

An active information systems approach to industrial planning

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Abstract

Industrial planning involves an in-depth understanding and continual consideration of all phases in the product lifecycle, and the interdependences of sub-tasks, from conceptual design to implementation and beyond. In some engineering disciplines; for example construction, the problem is compounded by the number and types of disparate disciplines involved in the lifecycle, and in the case of major projects, the final results are all too often characterised by budget deficits and project timescale overruns. This paper describes an approach to industrial planning which relies on a centralised symbolic model of the proposed project in terms of a fusion of three distinct relational models; component, action and resource. The paper describes the philosophy of model-based planning and its application in the industrial context.

1.0 The problems of industrial planning

Planning is not a trivial process, and conventional computer-based tools have satisfied only a small fraction of the needs of industrial users. The process involves an in-depth consideration of the entire lifecycle, and this can only be achieved through a thorough and up-to-date understanding, not only of the various sub-tasks in the process, but also an appreciation of their sometimes-complex interdependences. 'Conventional' tools are very efficient when used to present such information, and the best of them are designed to facilitate a good deal of project manipulation and experimentation through powerful user-interaction tools. However, the user of such systems has the responsibility of initially specifying the task-level project, based on personal understanding and expertise. It would assist greatly if the computer-based planning tool itself were able to automatically generate initial plans, based on specifications or product designs, and in addition were able to give advice on implications of design, production or specification/constraint changes. This paper describes two pieces of highly-related research and development in the area of model-based planning. The first deals with the problems of industrial design as a configuration problem, and the second is an example of planning subsequent to detailed

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design. The two pieces of work can be regarded as common in the provision of a comprehensive domain model, but the two differ in the way that the model is used. The configuration system produces an actual design, with a plan produced almost as a bi-product, through a process in which specifications and constraints are the system's primary input. The planning system provides a detailed, component-level design as its primary input, and produces a plan through a process of constraint satisfaction. This can be seen as operating in quite the opposite way to the configuration process, but each approach shares a reliance on an identical representation of the relevant domain.

The models employed are centered around a generic project description, based on the concepts of product breakdown structure, and similar data structures able to express actions and resources. Such systems use declarative knowledge of action/object pairs to identify activities within the plan, and object relationships for activity sequencing. This approach differs from the STRIPS-style 'classical', or state-based planners ¹, which are based on preconditions and effects of operators (in this case, activities). The central concept used in these early systems was that an operator, or activity, could only be applied if its stated preconditions can be satisfied, and that the application of the activity would have an explicit set of effects, which may or may not satisfy the preconditions of other activities, etc. Sophisticated solutions to the problems inherent in such systems have been proposed, but in all these cases the planning systems lack fundamental knowledge of engineered systems, and are unable to reason causally about the inclusion of activities in a plan, and their subsequent sequencing. An excellent review of planners of this type is provided in ².

PIPPA ³ was one of the first model-based planning systems to be developed and evaluated in an industrial context. The system was designed to cater for the configuration problems found in the design-to-implementation of large scale, high-technology engineering products. It is based around what the authors refer to as a central 'information base', which incorporates a generic description of the product and the processes required to produce it. The information base also contains a specific model of a project as it is dynamically planned and directed by the system during run-time. Each element in the component breakdown structure, action hierarchy and resource description holds information and fundamental knowledge, which can be applied as required through the invocation of rules ⁴. This implementation strategy results in an object-oriented system behaviour, where each component, action, resource and therefore activity is responsible largely for its own existence within the ensuing specific model and manufacturing plan.

2.0 A Configuration problem and the PIPPA system

The manufacture of complex, high-technology products normally involves a multi-disciplinary approach to project management, from conception, or bid preparation, through design to production and commission. For some manufacturing industries, such projects are characterised by a modular process of configuration, only parts of which may involve design from first principles. In the domain of flight simulator manufacture, as in most manufacturing domains, the process of project bid definition is one of the most important tasks in the initial phases of any new project, and is one which is time-consuming. An added, but nevertheless important constraint in the bidding process is the very

limited timescales involved. It cannot be easily standardised, especially when the product is one which is largely tailored to the specific requirements of the customer. The processes involved in bid definition are, ideally, exactly the same as those of full project management. The fundamental tasks being product definition, planning, and costing. In reality the bidding process differs from the project management/planning process by virtue of the time and cost constraints imposed. These prevent the full analyses that are performed once the bid has been successful and the project becomes active.

