do this face),
 - A feature definition problem (one UDF is not well defined or is missing).





Exporting Manufacturing Features



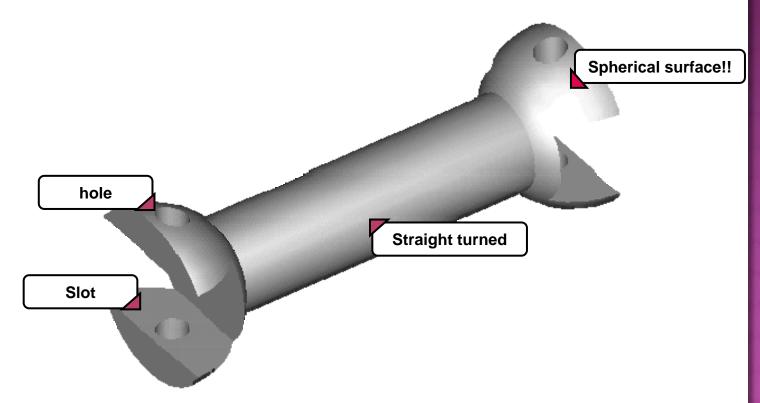
- Interface for the export of the feature set to the DFM Advisor
 - This command converts the feature set into a text file.



- The user has to enter his name and a part identification number, which will be used by the DFM Advisor to store the feature set.
- The generated text file is totally compatible with the DFM Advisor.



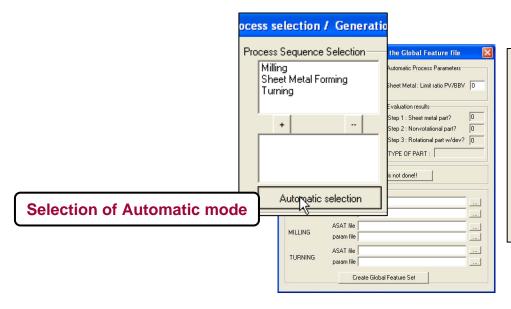
- Example of the feature generation process on a simple part : a link between two joints.
 - Milling and turning features are present on the part,
 - The spherical surfaces are non manufacturable with available processes.

