AI Planning Versus Manufacturing-Operation Planning: A Case Study

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Introduction

Techniques developped by the AI planning community can be applied to manufacturing domains, and have been frequently used, especially in scheduling scenarios.

However, they have failed to impact manufacturing practices in a considerable way.

Different Approaches

The main reason for the inapplicability of AI principles to Manufacturing and vice versa is considered to be the diverging nature of their purposes:

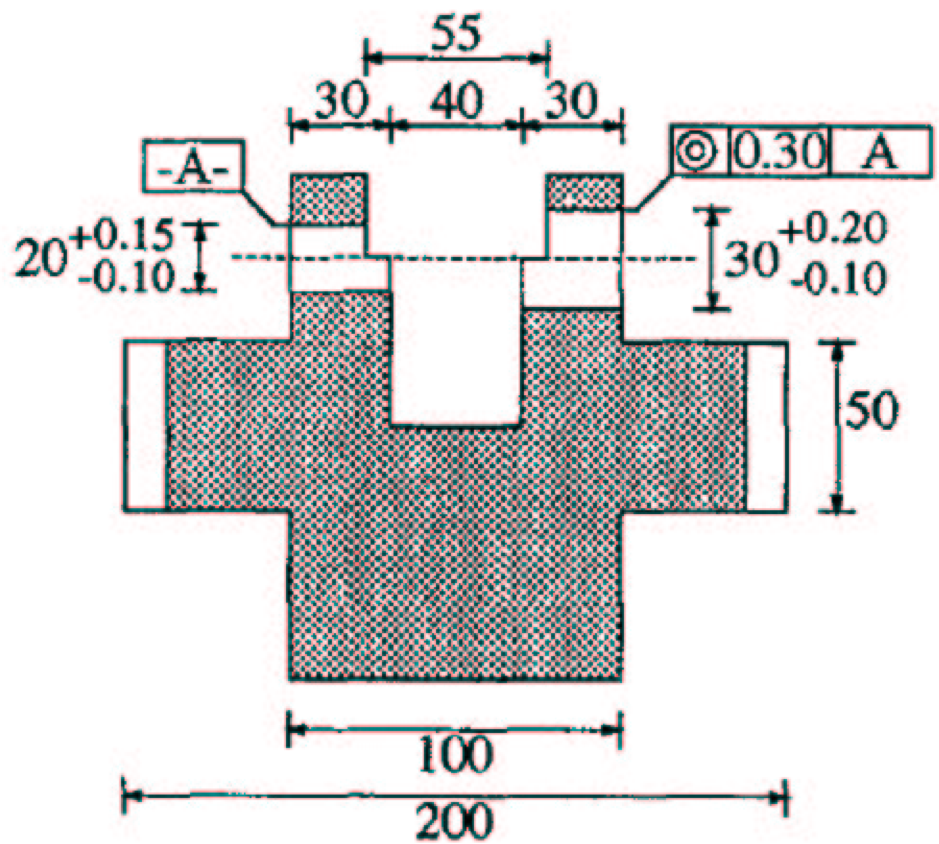
- *AI planning approach:* General problems are prefered over more domain-dependent scenarios. In Manufacturing problems for instance, AI researchers often discard details considered to be unimportant when analysing the overall plan, but which matter greatly when attempting to apply those techniques.

- *Manufacturing planning approach:* Manufacturing Planning researchers are usually concerned with specific problems, and present their approach accordingly. This makes it difficult for AI researchers to clearly identify the underlying problems and to extend these ideas as to apply them to more general problems.

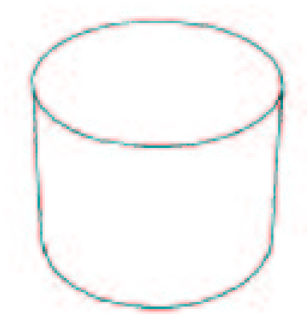
A Manufacturing Planning Example

IMACS: Interactive Manufacturability Analysis and Critiquing System.

