INTEGRATING DESIGN PLANNING, SCHEDULING, AND CONTROL WITH DEPLAN

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ABSTRACT

The planning and management of building design has historically focused upon traditional methods of planning such as Critical Path Method (CPM). Little effort is made to understand the complexities of the design process; instead design managers focus on allocating work packages where the planned output is a set of deliverables. All too often there is no attempt to understand and control the flow of information that gives rise to these deliverables. This paper proposes the combined use of the Analytical Design Planning Technique (ADePT) and Last Planner methodology as a tool called DePlan to improve the planning, scheduling and control of design. ADePT is applied during the early planning stages to provide the design team with an improved design programme that takes into account the complex relationships that exist between designers, and the information flows that flows between them. Then the Last Planner methodology is employed, through a program called ProPlan, to schedule and control the design environment. DePlan has been implemented as a PC-based computer program with web interface.

KEY WORDS

Design Management, ADePT, ProPlan, Last Planner, Production Management, Planning, Scheduling, Control, Dependency Structure Matrix.

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INTRODUCTION

The project programme drives current design management practices, with limited consideration given to the management of the production of design information. This is a fundamental problem because the design process is information intensive, and the timing and delivery of design information is crucial to the successful delivery of the design solution. Current planning techniques also do not take into account the iterative nature of design (Austin et al. 1996) with designers being expected to complete design as though it were a systematic and linear process. Jin et al. also (1996) point out the reciprocal dependence as well as the precedence relations and the resource dependence in a construction project. In other words, information or output of one activity could affect the decision made for another activity and vice versa. Thus, continuous communication among the involved parties is needed to insure that as much relevant pieces of information as possible are made available to the disciplines that requires them before a decision is made. Current planning methods force design teams to manage their work on a discipline basis, each working on achieving their deliverables as dictated by the design programme, with little regard of the relationship with other disciplines and organisations.

Design information tends to be formally distributed to all designers regardless of whether or not it is required, and the timing of information transfer is not properly controlled. All too often designers do not have the right information at the right time; therefore design tasks are undertaken with a risk of failure, and this leads to waste in the process due to unplanned rework (Huovila et al. 1997).

The introduction of ADePT as a planning tool for design has seen improvements in building projects, providing practicing design managers with means to plan more effectively, concentrating on the flow of information between design tasks (Austin et al. 1999a). The execution of design must also take advantage of this improved planning technique, so that designers are working in an environment that provides them with the means to identify what information is required, where that information resides, and who is responsible for providing it. Design programmes are also constantly being changed to reflect the intentions that are continually being defined by the project participants (Gurley and McManus 1998), which causes variability and uncertainty that is difficult to manage. As this variability and uncertainty manifest themselves as the design progresses, the activity definitions and the required information will need to be changed to reflect them.

In order to schedule the design programmes provided by ADePT, not only the activity sequence based on information relationships, but also the start/end dates, duration and resource requirement for each activity must be introduced. To assist in the scheduling and controlling of the design program, ProPlan has been developed, which helps to systematically develops lookaheads and weekly work plans. ProPlan, which adopts the Last Planner concept (Ballard and Howell 1994a, 1994b), allows the scheduler to detail design activities, identify additional constraints, check constraint satisfaction, release work packages, and allocate resources; then at the end of the week, collect field progress data and reasons for plan failure. The Last Planner methodology has already been applied extensively in construction (Ballard and Howell 1998) and has been implemented as a computer tool (Choo et al. 1998, 1999).

This paper introduces DePlan as a new approach to integrated design planning, scheduling and control that combines the benefits from the planning phase of design using ADePT, to the scheduling and control phase with a production management tool called ProPlan, as shown in Figure 1.

