Virtual Factories

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Institute for Systems Research
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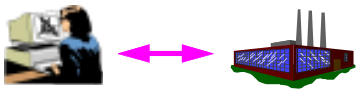
EMSYS: Electro-Mechanical Systems Design and Planning

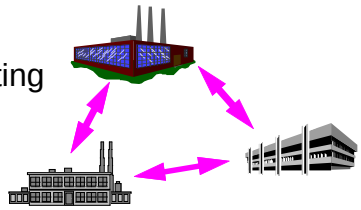
- Seven faculty (joint with ME, EE, CS, Business School)
- Ten years experience
  - » Process Planning, Concurrent Engineering, DFM
  - » Systems Engineering and Information Integration
  - » Facility Layout, Production Scheduling
  - » Inventory and Distribution Systems, Supply Chain Management
- Sponsors and Partners
  - » *Government:* DARPA, ONR, NIST, NSF, US Army TACOM, Wright Patterson AFB
  - » *Industry:* Bentley Systems, Black and Decker, IBM, Kopflex Inc., LAI, Lockheed Martin, Northrop Grumman, Pangborne Corp., Pepco, Simmons Mattress, Spatial Technologies, Texas Instruments, Washington Aluminum, Westinghouse

Virtual Factories: Two possible interpretations

- *Virtual Manufacturing (VM)*
  - » Computer environment to model or simulate manufacturing a product



- *Virtual Enterprise (VE)*
  - » Several companies cooperating to produce a product
  - » Activities integrated via computer networking



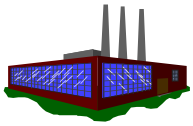
- VM technologies are enabling technologies for VE

Outline

- Design-Centered VM
  - » Overview
  - » Examples: two design-centered VM tools *Nau*
- Virtual Enterprises
  - » Overview
  - » Example: a partner-selection tool *Herrmann*
- Virtual Enterprises meet the Internet
  - » Information technology issues
  - » Summary and prospectus *Regli*

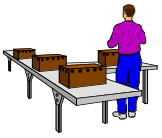
Virtual Manufacturing

- Model and simulate
  - » Do manufacturing activities "virtually" in the computer
- Predict and evaluate
  - » what would happen if the activities were actually carried out
- Make improvements
  - » before you do the actual manufacturing

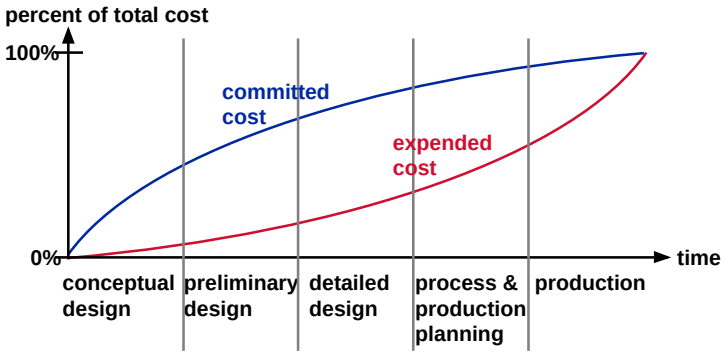


Areas of Applicability for VM

- Design-Centered VM
  - » a design-for-manufacturability (DFM) tool
    - – predict manufacturability & affordability, identify potential problems, improve the design
- Production-Centered VM
  - » generate/evaluate plans
  - » cost information, schedules
- Control-Centered VM
  - » simulate shop floor activities
  - » optimize processes, improve manufacturing systems

