CHAPTER 47

Work Breakdown Structure

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1. INTRODUCTION: DIVISION OF LABOR AND ORGANIZATIONAL STRUCTURES

1.1. Introduction

Division of labor is a management approach based on the breaking up of a process into a series of small tasks so that each task can be assigned to a different worker. Division of labor narrows the scope of work each worker has to learn enabling workers to learn new jobs quickly and providing an environment where each worker can be equipped with special tools and techniques required to do his job.

Some advantages of division of labor and specialization are:

- The fast development of a high degree of skill (specialization)
- The saving of set-up time required to change from one type of work to another
- The use of special-purpose, usually very efficient, machines, tools, and techniques developed for specific tasks.

These benefits do not come for free. Division of labor requires integration of the outputs produced by the different workers into the final product. Thus, some of the efficiency gained by specialization is lost to the additional effort of integration management required.

A common way to achieve integration is by a proper organizational structure, a structure that defines roles and responsibilities of each person as well as the inputs required and the tools and techniques used to produce that person's outputs.

This chapter discusses division of labor in projects. Section 1 deals with different organizational structures. Section 2 focuses on the work breakdown structure (WBS) as a tool that supports division of labor in projects. Section 3 discusses the relationship between the project organizational structure and the WBS, and Section 4 presents types of work breakdown structures along with a discussion on the design of a WBS. Section 5 discusses the building blocks of a WBS, known as work packages, and Section 6 discusses how the WBS should be used and managed in projects. Finally, Sections 7 and 8 present the issues of individual learning and organizational learning in the context of the support a WBS can provide to the learning process.

1.2. Organizational Structures

Organizations are as old as mankind. Survival forced people to organize into families, tribes, and communities to provide for basic needs (security, food, shelter, etc.) that a single person had difficulty providing. Kingdoms and empires of the ancient world emerged as more formal organizations. While these organizations had long-term goals, other organizations were created to achieve specific unique goals within a limited time frame. Some ambitious undertakings that required the coordinated work of many thousands of people, like the construction of the Pyramids, Great Wall of China, or the Jewish Temple, motivated the development of ad hoc organizations.

As organizations grew larger and spread geographically, communication lines and clear definitions of roles became crucial. Formal organizations based on a hierarchical structure were established. The hierarchical structure emerged due to the limited ability of a supervisor to manage too many subordinates. This phenomenon, known as the limited span of control, limits the number of subordinates one can supervise effectively. The role, responsibility, and authority of each person in the organization were defined. A typical example is documented in the Bible where Moses divided the people of Israel into groups of 10 and clustered every 10 of these basic groups into larger groups of 100, and so on. The underlying assumption in this case is that the span of control is 10. Clustering was based on family relationships. Formal authority was defined and lines of communication were established to form a hierarchical organizational structure. The idea of a formal organization, where roles are defined and communication lines are established, is a cornerstone in the modern business world. Division of labor and specialization are basic building blocks in modern organizations. There is a large variety of organizational designs; some are designed to support repetitive (ongoing) operations, while others are designed to support unique one-time efforts. A model known as the organizational structure is frequently used to represent lines of communication, authority, and responsibility in business organizations.

1.3. The Functional Structure

The functional organization is designed to support repetitive activities over a long (indefinite) period of time. It is a hierarchical structure in which roles are based on the function or specialization of the workers involved. Functions like marketing, finance, human resources, engineering, production, and logistics are common. In large organizations, each function is subdivided further, to the point that a proper span of control is achieved. For example, the marketing department can be divided geographically: marketing in Europe, the United States, Asia, and Africa. Engineering departments can be subdivided into electrical engineering, mechanical engineering, and industrial engineering. In a functional organization, the role of each organizational unit is to deal with the work content related to its function. Although fine tuning is required to define the exact border lines and interfaces between the different functions, division of labor is (naturally) along the functional lines.