In order to give a project management system an appreciation of this complex problem, it is necessary to provide a model of the product which is to be built. The PIPPA system holds a generic description of a flight simulator, basically representing the range of possible components which can be included in any simulator. This model is of the form of Figure 1. This diagram indicates the hierarchical nature of the component hierarchy of (in this case) a flight simulator. The abstraction hierarchy includes components, or component systems (classes), which must exist, or which may exist in a given configuration satisfying a particular specification set. Decision-making is facilitated through a distributed knowledge-based system, which has responsibility for making specific configuration choices; these choices being made through access to knowledge relating to conflicts, external influences such as regulations and safety considerations, and historical or organisational preferences. In Figure 1, the simulator must have an actuator system, but that system may have component-A or B. The syntax of the PIPPA system ensures correct behaviour in situations where a choice of one, one or more, or mutually-exclusive choices must be made.

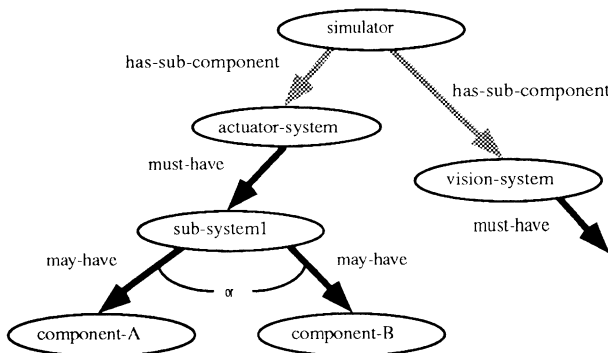


Figure 1. A representation of the General Model in PIPPA

Much of the configuration of the product can be inferred from information existing in the model, and the conclusions reached from user-dialogue. As the model becomes richer and more detailed, the amount of user-interaction reduces. Using this methodology and system framework, it is possible to generate a product definition from the customer's specifications and some domain knowledge regarding the structure of flight simulators. Further, this definition of domain concepts is extended to state that an activity is the performance of some

action upon some object. Therefore, a description ensues of all the objects which exist within the product, and the next stage is to install the necessary knowledge to allow the system to assess the actions which will be required to build this product. This can be viewed as an action configuration problem. This knowledge is modelled in a way which is very similar to that for the product configuration problem; the range of possible actions are modelled within the domain. These are again organised as a 'sub' hierarchy, resulting in actions being represented as composites of several 'sub-actions'. Thus the root action will describe the overall objective action for the project, e.g. 'build' or 'construct'. This action hierarchy is linked into the object hierarchy via the relation 'primitive_action'. The configuration itself is the main product of this system, but by virtue of the fact that component and therefore task dependences are explicit in the model, a precedence graph (a plan) can be readily produced.

3.0 A planning problem and The OARPLAN system

The Object, Action, Resource PLANner (OARPLAN)⁵ is a project planning system which has a detailed and knowledge-rich general model of the construction domain. As with PIPPA, its generic model comprises a hierarchical product breakdown structure, an action model and a resource model. The central concept of the system states that a specific project plan, i.e. a plan generated by the system to produce a specific product, is a logical sequence of activities, each of which is the intersection of an object, an action and one or more resources. This philosophy is identical to PIPPA, but the actual process of component selection, and hence activity generation, is different.

