Time-dependent Evolution of Work Packages

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ABSTRACT

We are working on a common information model called UNIWBS which uses the work breakdown structure concept. UNIWBS is intended to support project information integration and project planning and control as well. By using the UNIWBS, we are also developing a conceptual knowledge-based expert system called DYNAPACK for generating planning, design, and construction work packages. DYNAPACK will be a testbed to support time-dependent project information evolution.

1. INTRODUCTION

We are working on a common information model called UNIWBS, UNIfied Work Breakdown Structure, by using the functional approach to project structuring technique. The promise of this conceptual model is that it is built on a comprehensive set of basic funcTionAl and prOcess elements (TAOs) identified from the work packaging process. Built on the TAOs, UNIWBS will be able to holistically support project information integration and project planning and control as well.

With UNIWBS, we also propose a conceptual knowledge-based expert system called DYNAPACK, DYNAmic work PACKaging, for automated work packages generation. DYNAPACK is a blackboard architecture built on a hierarchy of knowledge sources representing work packaging criteria, constraints, and knowledge. These knowledge sources are being formulated from extensive knowledge acquisition efforts. DYNAPACK will be a testbed to support time-dependent project information evolution by generating planning, design, and construction work packages.

2. BACKGROUND: BASIC CONSTRUCTION PLANNING PROBLEMS

Some researchers and practitioners have concluded that the CPM/PERT network analysis technique cannot adequately address the needs of construction site management[1,2]. Further analysis suggests that this pitfall results not from the network technique itself, but from how the planner organizes the projects and applies the network technique.

Construction activities are implemented by specialized trades in different work locations on the job. Therefore, the heuristic construction process usually starts with determining the work sequence of the trades, their locations on the job, and their work flows through the work locations. Second, the planner will then try to balance the whole construction process. While doing this, the planner will check the possibility of introducing practical breaks in continuity or changes in crew sizes, and analyzing the whole process in terms of time and activity duration. Finally, the specialty subcontractors, who actually control many of the resources required to implement the work, will determine their own detailed work flow plans.

For network analysis, the planner is first required to breakdown the project into a list of discrete activities based on physical work items (e.g., form foundation, place concrete, cure concrete, etc.) and then determine the sequence of the work items from their technological connections. Second, the planner will calculate the duration of each activity and the critical path and available floats of the project plan. Finally, the planner will produce a progress schedule by incorporating resource restrictions of the project.

In comparison, the heuristic, area-by-area approach suggests that one organizes a construction process by work flows of trades through work locations on the site. "Work flow" is key to this process. It is defined as the trade sequence of the same work type and similar productivity through work locations on the job over time. On the other hand, the network analysis requires that one must decompose a construction process into a sequence of physical work items without explicit consideration of trade work flows. That is, *the heuristic approach explicitly identifies the trade work flow as a planning entity, while the network approach treats it as an attribute of network activities.* Ignoring trade work flows cause trade interference[3].

In addition, for network analysis, it is apparent that the construction planner does not initially consider resource constraints of the trades. But one cannot carry out the project without considering the trade resources. Therefore, complicated resource analysis has to be done after the schedule is produced. Usually resource analysis is implemented by sophisticated computer programs. These programs still may not lead to a practical solution because the work flow is ignored.

Consequently, the problem why the network technique is not capable to justify site operation is not from the network technique itself. Rather, it is because the planner is trapped into the "activity-oriented" network paradigm.

3. CONSTRUCTION PROJECT MANAGEMENT: A HOLISTIC VIEW

We have described the key issues of construction process planning. But a construction project requires many distinct functional and process efforts. For example, a turnkey project usually encompasses project definition, conceptual planning, detail engineering, detail estimating, detail scheduling, procurement, material management, construction, and startup. Each of these functions or processes can be further decomposed into a hierarchy of sub-functions and sub-processes. In addition, functions and processes are intra- and inter-related as well. Optimization in one process may not lead to the best solution. Strong coordination is therefore required in order to pursue the project efficiently and effectively.