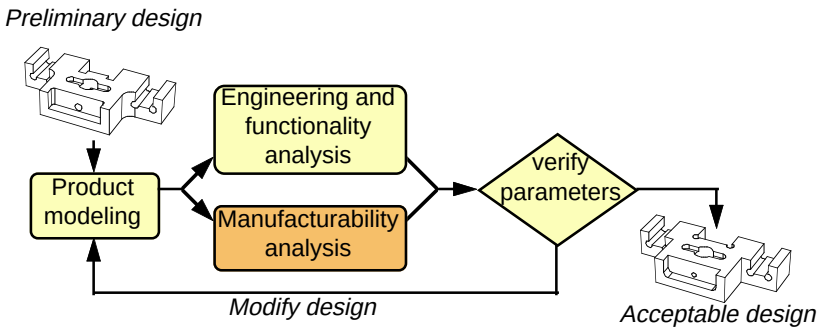


Motivation for DFM



Need to consider manufacturability while the product is being designed

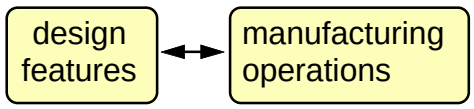
Manufacturability Analysis for DFM



- Augment the traditional design loop
  - » Predict cost, time, quality, manufacturing problems
  - » Modify the design to improve its manufacturability

Manufacturability Analysis Using the "Direct" Approach

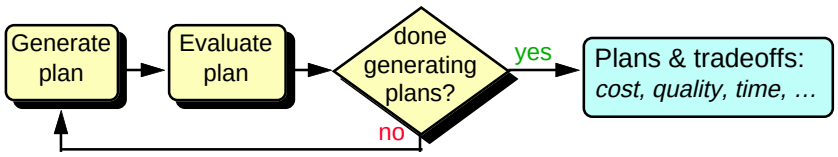
- Evaluate the design directly, using heuristic rules
  - » e.g., "for each hole, check whether length/diameter ≤ 3"
- ✔ Relatively easy to implement
  - » most existing approaches are of this type
- ✘ Only works if there's a clear correspondence



  - » Doesn't always exist

more than 500 ways to make this socket:

Manufacturability Analysis Using VM



Also called *plan-based manufacturability evaluation*

- » Generate process plans and/or production plans
- » Evaluate them (cost, time, quality, etc.)
- » Feedback to the designer

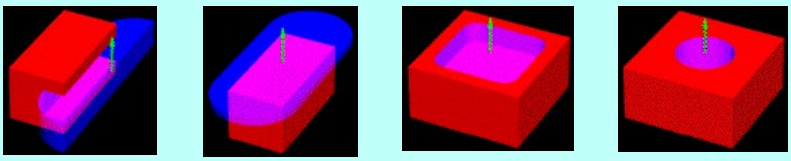
- Can also be useful for production
  - » depends on how accurate and detailed the plans are

Example 1: IMACS

Interactive Manufacturability Analysis and Critiquing System

- DFM tool for complex machined parts
  - » 3-axis vertical machining center
  - » Machining operations: milling and drilling

Example machining features:

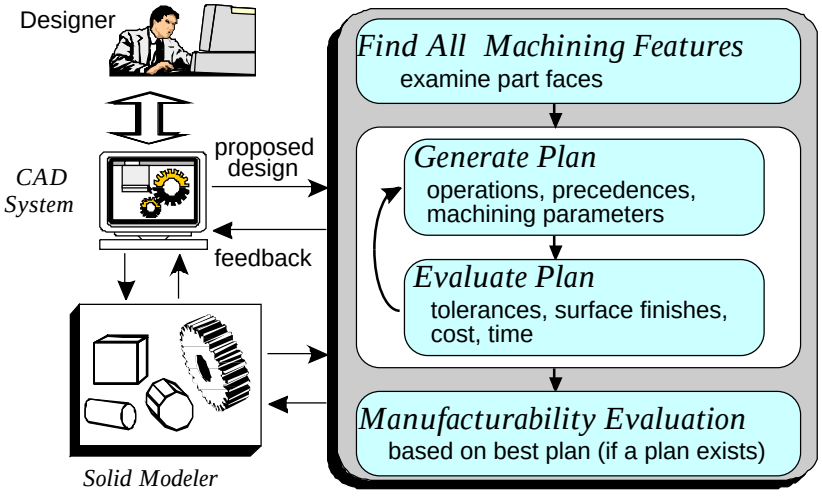


side-milling face-milling end-milling drilling

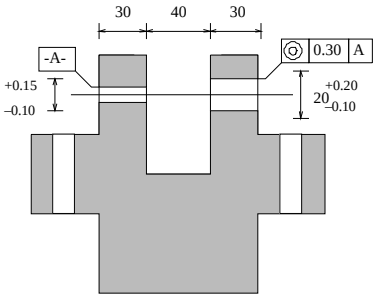
IMACS extracts these automatically from the CAD model