OARPLAN has been used to provide an integrated design/construction environment, in which detailed designs are available from the computer-aided design phase, to be used in the production of construction plans. Planning knowledge is used in the form of rules, which are applied to establish precedence between construction activities on the basis of inter-component relationships. currently these relationships include: *Supported-by*, *Enclosed-by*, *Damaged-by*, *Weather-protected-by*, *Covered-by*. These relationships have been shown to be adequate for the structural design and construction planning of real-life, full-scale buildings⁶, but in order to cater for the full range of interdependent construction processes (mechanical, electrical, finishing, etc.), more relationships are being experimented with.

Computer-aided design systems are able to provide descriptions of designs in terms of the project's individual components. A format used to describe these components and those related to them is shown below:

```
('component_class', 'specific_component', 'relationship'  
< a list of components related by 'relationship' >)
```

An example might be:

```
(BEAMS, B123, SUPPORTED_BY (C123, C124))
```

Relationships between these components (as shown previously), and groups (or classes) of components, are used in construction to properly sequence and consequently to schedule project activities. By representing objects at the most detailed level, along with information on their specifications, position and

relationship to other objects within the design it is possible to build a computer-based model of the product. The production of a specific model is crucial to the definition of a project and the subsequent planning process. The modelling module of OARPLAN takes each component that has been input (as shown above), and attempts to match the general part of the description, e.g. BEAMS, with a component existing within the general model. If this match is successful, an instantiation is performed. Figure 2 shows how activity nodes can share labourer with activity_31. In the figure, activity_23 shares the resource labourer with activity_31.

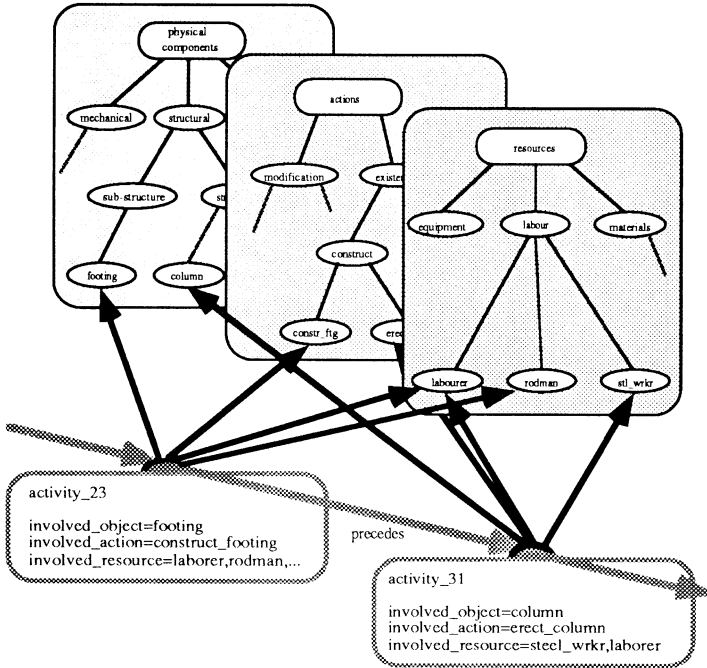


Figure 2. The 3 hierarchies and how they relate to the plan

By careful design of the action and object hierarchies, it is possible to describe activities at many levels. For example, at one level, it is possible to create an activity for the reinforcement of all the spans in a building by linking the object Spans (or rather the object *class* spans) with the action Reinforce. However, this activity can be represented by a number of lower-level ones. For example, by linking the action Reinforce_beam with the object Beam, and by linking the action Reinforce_column with the object Column, etc., a whole sequence of lower-level activities are created. Resources are represented in yet another hierarchy under the standard classes of *Equipment*, *Labour* and *Materials*. Resources are also defined as consumable or non-consumable, and specific resources are attached to the action hierarchy, so that for example, the action *construct column* would (or might) require the human resources *Carpenter*, *Rodman*, *Labourer* and *Finisher*.

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Planning knowledge exists in the form of rules, which are used to infer precedence between activities once the specific model has been produced. The general form of these rules is:

```
if activity_1 and activity_2 are in the plan
    and activity_1 is linked to object_1
    and activity_2 is linked to object_2
    and object_1 is related to object_2 by the dependency relationship P
then sequence activity_1 and activity_2 according to P
```

The application of these planning rules produces a logically correct sequence of activities (assuming correct input file representation). Rule classes are also implemented within the OARPLAN system to create and apply project start and end units, classify activities as simple or compound, i.e. that can or cannot be elaborated, and a rule class exists to carry out activity elaboration.