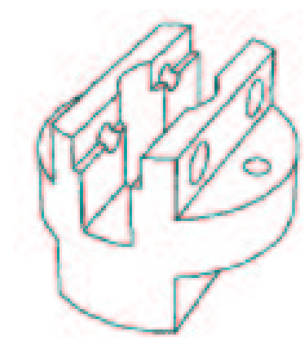
Uses planning mechanisms to facilitate the manufacturability of a design for machined parts. Takes into account the design tolerance, physical constraints and machining costs.



The Initial and Goal States



The initial and final states are represented as CAD models of the stock S_0 and the part P_0 to be machined.



Along with the model of the desired finished part, the designer also provides the system with tolerance specifications (or variations in geometry) that must not be exceeded.

Machining Operations and Features

IMACS will generate an operation plan which, in this specific examples, consists of machining operations (drilling, milling) which, when applied, will generate the desired part P_0.

Each machining operation includes information about the type of operation, the material removal volume, and the accessibility volume. The last two are equivalent of preconditions in traditional planners.

In order to be able to generate a plan, IMACS must be able to determine the conditions to be satisfied (here called machining features). The first phase is therefore to compute the set $\mathscr{F}$ of all features for P_0.

Generating a Plan

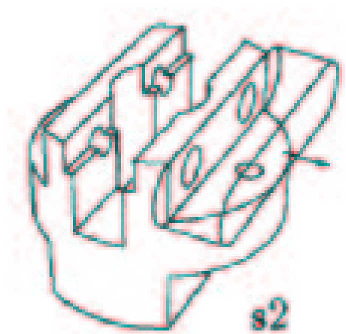
Given the set $\mathscr{F}$ of features, many of which might overlap, IMACS builds a FBM (feature-based model) which contains any irredundant subset of features $F \subseteq \mathscr{F}$ that lead to the goal state.

Instead of generating all the possible FBM's (which equates solving a set-covering problem), IMACS uses a depth-first branch-and-bound search to construct and evaluate the FBM's one at a time.

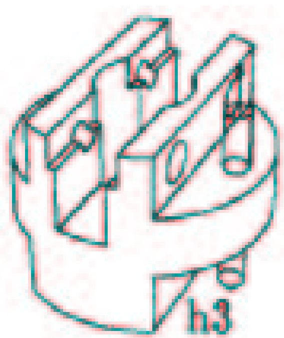
Each FBM is a totally unordered plan.

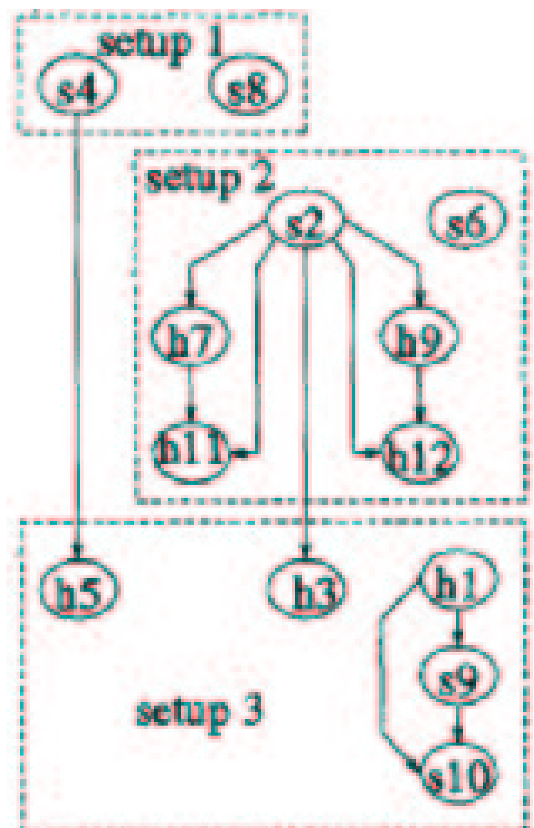
Ordering

Due to a variety of factors such as accessibility, likelihood of tool breakage, respect of machining tolerance, ordering of the actions is necessary.