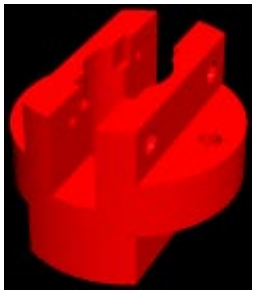
»even if they intersect in arbitrarily complex ways

How IMACS Works



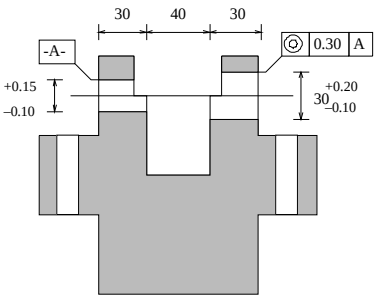
Socket Design #1

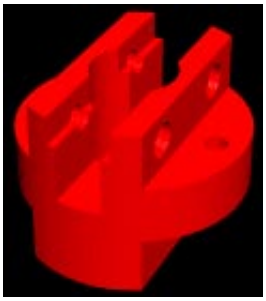




- IMACS's Analysis:
  - » *Can't make this part with the available machining operations*
    - – the top pocket has no corner radius
    - – concentricity tolerance requires drilling the holes in same setup; this violates the L/D ratio limit for the smaller hole

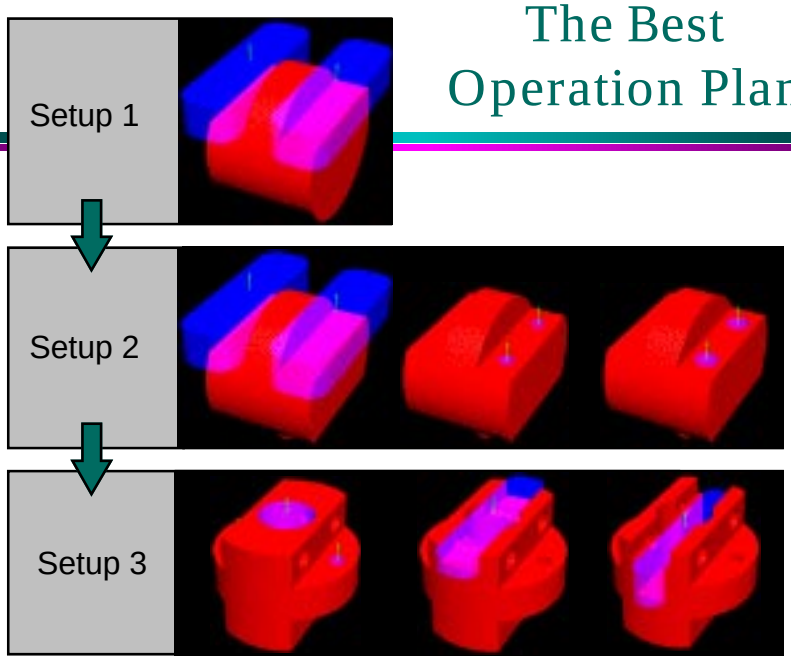
Socket Design #2





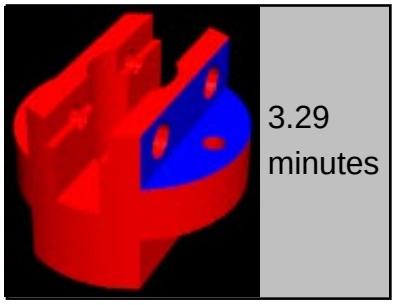
- IMACS's analysis:
  - » Machinable using drilling and end-milling operations
  - » Best operation plan: 13 operations, 3 setups