3.1 Managing complexity through activity aggregation

Although the sequence of activities in a plan may be subject to verification, the sheer size of the plan produced at the component level granularity causes problems by virtue of the resulting network complexity. Precedence relationships can be displayed to great effect graphically, but with such very large networks, a clear graphical presentation is important. Textual output and the use of commercial project planning software can alleviate plan presentation difficulties, but the sheer size and complexity of component-level precedence networks remains a problem. Component-level precedences are useful mainly at the line engineer or foreman levels. However, it is possible to aggregate activities into realistic work 'packages', each with their own set of activities, actions, objects and resources, and capable of being scheduled as such. This approach, which we have termed 'zoning', allows for bottom-up aggregation to any level; that level being specified by the designer and represented directly within the CAD output file. Using zone boundaries, defined around such virtual components, it is possible to quite literally partition the problem into smaller clusters of components.

Once the modelling phase has been completed on this building, a number of activities are created, each with an attached object, activity and resource, as well as 'place holders' for activity durations, etc. The planning phase produces a large precedence network of activities, and the zoning phase results in activity aggregation. Figure 3 is an OARPLAN view of a zoned plan, and clearly shows groupings of activities, delimited by zone start and end nodes.

Any conflicts which might exist between zones, and which would present during scheduling, can be detected at the post-zoning stage by checking for any dependency relationships that exist 'beyond the zone boundary'. Any such multiple relationship signals a potential conflict, and this can be taken account of during scheduling. This strategy ensures that the soundness of the planner is not compromised by the zoning process.



Figure 3. An OARPLAN display of part of a zoned plan

4.0 Scheduling and Presentation

Project planning techniques and accepted practices have been developed and have evolved over the years to cater for the various needs of their users. Planning functionality is important, but information and plan presentation is crucial to the acceptance and routine use of new technology in the manufacturing and construction industries. Not only was a comprehensive plan output deemed a priority in our environment development, but the ability to manipulate, query, improve and schedule was considered necessary for any real-life application. Our strategy was to integrate into our system, an industry standard commercial software package - Primavera™ for these purposes. Our model-based planning systems are capable of communication with such scheduling tools, through the automated provision of the following information:

- The project title
- Project start, finish and data dates
- Information on the working week and non-work periods
- Activity code definitions and activity codes
- Resource definitions (resource dictionary)
- Activity records (containing a unique identifier, activity title, and calendar ID)
- Precedence relationships between the activities defined in the activity records

With this facility, it is possible to provide scheduling functionality, and plan/schedule presentation in a range of standard formats. It is also possible, through bidirectional communication, to dynamically update the project model stored in OARPLAN.

5.0 Conclusions

The work described in this paper has demonstrated the power and general applicability of the model-based planning system strategy in the engineering industries. With the configuration system, an ordered sequence of plan activities is produced subsequent to design, and in the case of the construction planner, planning is performed on the basis of the pre-existence of a complete and detailed design. However, although the two application areas may be seen to address two completely different problems, the core modelling and planning functionality remains the same, i.e. both systems attach specific components (named in the design) to concepts within the generic component model. Once a specific component model exists, the planning system can dynamically create activities as actions upon objects using resources. The next phase for both systems is to create a precedence graph, and it is at this stage where important choices can be made. Long-term research has shown that constraint satisfaction on relationships is a powerful means of sequencing specific activities, but the potential problems of conflicts arises when using a large and complex set of constraints. Our work has demonstrated that it is possible to provide realistic and effective planning functionality in complex and high-value industrial domains. The existence of the product and process models leads to the possibility of adding more value through the 'add-on' capability of design and plan analysis, risk assessment, estimation, and visual presentation of the plan during simulation or in real time.

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