Exhibit 1 provides a holistic view of a typical refinery turnkey project. All project functions and processes are depicted and associated with resources, controls, and information flows. The technique used to analyze this project development process is called Structured Analysis and Design (SAD). It is a useful tool for information modeling. For example, based on SAD, Sanvido et. al. have developed an integrated building process model for building construction projects and identified information requirements associated with this model[4].

4. WORK BREAKDOWN STRUCTURE FOR CONSTRUCTION PROJECT INTEGRATION

4.1. WBS for Project Integration

As we have described before, the area-by-area work flows is a heuristic concept for construction process planning. Birrell has used this concept to develop a work packaging model based on time phases and locations similar to that shown in Exhibit 2[1]. Each interaction of the time phases and locations in the Birrell's model is a work package defined as "a quantity of a particular type of work at a specific location to be carried out by a specific work squad." Under this definition, a work package usually carries time, area, trade, work flow, work type, responsible supervisor, and quantity information. We define "trade", "work flow", "area", and "work item" as basic funcTionAl or prOcess elements, or TAOs, of a construction work breakdown structure (WBS). *"TAO" is a basic planning and control unit. It is an independent entity and can be created, stored, reused, modified, and erased according to specific planning and control needs.*

The work packaging concept is also applicable to other project functions and processes. For example, Elmore and Sullivan describe how to use the work packaging concept to improve cost visibility of construction projects[5]. Neil presents how to use the work packaging concept to integrate cost with schedule control[6]. Walsh uses the work packaging concept to integrate engineering plans with construction plans[7]. A more recent example, Rasdorf and Abudayyeh, offers a work packaging approach for integrated cost and schedule control on the job site[8].

Therefore, work packaging is a prospective technique for project integration. The work packaging technique we use for project integration is called *the functional approach to project structuring*, which we will describe in more detail later. For project integration, we assume that every construction project function or process require a finite