An advantage of functional organization stems from the pooling together of similar resources: when all the electrical engineers are pooled together into one organizational unit, efficiency and effectiveness are achieved. Furthermore, workers in the same organizational unit (same function) share similar knowledge, education, and experience. They can learn from each other, and the flow of information within organizational units is natural. The stability of this organizational structure promotes career development to the point that people spend their entire career with the same organization moving up the hierarchical ladder while gaining expertise in their profession.

A disadvantage of this structure is its rigidity in dealing with complex tasks where different functions (or disciplines) must collaborate and the difficulty in introducing change. The flow of information between (different functions') organizational units may be difficult, causing difficulty in integration. Furthermore, customers frequently have to interact with several functions—they do not have a single point of contact.

1.4. The Project Structure

The project structure is designed to handle one-time, unique, and nonrecurrent endeavors. It is based on a task force assembled for a limited time to achieve a predefined goal. The members of the project team may come from different organizational units and have different educations and backgrounds. They have a common goal—the project success; and a common leader—the project manager. Organizations dealing with projects may adopt a flexible structure in which only a core group has a permanent structure while most of the organization is assigned to project groups.

An advantage of the project structure is its flexibility; the project team can be assembled exactly according to the task at hand. Another advantage is the creation of a single point of contact for the customer—the project manager has complete responsibility for the project and for customer satisfaction. Teamwork and coordination between people coming from different disciplines is easier to achieve when they belong to the same project, share a common goal, and have the same project manager.

The disadvantages of the project structure are related to its temporary nature—resources are not pooled and thus efficiency and effectiveness are hard to achieve. The limited life of the project's organizational structure creates anxiety and uncertainty about the future role of the team members, mainly at the final stages of the project, and information between project teams is not flowing easily.

A major problem in the project structure is division of labor. Unlike the functional organization, in which division of labor is natural because it is based on the specialization of each function, in a project there is no natural division of labor. It is important to allocate the work among the project participants in a very precise way so that the schedule and budget constraints will not be violated and resources will be efficiently and effectively utilized but not overloaded. Most importantly, it should be possible to integrate the parts of the work performed by different individuals and organizations participating in the project and to produce the deliverables required by the customers.

In the functional organizations where division of labor is based on specialization, each function performs the same set of tasks repeatedly. Due to repetition, learning is built into the process. In a project, division of labor can take many different forms and has to be designed carefully because a project is a one-time effort and improvement by repartition is not built into it.

The work breakdown structure is the tool used to divide the project work content among individuals and organizations so that efficiency and effectiveness will be achieved while ensuring the integration of work efforts to produce the project-required deliverables.

1.5. The Matrix Structure

Organizations involved in ongoing operations and multiple projects simultaneously develop hybrid structures that mix the functional organizational structure with the project structure. Although a large variety of such structures exist, most of these structures are based on a permanent functional skeleton and temporary project structures. Each project has a project manager (or coordinator) that serves as a point of contact for the customers and is responsible for the project success. A team that (typically) combines some members who are employed full time by the project and other members that belong to a functional unit and employed part time on one or more projects is assigned to the projects.

While the tasks assigned to each functional unit are repetitive and can be learned by repetition, the work content of each project must be defined and properly allocated to individuals and organizations participating in the project. The work breakdown structure (WBS) is the tool commonly used to ensure proper division of labor and integration of the project deliverables.

2. HIERARCHIES IN THE PROJECT ENVIRONMENT: THE NEED FOR A WORK BREAKDOWN STRUCTURE

2.1. Introduction

As discussed in Section 1, the natural division of labor that exists in a functional organization is missing in projects. It is important to divide the total scope of the project (all the work that has to be done in the project) among the individuals and organizations that participate in it in a proper way, a way that ensures that all the work that has to be done in the project (the project scope) is allocated to participants in the project while no other work (i.e., work that is not in the project scope) is being done. A framework composed of two hierarchical structures known as the work breakdown structure (WBS) and the organizational breakdown structure (OBS) is used for dividing the project scope amongst the participating individuals and organizations in an efficient and effective way, as discussed next.