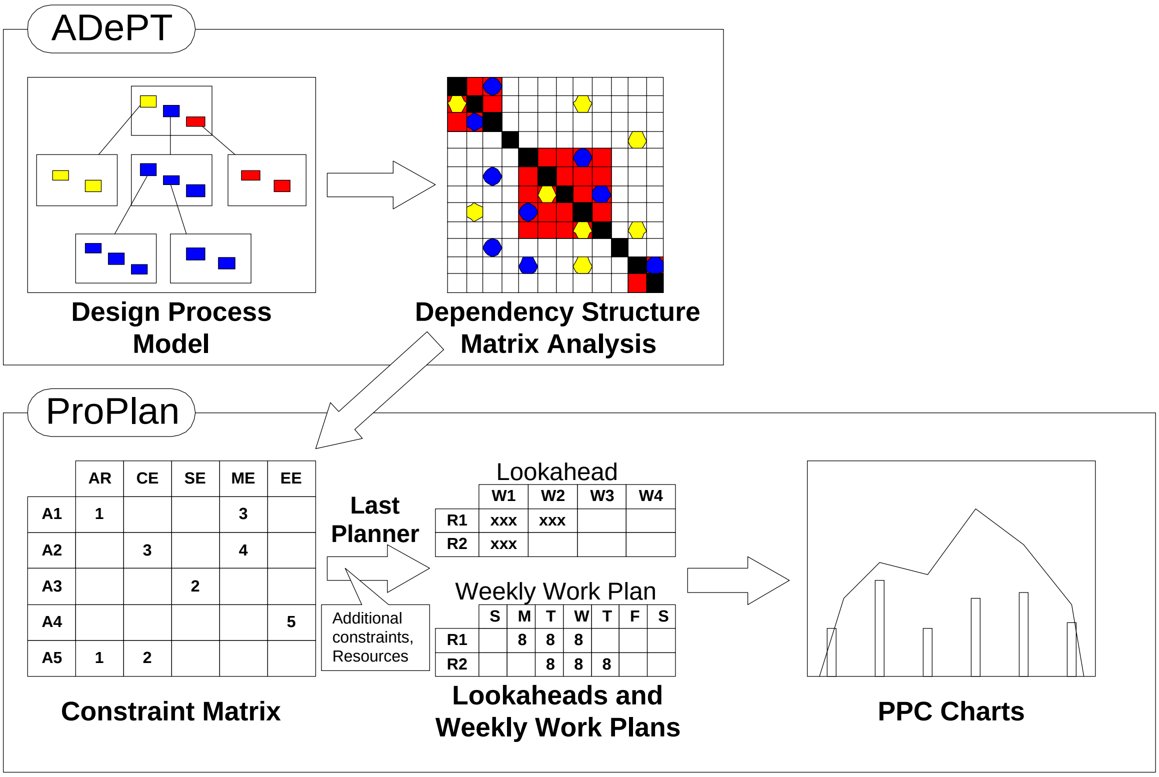


Figure 1. DePlan

ADEPT AS A PLANNING TOOL

The ADePT methodology has been developed to improve the planning and management of the design process. The first stage illustrated in Figure 2 is the production of a design process model for building design that defines the design activities and the information requirements that flow between them.

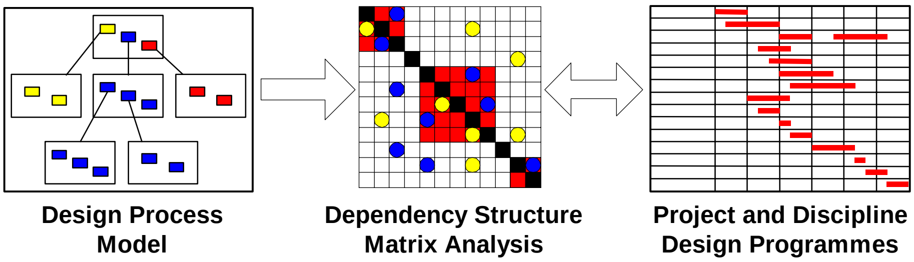


Figure 2. Analytical Design Planning Technique (ADePT)

The second stage imports the data from the design process model into the Dependency Structure Matrix (DSM) analysis tool. Iterations within the design process are identified and design activities are scheduled to provide an optimized order of tasks. The third stage of the ADePT methodology relates the matrix to a project programme, where the optimized order of tasks is reviewed, and resources are allocated. Other project constraints such as construction requirements will have an impact on the design programme; therefore there is iteration between the DSM and programming stages.