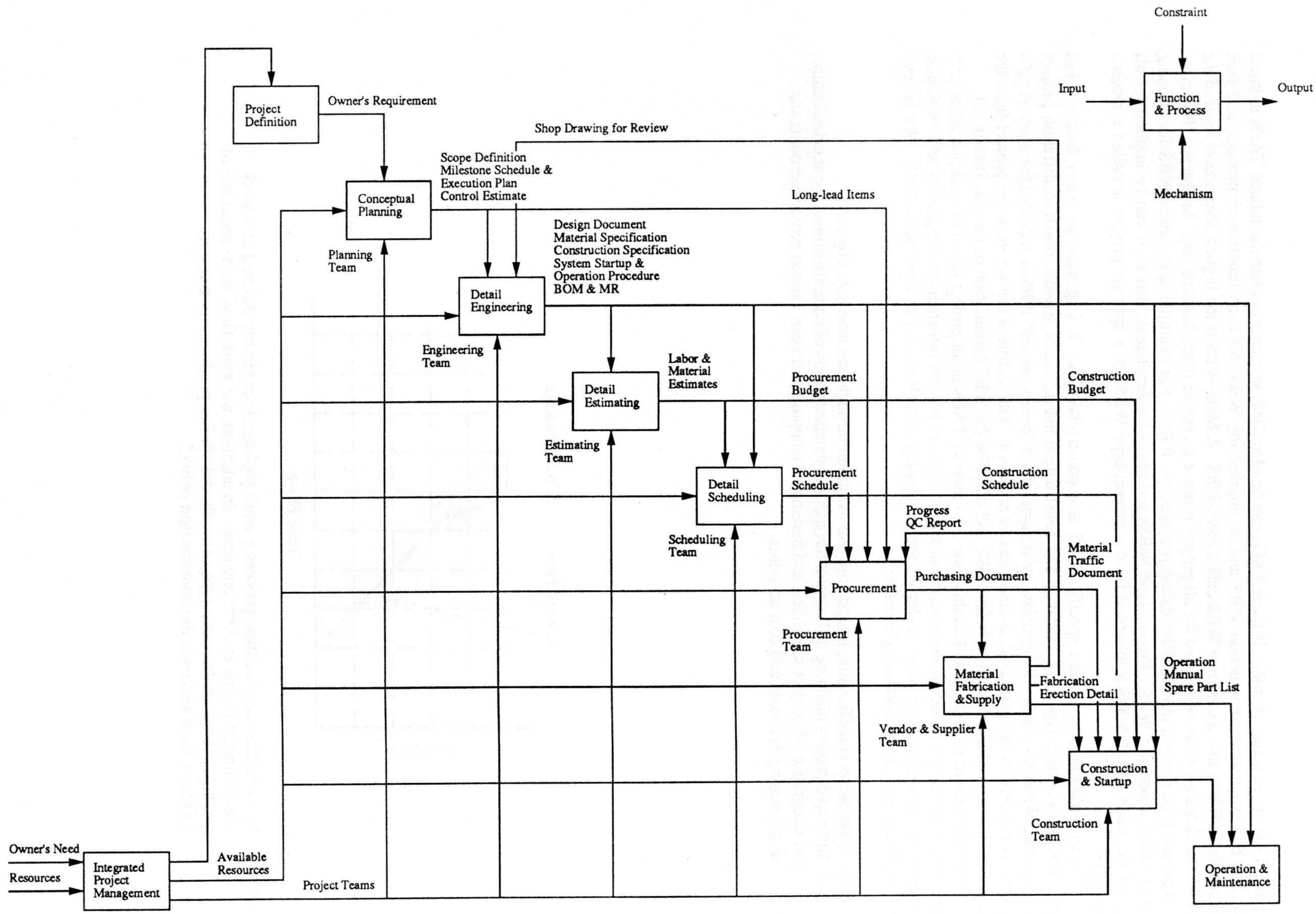


Exhibit 1: Holistic view of overall construction project management: An example of typical refinery projects.

set of basic TAOs to structure its jobs. If these TAOs can be identified, we can associate the related TAOs to build *functional WBSs*, such as a construction WBS and an engineering WBS, for each function or process, and then consolidate these WBSs into a common WBS called *meta-WBS*. A Meta-WBS is the highest abstraction level of the various WBSs. Ideally, it can be applied for all project types, e.g., power plant, housing, etc. In practice, however, a special project type needs a unique WBS called *project-type WBS*. For example, a common WBS for housing projects is called a housing WBS. Project-type WBSs are project independent; that is, it can be applied for all projects of the same type. A WBS inherited from a project-type WBS for a specific project is called a *project-specific WBS*.

The formulation of a project-specific WBS is a non-trivial task. It is govern by many factors. For example, different contract types, e.g., turnkey and construction management, usually result in different project WBSs. *By using WBSs for project integration, we assume that a "compromised" WBS is required for a project if a satisfactory, not necessary the optimized, solution can be achieved.* This is true when we view the project from the holistic perspective as we have described before. We will describe the WBS formulation process in Section 6.1.

The major thrust of our research at this time is to identify TAOs in all project functions and processes, and use these TAOs to build a common information model to support project information integration and evolution. By definition, the common information model we are developing is itself *a computerized meta-WBS*. We believe that this model can provide the following benefits:

(1) Information classification, integration, and evolution through common data objects.
(2) Improved project planning and control through the standardization of code structures, the standardization and integration of project schedules, and automated mappings between various project accounts such as estimating accounts and cost accounts.

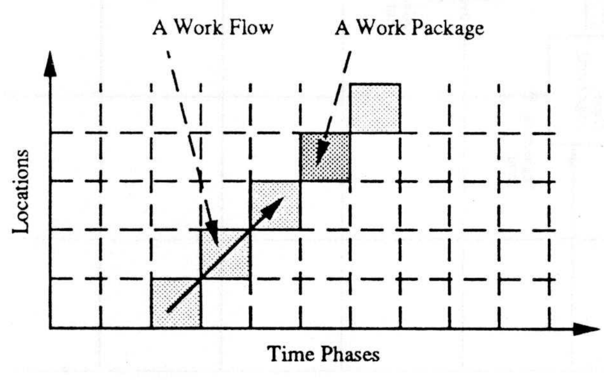


Exhibit 2: In a heuristic construction process a work package is explicitly defined as a work space limited to one trade at one time. In addition, the work flow is the sequence of work packages of the same type of work and similar productivity through different locations over the construction period.