Here, h_3 cannot possibly be performed before s_2





Additional Steps

- *perform finishing operations*: for any surfaces with finishing operations, give priority to the roughing operations.

- *modify goals*: if two features f and g overlap, and f precedes g, then truncate g.

- *determine setups*: if multiple operations require the same machine setup (ie: same approach direction of the drill), then they are part of the same setup.

Plan Evaluation

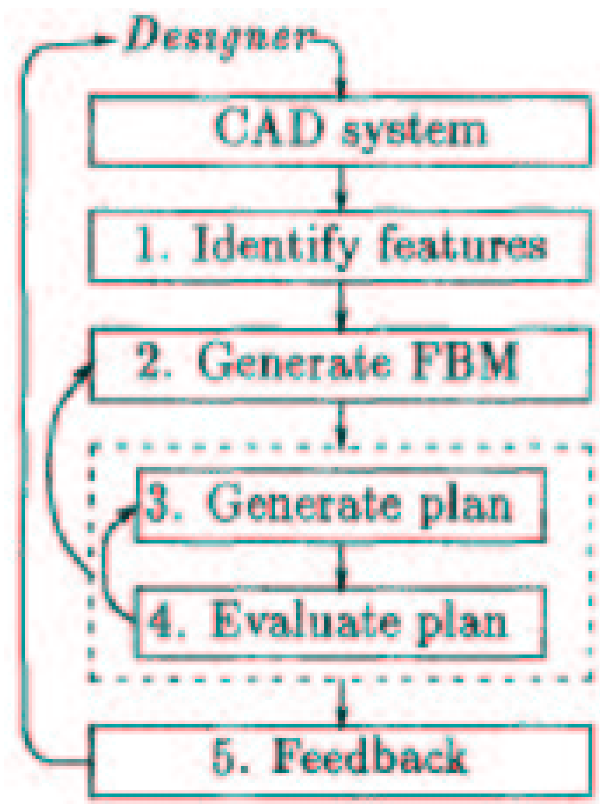
After finding a plan, IMACS must ensure that it can achieve the design tolerances specified by the user. If it fails to satisfy these constraints, then the plan is discarded, and IMACS generates another.

If it is a valid plan, then IMACS estimates the manufacturing time associated with this plan. This includes the time machining the part, as well as non-cutting time (tool-change and setup time). If the lower bound of the estimated machining time is above the one achieved by the best plan so far, IMACS will discard the current FBM.

Conclusion

The method used by IMACS can be generalized to other AI planning problems:

- enumerate the set of all tasks that might be relevant
- loop:
  - generate an incomplete plan
  - if the plan has a goal interaction that can't be solved via precedence constraint, discard it
  - flesh out the plan

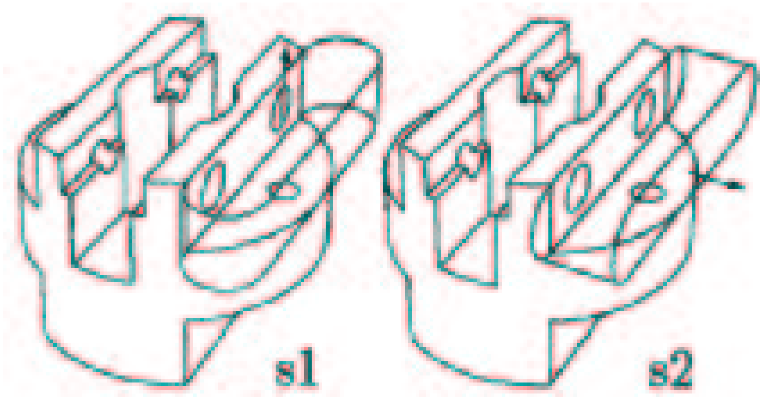


Notes

Machining operations: elementary actions
Machining features: tasks
FBM: incomplete plan

Material removal volume: vol of space in which material can be removed
Accessibility volume: volume of space needed for access to the part

Additional Figures



Redundant features