DESIGN PROCESS MODEL

The ADePT generic design process model (Austin et al. 1999b), used to develop DePlan, has been applied on a range of building projects varying in value between £2M and £180M. The process is represented graphically by a modified version of IDEF0 (Figure 3) and a project-specific model created for each building.

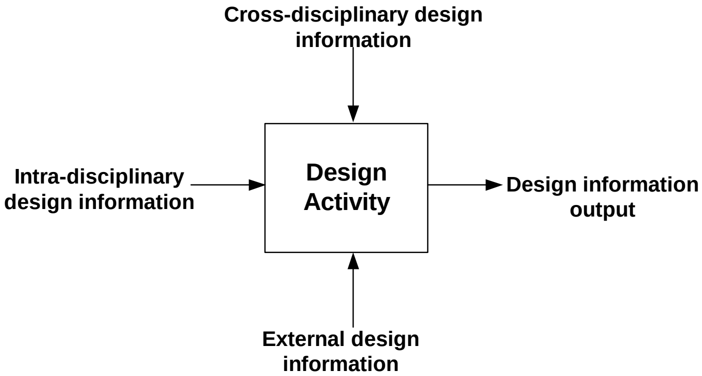


Figure 3. IDEF0v Notation

The hierarchical design process model is based on the five major building design disciplines: architecture and civil, structural, mechanical, and electrical engineering. Each discipline’s activity is decomposed to reveal systems, subsystems, and individual design tasks and the information requirements and output.

DEPENDENCY STRUCTURE MATRIX ANALYSIS

Dependency (Design) Structure Matrix analysis was developed by Steward (1981) to improve the efficiency of solving complex problems. By using a matrix to represent the interrelationships between activities, Steward found that a problem could be divided into contributing sub-problems. DSM has since been used by a number of researchers. Rogers (1989) improved the scheduling of problems with up to 50 activities at the conceptual design stage. Huovila et al. (1995) applied DSM to building design problems and McCord and Eppinger (1993) to various engineering problems, including semi-conductor design and automotive engineering design. The ADePT model represents one of the biggest applications of DSM, with 350 to over 800 activities and 2,400 to 10,000 information dependencies.

Figure 4 (left) illustrates a dependency structure matrix with ten design tasks listed vertically from Task A to Task J. The same tasks are horizontally listed in the same order. Each cross in the matrix illustrates a dependency on the vertical task from the corresponding horizontal task, where crosses below the diagonal represent required design information that is available, and crosses above the diagonal reflect information that originates from design tasks that have not yet been undertaken. That is, the order in which tasks appear in the first column suggests that those higher up will be performed before (or concurrently with) those lower down. For example from Figure shows that Task D requires information from Task C and Task F. Task C information is available since it has already been completed; however Task F information is not available because Task F is not scheduled (due to its position in the matrix) to start until later.