4.2. Functional Approach to Project Structuring: Developing the Meta-WBS

As we have described, the area-by-area work flow approach is common for construction projects. By this approach one can break a construction project into basic planning elements such as trade, area, work flow, work type. We have defined these planning elements as basic functional process elements, or TAOs, of the construction WBS. We recognize that different functions or processes require different TAOs. For example, engineering is usually organized and performed in terms of systems, subsystems, disciplines, and engineering deliverables such as drawings, specs, and studies. "System", "discipline", and "engineering deliverable" therefore are TAOs for engineering projects.

Recognizing the functional requirements of the WBS, Ponce-Campos and Ricci provide a technique called functional approach for project structuring to develop WBSs for specific planning and control purposes[9]. As shown in Exhibit 3, the Ponce-Campos and Ricci (PCR) WBS model, defines "assemblies", "systems", "areas", and "components" as the basic TAOs for contracting, engineering, construction, estimating, etc. Each TAO is composed of a hierarchy of TAOs that can be combined with other TAOs to produce various schedule types, e.g., master, engineering, construction.

The purpose of the PCR WBS model is to develop a WBS hierarchy that: (1) will integrate all functions so that, for instance, a change in cost status will be reflected in all pertinent schedules; (2) will be in accordance with the way the actual work is to be performed; and (3) can provide all the activity definitions for networking. PCR recognize that the WBS is developed not only to provide "what has to be done," but also in accordance with "the way in which the project is to be performed." They also believe that the development of the WBS is a step that precedes networking, and which can aid in the standardization of levels of schedules.

To sum up, the P-C-R WBS model: (1) provides a basic framework to identify basic TAOs in various project functions and processes; and (2) defines levels of abstraction within various functional breakdowns, which may not be complete, but provide insights for deriving the basic TAOs.

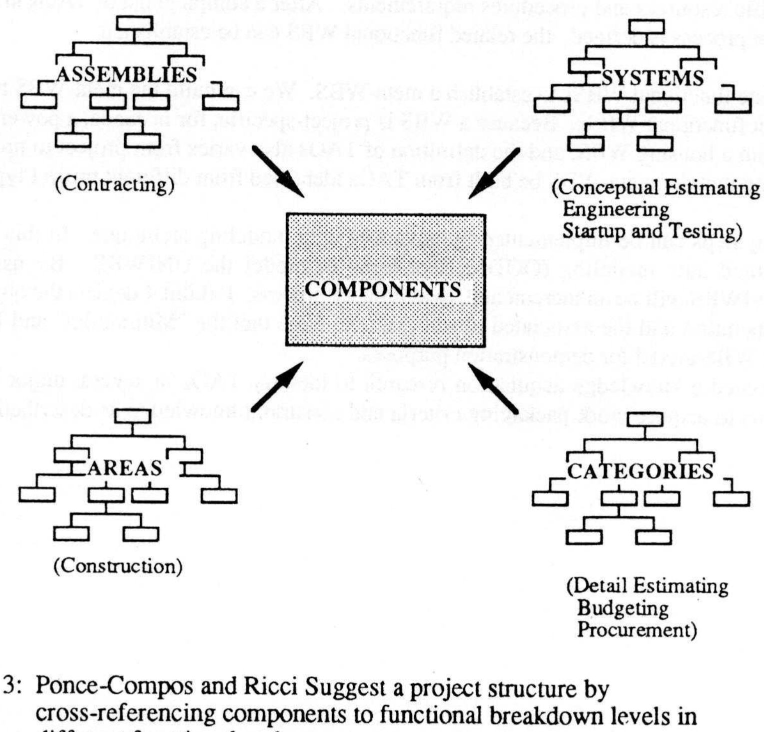


Exhibit 3: Ponce-Compos and Ricci Suggest a project structure by cross-referencing components to functional breakdown levels in different functional and process areas.