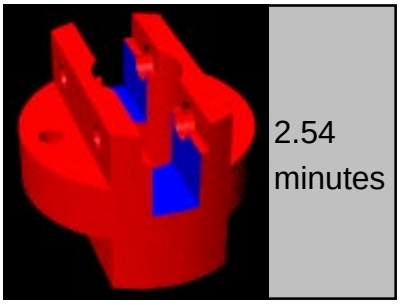
The Best Operation Plan



Process Plan Evaluation

- Calculate process parameters using handbook data
- Use this information to calculate processing times





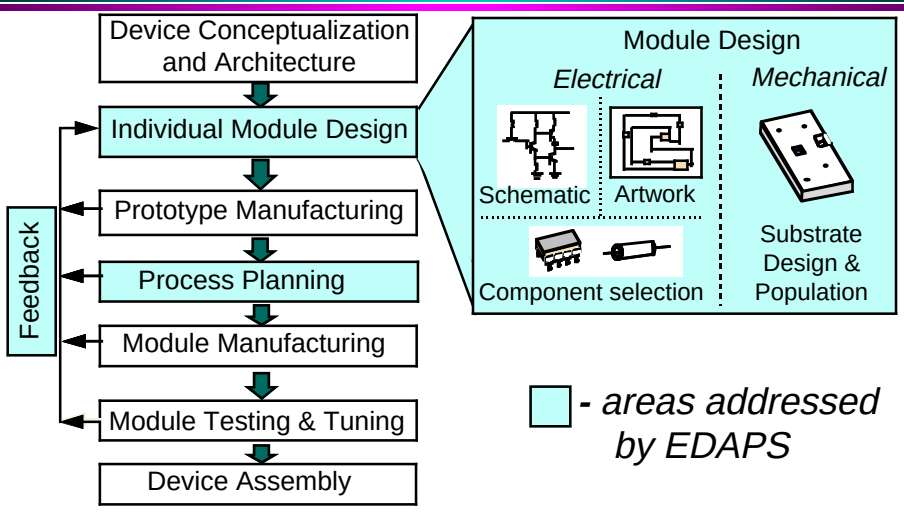
- Total for all 13 operations and 3 setups: 31.13 minutes

Example 2: EDAPS

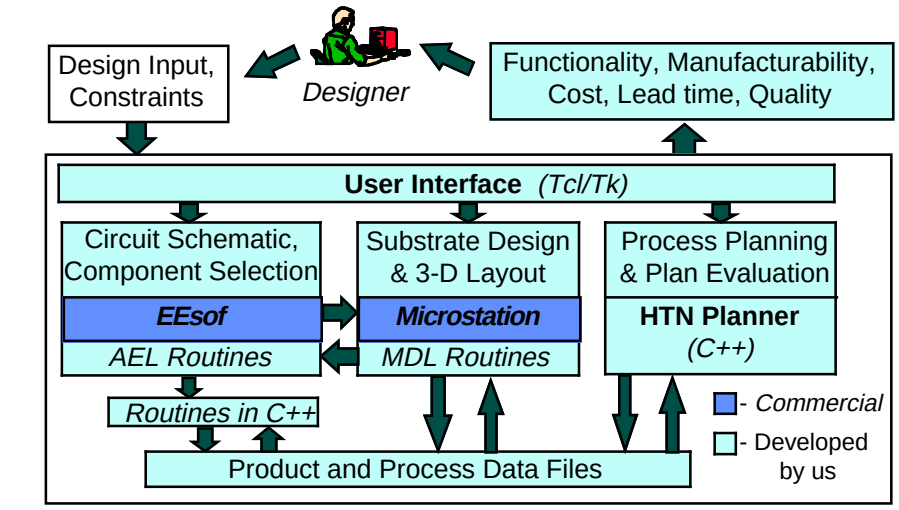
Electro-Mechanical Design And Planning System