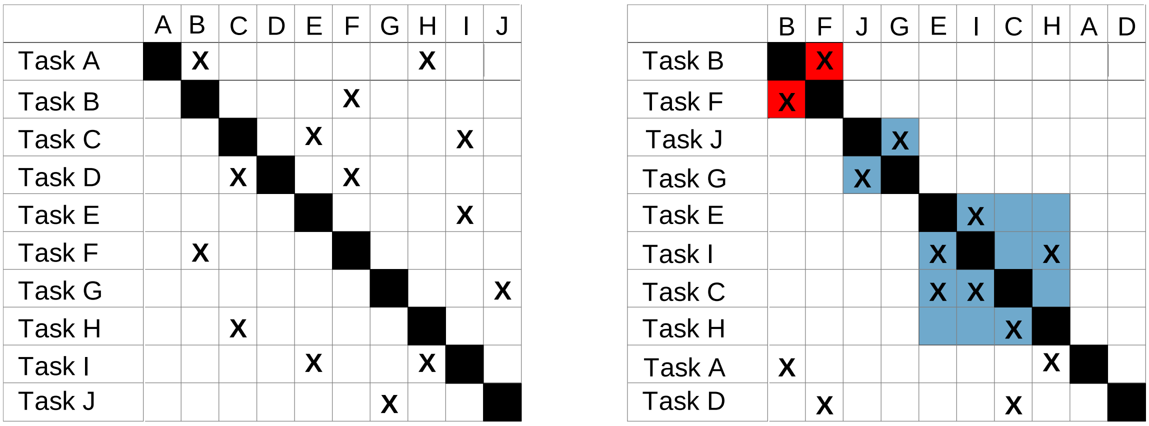


Figure 4. Example of DSM Analysis before (left) and after (right) Partitioning

Special considerations need to be given to the situation when the dependency requires information from an activity that has not yet been undertaken. This information will have to be estimated so that the design task depending upon it can be enabled. This means that the design task may have to be re-visited to update the estimated design information to check whether or not the original estimate was satisfactory. This iteration is characteristic of the design process; therefore by using the DSM analysis the design planner can begin to allocate necessary resources and planning strategies to manage the iteration.

The estimation of information is not always an acceptable solution therefore some design task information dependencies will need to be treated differently. The DSM software can partition the matrix by re-ordering the sequence of design tasks to maximise the number of design tasks below the diagonal, as shown in Figure 4 (right). The profile of the matrix has changed and now shows smaller blocks of inter-related design tasks that are easier to plan and manage.

DESIGN PROGRAMMING

The partitioned matrix is linked to a planning tool to generate a programme for the design activities by the addition of resources and durations. The sequence of design work is defined by the output from the DSM, however where there are blocks of interrelated tasks the project planner will need a strategy to de-couple the design tasks. This may involve planning the tasks within the block concurrently so that iteration can be achieved and a design solution delivered efficiently. Figure 5 shows an example of planning a block of interrelated tasks concurrently. The block has a finite duration, and the constituents of the block are planned to start and finish so that the flow of information maximizes the opportunity to complete the design iteration and yield a design solution. Other strategies are described in Austin et al. (1999a).

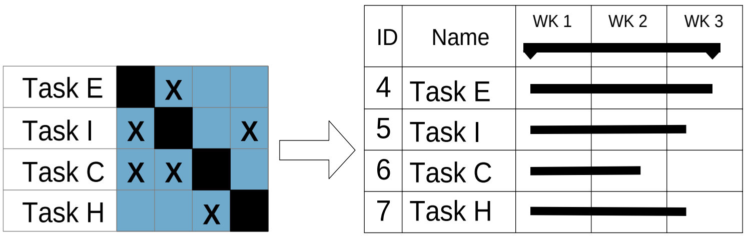
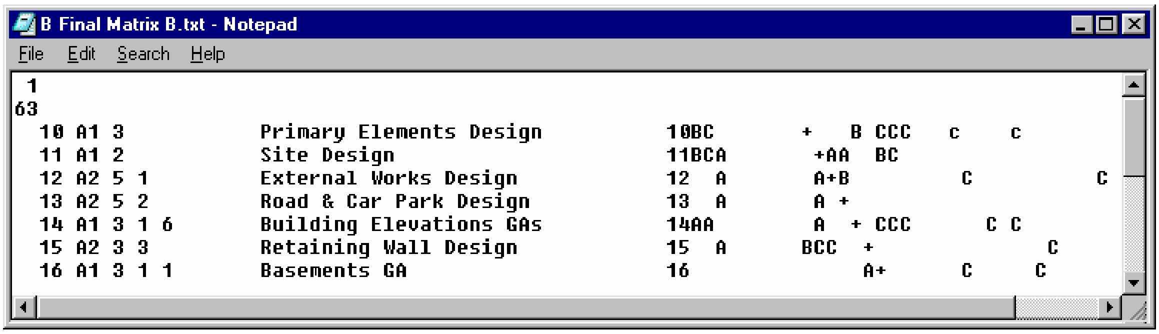


Figure 5. Programming Iterative Blocks of Tasks

PROPLAN AS A PRODUCTION MANAGEMENT TOOL

ProPlan has been developed to support scheduling and control of the design process according to the Last Planner concept. ProPlan allows the user to generate project data from the start but is also capable of importing the ADePT output matrix (Figure 6), i.e., the list of activities, the responsible disciplines for each activity, and the informational dependencies.