5. UNIWBS: A COMMON INFORMATION MODEL TO SUPPORT PROJECT INTEGRATION

5.1. The Promise

Development of common, project-independent information models for project information integration is a priority of current research in the construction industry. For example, Bjork is working on a unified information model to support Construction Integrated Construction (CIC)[10]. Froese & Paulson are developing domain models to facilitate integration of construction management systems[11]. In this research, we emphasize *integration of project management and control functions* through the establishment of a common information model using the meta-WBS concept. In addition, we are developing a computerized work packaging system to support evolution of project information.

5.2. The Approach

The common information model that we are developing is called UNIfied Work Breakdown Structure, or UNIWBS. The proposed approach is based on the assumptions described in Section 4 and composed of the following steps:

(1) Identify basic TAOs in all project functions and processes. This is a bottom-up process, that begins with the lowest level of each project function or process. For example, "Craftsman_A Pour Concrete_Column_6 of Micro_Module_3 at Date_XXX." After identified, each TAO should be define and have a unique code for identification purpose. Standard coding systems such as the MASTERFORMAT can be used to code the TAOs.

(2) Establish functional WBSs. As defined before, a functional WBS represents the task structure of individual functions or processes. For example, in the heuristic, area-by-area work flow approach, a project can be divided into trades, areas, work flows, and work types. Each work type is associated with specific resources and procedures requirements. After a complete list of TAOs in a specific function or process is defined, the related functional WBS can be established.

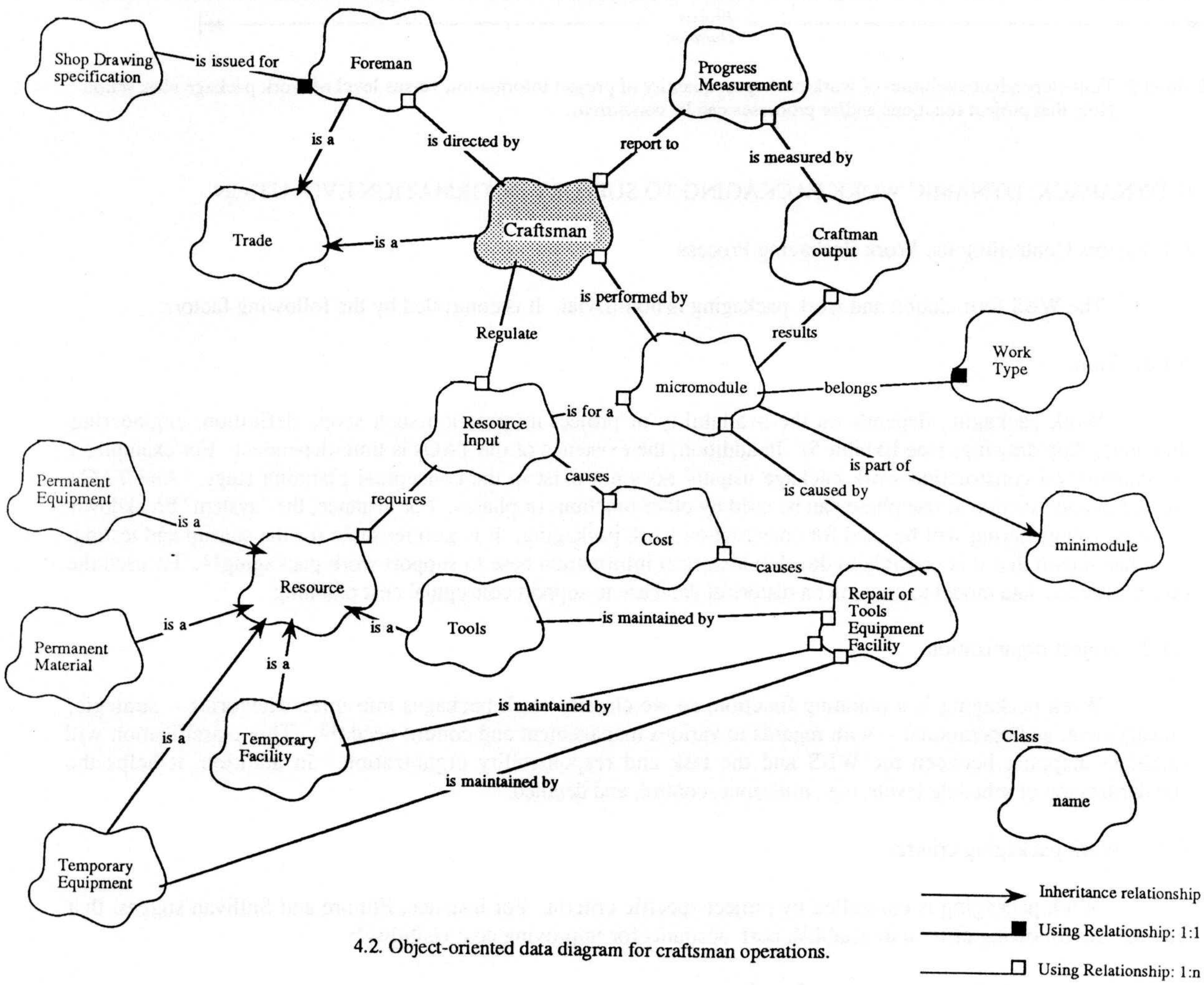
(3) Consolidate functional WBSs to establish a meta-WBS. We can build the meta-WBS by consolidating all project functional WBSs. Because a WBS is project-specific, for instance, a power plant WBS differs from a housing WBS, and the definition of TAOs also varies from project to project, we recommend that the meta-WBS be built from TAOs identified from different project types.