- Integrated DFM tool for Microwave T/R Modules

Design and Manufacture of Microwave Modules

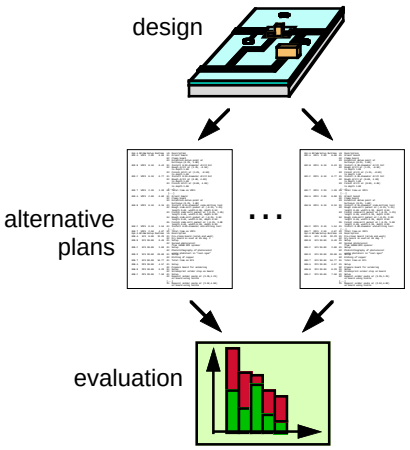


EDAPS System Architecture

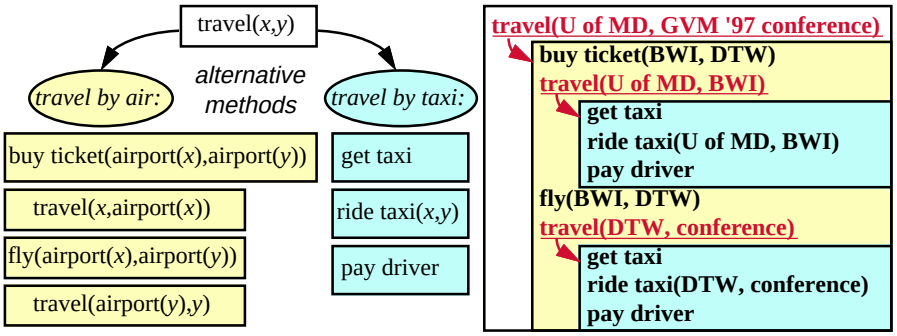


Process Planning for Microwave T/R Modules

- General approach:
  - » Generate and evaluate process plans
    - – Hierarchical Task Network (HTN) planning from AI
- Will discuss
  - » What HTN planning is
  - » Process planning for mechanical features
  - » Process planning for electronic features



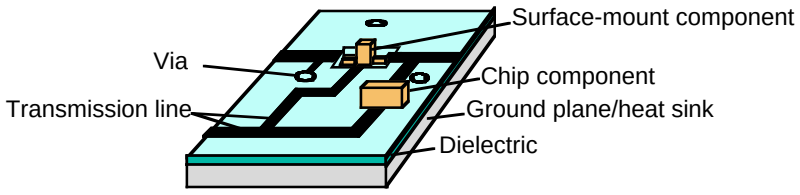
HTN Planning



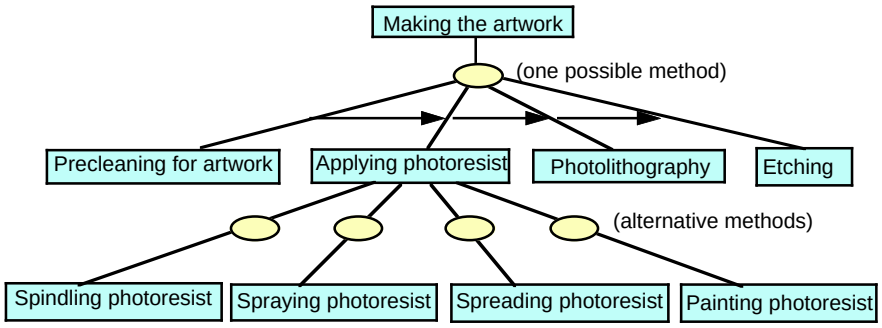
- Decompose tasks into smaller and smaller subtasks
  - » Handle constraints (e.g., taxi not good for long distances)
  - » Resolve interactions (e.g., take taxi early enough)
- If necessary, backtrack and try other methods

Process Planning
1. Mechanical Features

- Want to generate plans for drilling, milling, etc.
  - » The general problem is quite difficult (e.g., IMACS)
- For microwave modules it is easier
  - » Simple geometry - the features don't intersect
    - – one-to-one correspondence to operations
  - » Easy to use HTNS to encode processes, generate plans