B Final Matrix B.txt - Notepad

File Edit Search Help

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 1
63
  10 A1 3           Primary Elements Design          10BC       +   B CCC   c    c
  11 A1 2           Site Design                      11BCA       +AA  BC
  12 A2 5 1         External Works Design            12  A       A+B         C          C
  13 A2 5 2         Road & Car Park Design           13  A       A +
  14 A1 3 1 6       Building Elevations GAs          14AA        A  + CCC      C C
  15 A2 3 3         Retaining Wall Design            15  A      BCC  +              C
  16 A1 3 1 1       Basements GA                     16              A+      C     C
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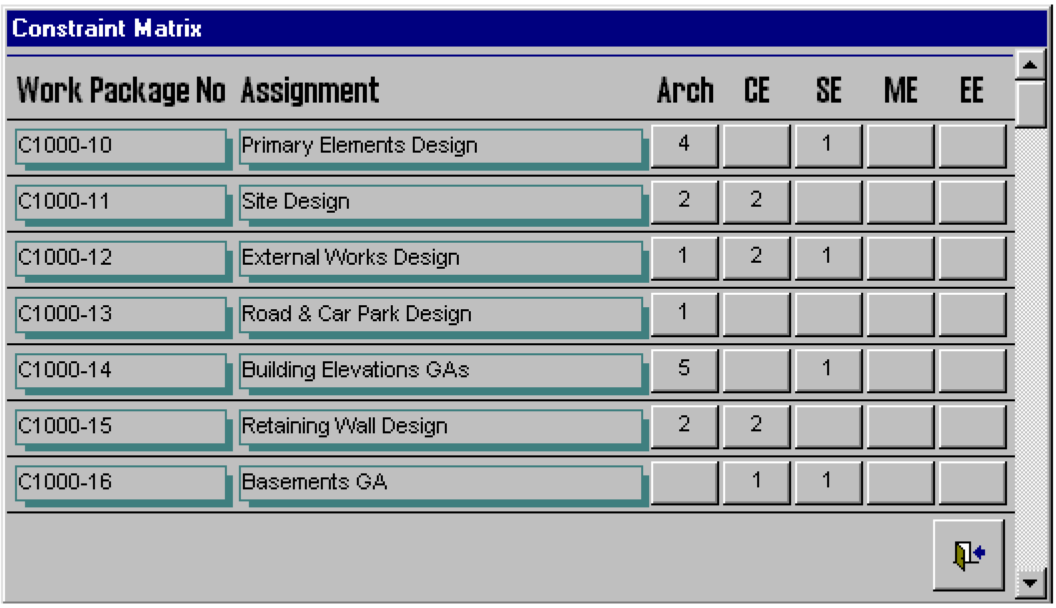
Figure 6. Sample Output Matrix Generated from ADePT

The imported information is then automatically restructured to generate the constraint matrix (Figure 7). Each design activity corresponds to a work package in ProPlan. The constraint matrix shows the number of design activities that belong to each responsible discipline. These activities are informational constraints that must be attained in order for each activity to be carried out successfully. By categorizing the constraints by disciplines, the planner can determine which discipline is most critical to the release of design activities.