The foregoing steps can be implemented by advanced data modeling technique. In this research, we are using the object-oriented data modeling (OODM) technique to model the UNIWBS. By using OODM, the development of the UNIWBS will be an incremental, evolutionary process. Exhibit 4 depicts the object-oriented data model of craftsman operation and the associated object classes. Note that the "Minimodul" and Micromodul" are adapted from the PCR WBS model for demonstration purposes.

We have initiated a knowledge acquisition research to identify TAOs in several major turnkey projects. This program also aims to acquire work packaging criteria and constraint knowledge as described in the following section.

- **Shop Drawing**
- **Trade**
  - **Foreman**
    - **Craftman**
- **Process**
  - **Minimodule**
    - **Micromodule**
- **WorkType**
- **ResourceInput**
- **Resouec**
  - **PermanentEquipment**
  - **PermanentMaterial**
  - **TemporaryEquipment**
  - **TemporaryFacility**
  - **Tools**
- **RepairOfToolsEquipmentFacility**
- **CraftsmanOutput**
- **ProgressMeasurement**
- **Cost**

4.1. Object classes associated with craftsman operations.



4.2. Object-oriented data diagram for craftsman operations.

Exhitbit 4: Object-oriented data modeling of construction process at the craftsman level.

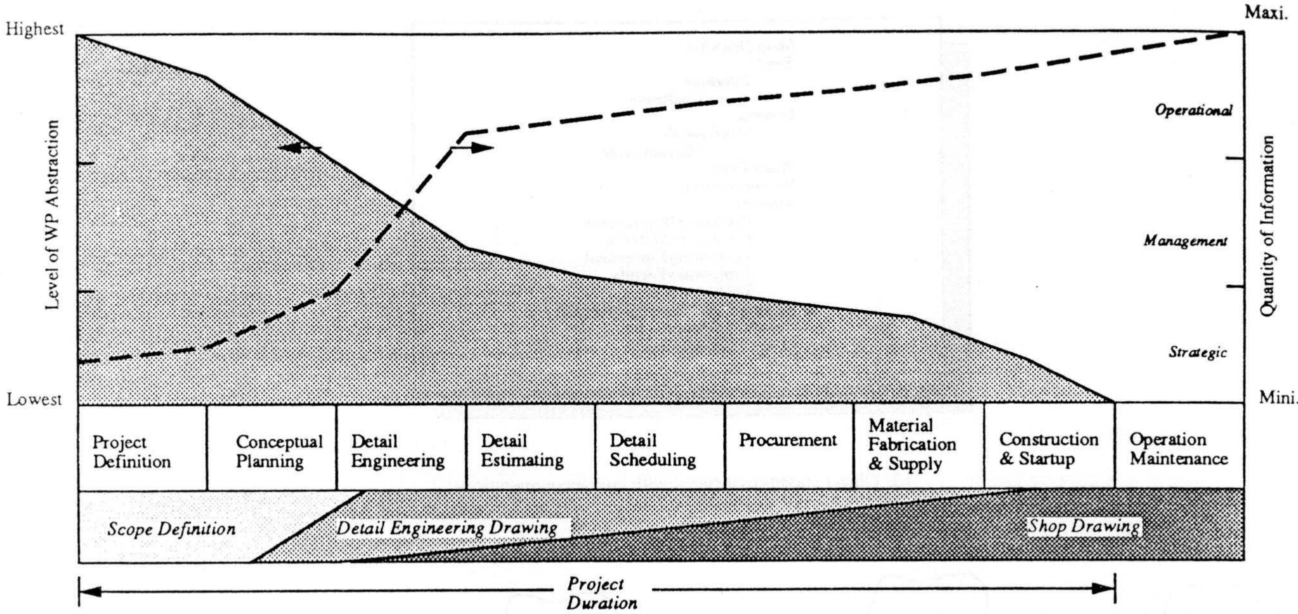


Exhibit 5: Time-dependent evolution of work packages: quantity of project information versus level of work package abstraction. Note that project functions and/or processes can be concurrent.

6. DYNAPACK: DYNAMIC WORK PACKAGING TO SUPPORT INFORMATION EVOLUTION

6.1. Factors Controlling the Work Packaging Process

The WBS formulation and work packaging is non-trivial. It is controlled by the following factors:

6.1.1. Time