2.2. The Scope

In a project context the term scope refers to:

- The product or service scope, defined as the features and functions to be included in the product of service
- The project scope, defined as the work that must be done in order to deliver a product or service with the specified features and functions

The project total scope is the sum of products and services it should provide. The work required to complete this total scope is defined in a document known as the statement of work, or scope of work (SOW). All the work that is required to complete the project should be listed in the SOW along with explanations detailing why the work is needed and how it relates to the total project effort.

An example of a table of contents of a SOW document is given in the Appendix. This example may be too detailed for some (small) projects, while for other (large) projects it may not cover all the necessary details. In any case, a clearly written SOW establishes the foundation for division of labor and integration.

2.3. Implementing Division of Labor in Projects

The SOW is translated into a hierarchical structure called the work breakdown structure (WBS). There are many definitions of a WBS:

1. The Project Management Institute (PMI) defines the WBS as follows: ''A deliverable–oriented grouping of project elements which organizes and defines the total scope of the project. Each descending level represents an increasingly detailed definition of a project component. Project components may be products or services'' (PMI 1996).
2. MIL-STD-881A defines WBS as ''a product-oriented family tree composed of hardware, services and data which result from project engineering efforts during the development and production of a defense material item, and, which completely defines the project, program. A WBS displays and defines the product(s) to be developed or produced and relates the elements of work to be accomplished to each other and to the end product'' (U.S. Department of Defense 1975).

Whatever definition is used, the WBS is a hierarchical structure in which the top level represents the total work content of the project while at the lowest level there are work elements or components. By allocating the lower-level elements to the participating individuals and organization, a clear definition of responsibility is created. The WBS is the tool with which division of labor is defined. It should be comprehensive—that is, cover all the work content of the project and logical—to allow clear allocation of work to the participating individual and organizations as well as integration of the deliverables produced by the participants into the project-required deliverables.

2.4. Coordination and Integration

Division of labor is required whenever the work content of the project exceeds what a single person can complete within the required time frame or when there is no single person who can master all

the knowledge and abilities required for the project. However, the following two reasons that promote division of labor may lead to the failure of the project:

1. Coordination of the work performed by different individuals and organizations is required because outputs (deliverables) of some participants provide inputs to the work of other participants in the project. For example, in a construction project, civil engineers and architects produce the design while construction workers perform construction work. However, without the plans and drawings produced by the design team, construction workers cannot do their work.
2. The ability to integrate the deliverables produced by different participants is crucial. Thus, for example, the fact that in a new car development process one team developed an outstanding new body for the car and another team developed a state-of-the-art engine does not guarantee a project's success. Only a successful integration of the engine with the car that results in a vehicle that satisfies all the requirements and specifications of the project constitutes a success. For example, if the car becomes unstable after engine assembly due to a high center of gravity caused by the location of the assembled engine, the fact that the car body is excellent and the engine performs very well does not make the project a success.

In addition to defining the division of labor in the project, the WBS should support integration and coordination. Properly designed WBS is the tool for division of labor, integration, and coordination.

3. THE RELATIONSHIP BETWEEN THE PROJECT ORGANIZATION AND THE WORK BREAKDOWN STRUCTURE

3.1. Introduction

As explained earlier in this chapter, the WBS is designed to support the division of the project scope (work content) amongst the individuals and organizations participating in the project, which is accomplished by combining the WBS with the project organizational breakdown structure (OBS). The combined framework of OBS and WBS allocates each component of the project scope defined at the lowest WBS level to an organizational unit or a specific individual responsible for it in the OBS. The emerging framework of two hierarchical structures integrated at the lowest level provides an important tool for project-planning execution and control.

3.2. Responsibility

To support division of labor, the WBS should integrate with the organizational breakdown structure (OBS) of the project. The OBS is a hierarchical structure that depicts the relationship among the organizations and individuals participating in the project. At the top level of the OBS is the project manager, and at the bottom are individuals responsible for the accomplishment of specific work content in the WBS. These subprojects allocated to responsible managers are known as work packages. The manager of a work package is an expert in its product scope and project scope. Thus, all the project-management processes at the work package level are the responsibility of the work package manager. These include tasks such as scheduling the activities of the work packages, assigning resources, estimating cost, and monitoring and control. The work package tasks related to the product scope are also the responsibility of the work package manager. These tasks are specific to the work package and may include such activities as design, manufacturing, training, testing, and support.