Constraint Matrix

Work Package No	Assignment	Arch	CE	SE	ME	EE
C1000-10	Primary Elements Design	4		1		
C1000-11	Site Design	2	2			
C1000-12	External Works Design	1	2	1		
C1000-13	Road & Car Park Design	1				
C1000-14	Building Elevations GAs	5		1		
C1000-15	Retaining Wall Design	2	2			
C1000-16	Basements GA		1	1		

Figure 7. Constraint Matrix based on Figure 6

By clicking on any numbered cell in the matrix, details of the corresponding number of constraints can be seen. For example, the detailed description for "1" in the civil engineering discipline (CE) for work package C1000-16 can be seen by clicking that number. Figure 8 shows two sections of constraints. The top section refers to the constraints that have been met and the bottom section refers to the constraints that have not yet been met. The number "1" corresponds to the number of filled-out rows in the bottom section of the screen, where each row represents a constraint that remains to be met. The top section, which represents the constraints that have been met, allows the planner to keep track of what constraints have been satisfied. Thus, the planner is able to track what needs to be done but also what was done. This is valuable if the planner needs to recheck the constraints due to unforeseen changes occur to design activities. The planner can also add additional constraints as they are identified during project execution.

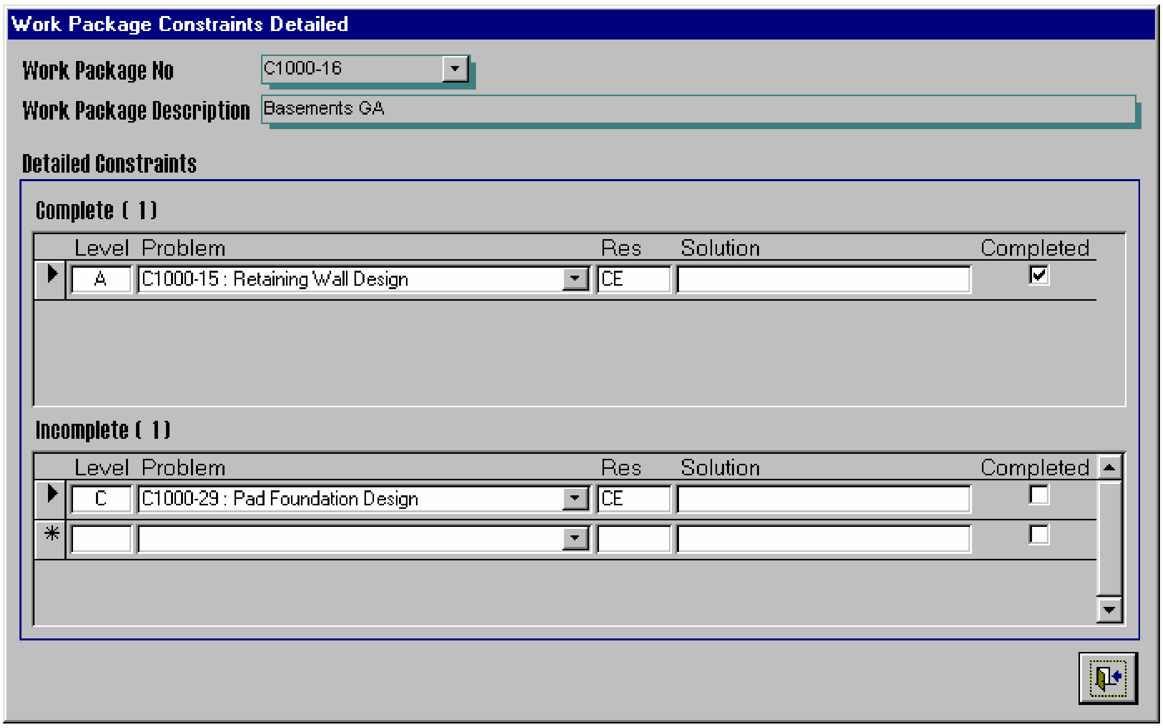


Figure 8. Detailed Design Constraints for C1000-16

Other types of constraints can also be specified. These constraints are divided into five categories: contract, engineering, samples, resources, and design constraints (Figure 9). Contract refers to constraints regarding contractual finalization, commercial constraints, permits, subcontracting, etc. Engineering refers to constraints from other engineering functions such as construction management and planning supervisors. Samples refer to instances where design is constrained by the agreement to provide samples or mock-ups. Resources refer to constraints regarding planning and management of resources, including designers and supporting services**.** Design Constraints are the information provided by ADePT. Design Constraints for all disciplines are shown on this screen. Figure 8 shows Design Constraints that belong to a single discipline where as Figure 9 shows Design Constraints that belong to all disciplines as well as other types of constraints.