Work packaging depends on the availability of project information such scope definition, engineering drawings, shop drawings (see Exhibit 5). In addition, the existence of the TAOs is time-dependent. For example, a craftsman-level construction work package usually does not exist in the conceptual planning stage. And TAOs created in one function at one phase can be used by other functions or phases. For instance, the "system" breakdown created by engineering will be used for construction work packaging. It is also reusable for the startup and testing. Choi has shown that it is possible to develop historical information base to support work packaging[12]. He used the object-oriented data model to construct a historical database to support conceptual cost planning.

6.1.2. Project organization

Work packaging is a planning function, so we classify work packages into three categories -- strategic, management, and operational -- with regards to various management and control needs[13]. This classification will facilitate mapping between the WBS and the task and responsibility organization. In addition, it helps the standardization of schedule levels, e.g., milestone, control, and detailed.

6.1.3. Work packaging criteria

Work packaging is controlled by project-specific criteria. For instance, Elmore and Sullivan suggest that one use the following criteria to establish cost accounts for improving cost visibility[5]:

- Logical, discrete elements of work.
- Related to way work will be performed.
- Assignable to supervisor.
- Realistic but challenging budgets built from detail work steps.
- Performed in a short period of time.

6.1.4. Project constraints

Project-specific constraints such as resource availability and nature of the work are fundamental to work packaging. For example, Kim has identified work complexity, work density, and material, labor, and crane availability as major variables for piping construction work package definition[14].

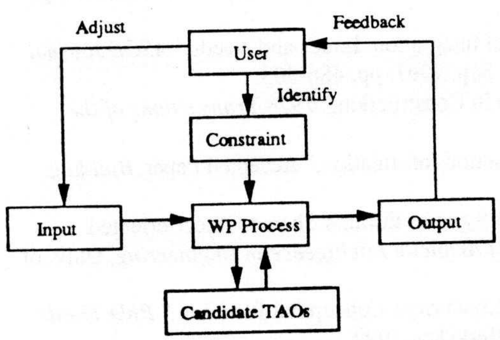
6.1.5. Domain knowledge

Work packaging is led by human experts, thereby domain-specific knowledge. Domain-specific knowledge include design criteria, engineering methods, procurement process, construction methods and technology, startup sequence, etc.