Process Planning
2. Electronics



- Process structure is more complicated, but:
  - » decomposes into tasks and subtasks that occur in a fixed sequence
- Develop plan details depending on the details of the design

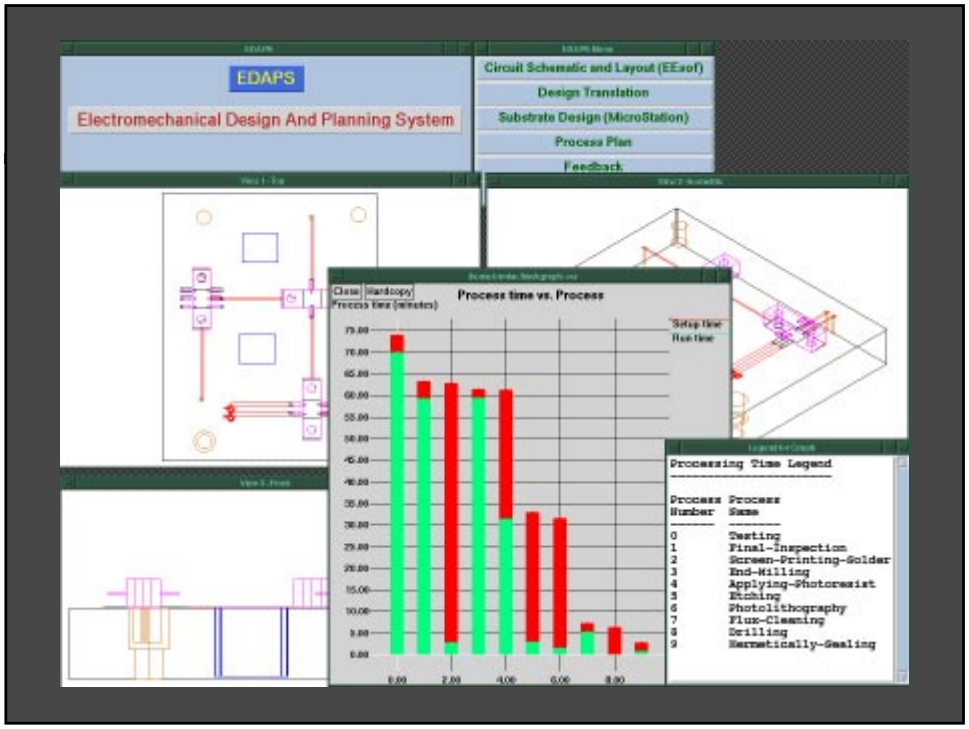
Example Process Plan Output

Substrate
Dimensions: 7,4,1
Ground Material: Aluminum
Material: Teflon
Substrate thickness: 30 mils
Metallized thickness: 7 mils

Processes:

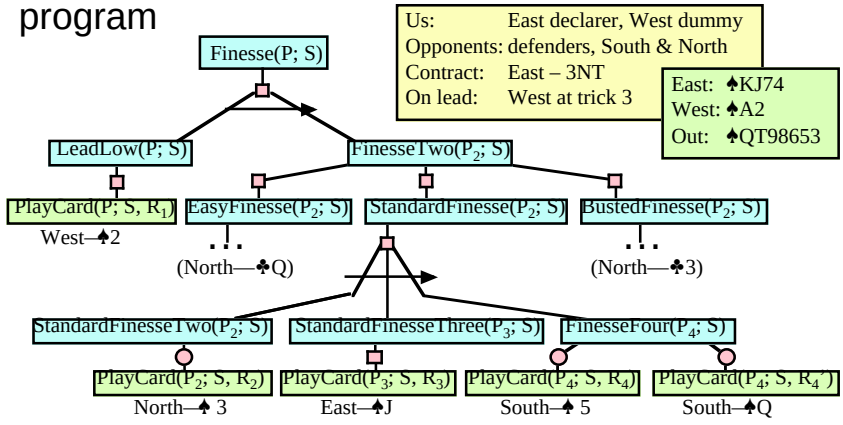
Opn	A	BC/WW	Setup	Runtime	LN	Description
001	A	VMC1	2.00	0.00	01	Orient board vertically
					02	Clamp board at (1,1,1)
					03	Establish datum point
001	B	VMC1	0.10	0.43	01	Tool: 0.30-diameter drill bit
					02	Drill at (1.25,-0.50 d:1.00,f:50,s:30
					03	Drill at(1.25,-0.50) d:1.00,f:20,s:60
001	C	VMC1	0.10	0.77	01	Tool: 0.20-diameter slot miller
					02	Mill start (0.044, 4.88)
						l: 0.5, w: 0.5, d: 1.00, f: 50, s: 40
001	T	VMC1	2.20	1.20	01	Total time on VMC1
…						
006	A	PLAT1	1.00	0.60	02	Dip in bath for 2 minutes
						Temperature:100C, Conc:1000ppm
007	A	ETR1	0.50	0.60	01	Etch plate for 1 minute
008	A	ETC1	0.20	0.30	01	Etch board for 2 minutes
…						Temperature:100C, Conc:1000ppm

- Estimate lead time, cost, quality
- Evaluate other plans
- Display results graphically

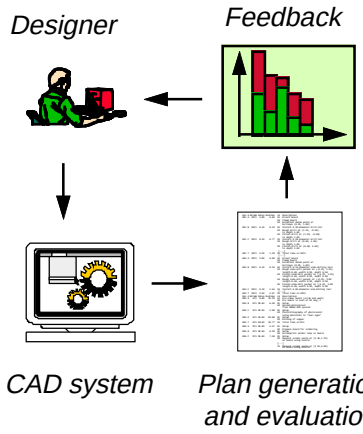


Generality of Our Planning Methods

- Contract bridge, better than the best commercial program

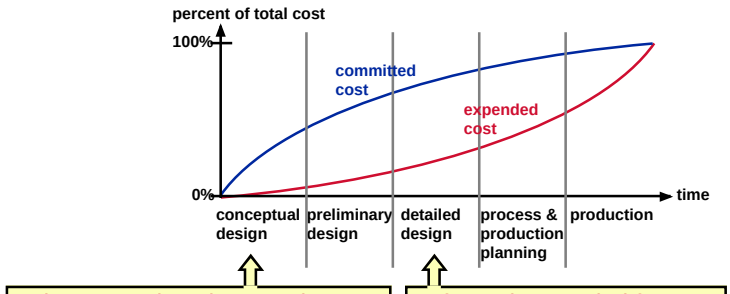


Challenges for Design-Centered VM
1. Short Term

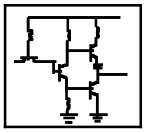


- Making the technology more robust
- Industrial practice
  - » developing the tools
  - » using them effectively

Challenges for Design-Centered VM
2. Long Term



- Extend VM to work for conceptual designs?
  - ✘ Complex mechanical parts: difficult
  - ✔ Electro-mechanical systems: easier
    - – take advantage of standard representations



How to Extend EDAPS for Conceptual Designs

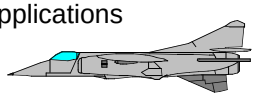
- What drives EDAPS's process planning:

Process planning	Schematic diagram	Component selection	3-d layout
Electrical	✔	✔	
Mechanical		✔	✔

- Should be able to
  - » generate partial plans
    - – most of the electrical processes, some mechanical ones
  - » estimate lead time, cost, quality

Further Information on VM

- Our assessment of VM for Wright Patterson AFB
  - – assess relevant research and applications
  - – identify gaps
  - – present future outlook



  - » Background study for a large and successful VM project
- Virtual Manufacturing web site

http://www.isr.umd.edu/Labs/CIM/virtual.html

  - – results of our study
  - – other related materials

mixed upper and lower case

- My own web site

http://www.cs.umd.edu/~nau