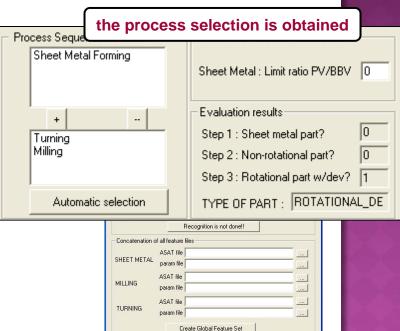




Step 1: Automatic Process selection



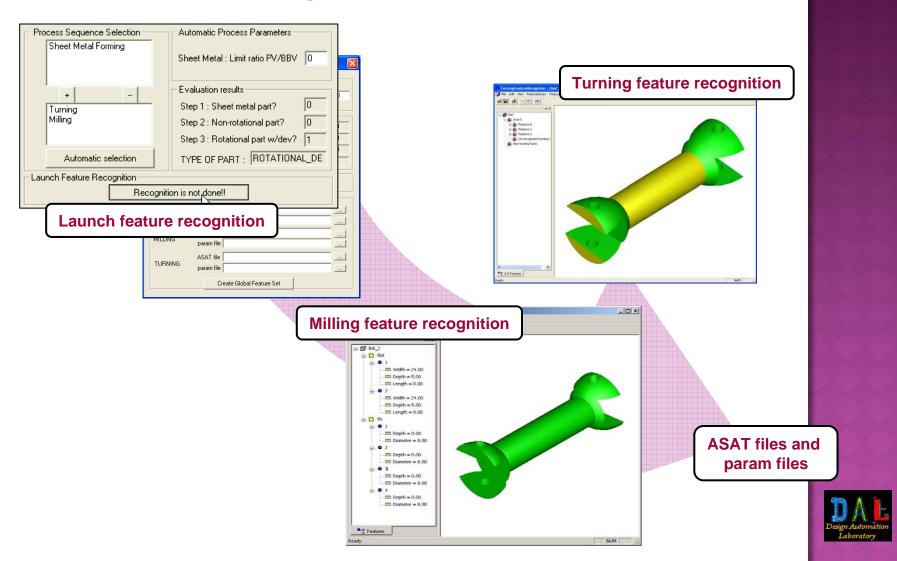






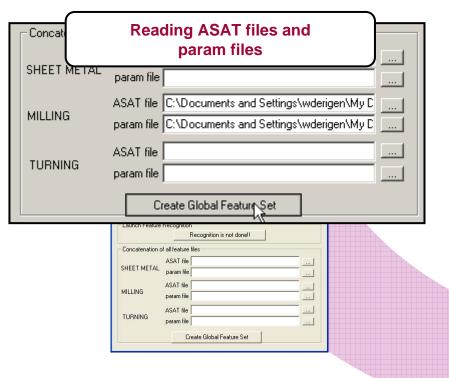


Step 2: Feature recognition





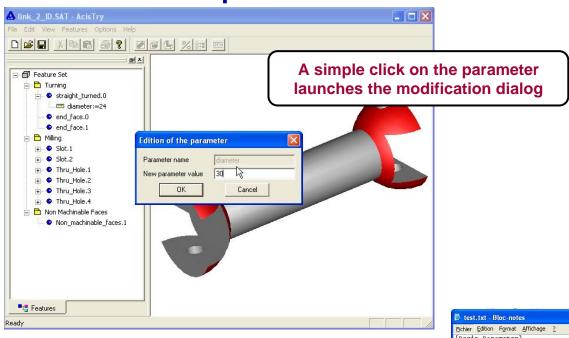
Step 3: Generation of the global feature set



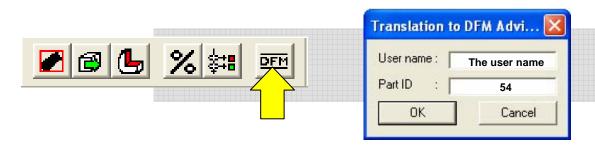
Global feature set with nonmanufacturable faces File Edit View Features Options Help ☐ Feature Set - Turning straight_turned.0 diameter:=24 o end_face.1 → Slot.1 + • Slot.2 Thru_Hole.1 Thru_Hole.2 ➡ ● Thru_Hole.3 → ◆ Thru_Hole.4 Non Machinable Faces The spheres are nonmanufacturable!!! Features



Step 4: Modification of feature parameter



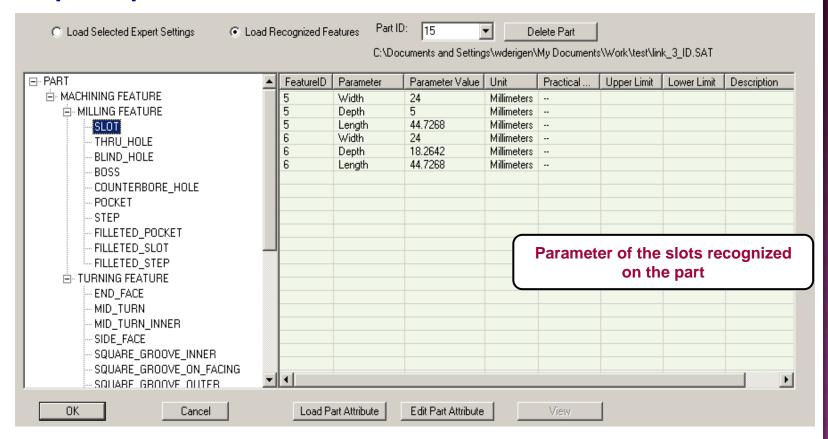
Step 5: export to DFM Advisor







Step 6: Open the file with the DFM Advisor



Step 7 (to come): manufacturability study and re-design