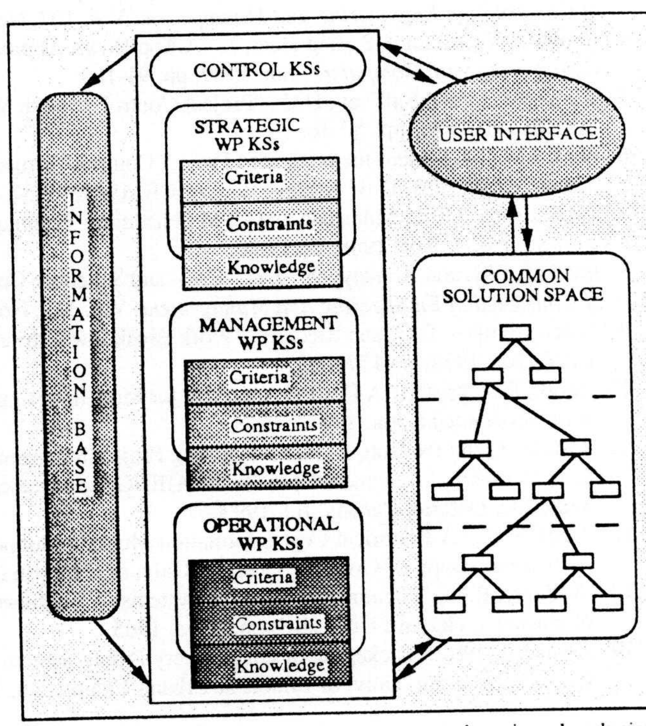
6.2. Dynamic Work Packaging System: A Conceptual Architecture

DYNAPACK, DYNAmic work PACKaging, is a knowledge-based expert system to support automated generation of WBSs. Exhibit 6 depicts the modified SAD diagram showing the dynamic work packaging process and the associated conceptual DYNAPACK blackboard architecture. First, we formulate "constraint" as work packaging criteria, project constraints, and domain knowledge. Secondly, the "mechanism" is built on a set of candidate TAOs associated with the work packaging process. Thirdly, we define the work packaging "input" as the scope of the intended work package, project information, and related historical data and information. Finally, the "output" is defined as a list of TAOs representing actions to finish the intended work package. These TAOs will be sent to the user, so s/he can decide if further elaboration is required.

DYNAPACK is composed of: (1) a hierarchy of knowledge sources representing work packaging criteria, project-specific constraints, and domain-specific knowledge; (2) a set of control knowledge sources representing reasoning strategies, e.g., forward or backward chaining; (3) a layered common solution space or blackboard holding the evolving solution of the work packaging process; (4) an information base containing project information collected form past experience; and (5) a user interface which interacts with the user. The hierarchy of knowledge sources is resulted from the needs to classify work packages into strategic, management, and operational levels for specific organizational, management, and control purposes. Future papers will describe the details of our efforts in these areas.



6.1. The modified SAD diagram for the dynamic work packaging concept.



6.2. The conceptual blackboard architecture to support dynamic work packaging.

Exhibit 6: The concept of dynamic work packaging and its conceptual blackboard architecture.

7. CONCLUSION

As described in this paper, we are developing a common information model called UNIWBS by using the WBS concept. Also, the proposed dynamic work packaging system, DYNAPACK, will be a testbed to support information evolution by providing basic product and process information for specific project planning and control purposes. Currently UNIWBS and DYNAPACK are conceptual. We have initiated a knowledge acquisition research to investigate state-of-art applications of the WBS, identify TAOs in various functions and processes, and acquire work packaging criteria and constraint knowledge. The results of this program will become the basis for both the UNIWBS information modeling, and the formulation of work packaging knowledge sources for the DYNAPACK.

We believe that the success of this research will provide two contributions:

(1) A common information, the UNIWBS, to facilitate project information integration and support project planning and control as well.
(2) A computerized work packaging system, the DYNAPACK, to support automated generation of the WBSs, which will facilitate information evolution.

Together, these systems will support time-dependent or dynamic evolution of work packages.

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