When constraints for a design activity are satisfied or are expected to be satisfied, this activity can be released for scheduling. In the scheduling phase, explicit resources such as designers and supporting services (accounting, administration, drafting department, etc.) are assigned to generate weekly work plans (Figure10). For tracking purpose, constraints that are expected to be met are automatically printed in the "make ready" section. Weekly work plans are special purpose planning that is carried out with the highest level of detail prior to carrying out the work. Ballard and Howell (1994a) refer to weekly work planning as "commitment planning" because, at this stage, the specific resource assignments need to be made so that work can actually be performed. The scheduling window for weekly work plans is one week.

Design activities in the weeks beyond one week are scheduled using the lookahead window (not shown). Since it is hard to precisely determine which specific designers and corresponding supporting services need to be assigned to each design activity, the planner can denote with a simple "yes/no" whether each design activity will need to be carried out each week.

Ballard (1997) describes the purposes for lookahead planning as:

1. Shape work flow in the best achievable sequence and rate for achieving project objectives that are within the power of the organization at each point in time.
2. Match production unit and related resources to work flow.
3. Produce and maintain a backlog of assignments for each frontline supervisor and production unit, screened for design, materials, and completion of prerequisite work at the CPM level.
4. Group together work that is highly interdependent, so the work method can be planned for the whole operation.
5. Identify operations to be planned jointly by multiple trades.

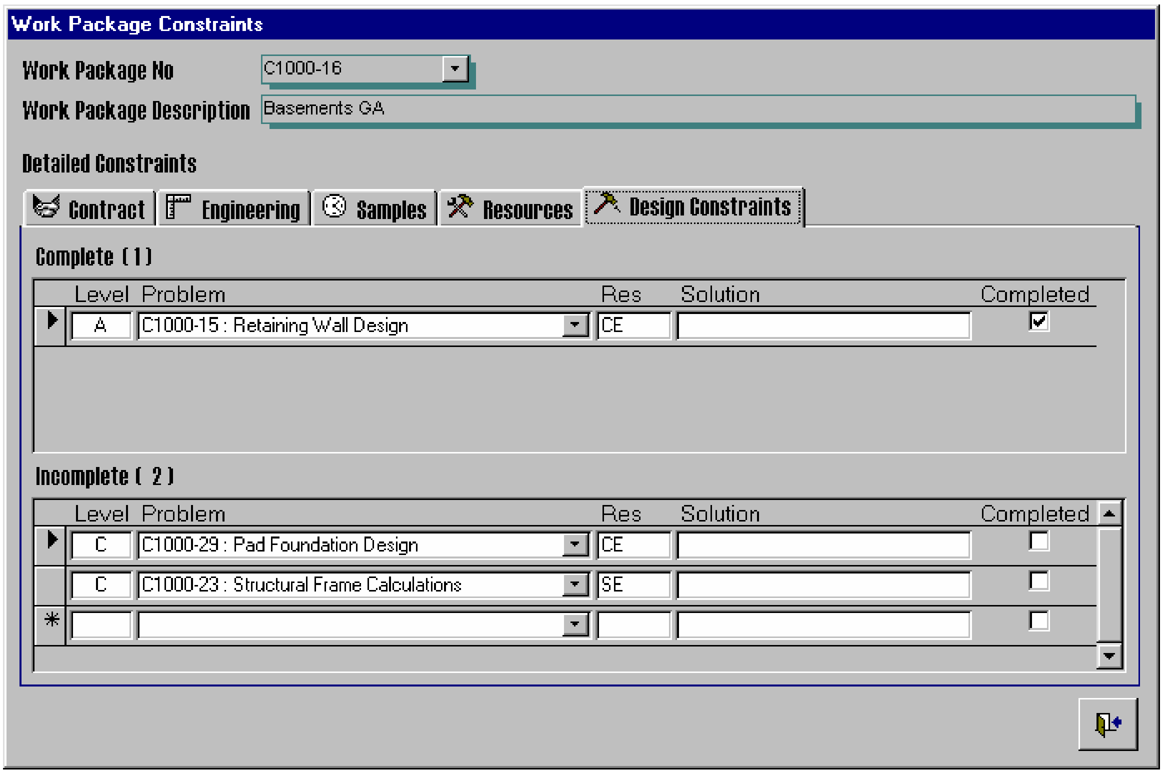


Figure 9. Detailed Constraints for C1000-16

Date Prepared : Thursday, April 20, 2000

Weekly Work Plan **DePlan**

Project No / Cost Code	Project Name / Assignment	Make Ready Needs / Name	(Apr) 16	17	This Week 18	19	20	21	(Apr) 22	Plan Percent Complete Yes	No	Reasons For Variance
C1000		[1] C1000-23 : Structural Frame Calculations (SE)										
01	Ground Floor GA											
		Jamie Hammond		8	8							
		James Hyun Choo		8	8							
		Accounting		8	8							

Figure 10. Weekly Work Plan Generated from ProPlan

The lookahead acts as an interface between the overall project schedule and the weekly work plan (production schedule). The production activities (design activities) need to be executed according to the overall project schedule since there are milestone dates (meetings, inspection, due dates, etc.) that determine the latest finish dates for certain activities. Therefore, it is important to note that the main objective of the lookahead is to determine which activities need to be carried out in which week and to make those activities ready according to the project schedule, so they will meet the Last Planner's criteria for assignment during weekly work planning. Figure 11 is an example of a lookahead generated from ProPlan.

Lookahead

WP No	Assignment	Apr. 23	24	25	26	27	28	29	30	May 1	2	3	4	5	6
C1000-10	Primary Elements Design														
C1000-11	Site Design														
C1000-12	External Works Design		Yes	Yes	Yes	Yes	Yes								
C1000-13	Road & Car Park Design		Yes	Yes	Yes					Yes	Yes	Yes			
C1000-14	Building Elevations GAs									Yes	Yes	Yes	Yes		
C1000-15	Retaining Wall Design														
C1000-16	Basements GA														

Figure 11. Lookahead Generated from ProPlan

After each week, the designers need to fill out the actual number of hours they worked on each design activity and check whether or not their assignment was completed as planned. If not, they must provide reasons for variance. This data is used to calculate Percent of Plan Completed (PPC) (Ballard and Howell 1994a, 1998) to measure the reliability of the planning system. PPC is calculated by dividing the number of completed assignments by the total number of assignments each week. Recording the completion status of design activities for PPC calculation is important, but elaborating on reasons for failure is even more valuable because it enables learning, thereby preventing the mistakes from reoccurring in the future.

DEPLAN CHARACTERISTICS AND FUTURE WORK

The concept of DePlan is relatively straight forward: define the design process from a generic model and produce an integrated project plan by DSM analysis; then schedule and control design production with lookahead and weekly work plans by assigning design activities as the required information and resources become available. Design is thus planned and managed based on the generation of information with realistic and achievable task setting, not deliverable production. The effects of change can be managed by further matrix analysis and process reliability monitored by measurement of PPC.

ProPlan is ready for test projects. Three candidate projects have been identified in the US with testing expected to start in May 2000. Candidate projects are being negotiated in the UK as well. The main purpose of the test projects is to determine the merits and demerits of DePlan, i.e. the integrated application of ADePT and ProPlan. ProPlan will also be modified according to findings from on these test projects.

The input design model for DePlan was developed based on UK industry. UC Berkeley is presently creating a model based on US industry. The data generated from ProPlan will facilitate the creation of the model because it will reflect the actual practices of description of activities and the relationships between them.

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