The assignment of responsibility to the work package managers should be based on a clear definition of the work content of the work package, including:

- Deliverables and the delivery time of each
- Required inputs to the work package (data, output from other work packages, etc.)
- Required resources to perform the work package
- Cost of performing the work package
- Tests and design reviews

When a work package is subcontracted, the definition is part of the contract. However, when the work package is performed internally, it is important to define the content of the work package as well as all other points listed above to avoid misunderstanding and a gap in expectations between the performing organization and the project manager. A special tool called the responsibility assignment matrix (RAM) relates the project organization structure to the WBS to help ensure that each element in the project scope of work is assigned to an individual. As an example, consider a project in which six work packages, A, B, C, D, E, and F, are performed by an organization with three

departments, I, II, and III. Assuming that in addition to the project manager the three department heads, the CEO, and the controller are involved in the project, an example RAM follows:

Work Package Person	A	B	C	D	E	F
CEO	S					
Controller	R	R	R	R	R	R
Project manager	A	S	S	S	S	S
Head Department I	P		I	P	I	A
Head Department II	I	P	A	P	A	
Head Department III	P	A	I	A	P	I

Legend:

- P: Participant
- A: Accountable
- R: Review required
- I: Input required
- S: Sign-off required

3.3. Authority

Along with the responsibility for on-time completion of the content of the work package and performance according to specifications, the work package managers must have proper authority. Authority may be defined as a legal or a rightful power to command or act. A clear definition of authority is important for both project scope and product scope. For example, the work package managers may have the authority to delay noncritical activities within their slack but have no authority to delay critical activities—this is the authority of the project manager only. In a similar way, the work package manager may have the authority to approve changes that do not affect the product form fit or function, while approval of all other changes is by the project manager. The authority of work package managers may differ according to their seniority in the organization, the size of the work package they are responsible for, geographical location and whether they are from the same organization as the project manager. Clear definition of authority must accompany the allocation of work packages in the WBS to individuals and organizations.

3.4. Accountability

Accountability means assuming liability for something either through a contract or by one's position of responsibility. The project manager is accountable for his own performances as well as the performances of other individuals to whom he delegates responsibility and authority over specific work content—the managers of work packages. The integration of the WBS with the OBS through the responsibility assignment matrix (RAM) is a major tool that supports the mapping of responsibility, authority, and accountability in the project.

To make the WBS an effective tool for project management, it should be properly designed and maintained throughout the project life cycle. The project's work content may be presented by different WBS models, and the decision which one to select is an important factor affecting the probability of project success.

4. THE DESIGN OF A WORK BREAKDOWN STRUCTURE AND TYPES OF WORK BREAKDOWN STRUCTURES

4.1. Introduction

The WBS serves as the taxonomy of the project. It enables all the project stakeholders—customers, suppliers, the project team itself, and others—to communicate effectively throughout the life cycle of the project. For each project, one can design the WBS in several different ways, each emphasizing a particular point of view. However, different WBS patterns call for different organizational structures or management practices during the implementation of the project. Thus, the design of the WBS at the early stage of the project life cycle may have a significant impact on the project success. Often the individuals who prepare the WBS are not aware of the crucial role they play in determining future coordination and understanding among the operational units who eventually execute the work

packages. A mismatch among the WBS, the OBS, and the management style of the project manager may lead to a poor project-completion record. Such difficulties are compounded if different parties that are involved in the project have produced different WBSs. In this section, we present alternative WBS patterns and explain their possible impact on OBS and management practices. We use an example project to illustrate different patterns and indicate their strengths and weaknesses. The example project assumes that a large multinational corporation operating in the semiconductor business has just finished evaluating existing and future markets and obtained forecasts on the demand for its products in the next five years. Based on these forecasts, the firm has decided it will need five new plants (also known as FABs) in addition to the nearly dozen it currently operates. Labor availability, wage levels, and tax regulations were chief considerations affecting the decision to construct the plants in three countries.

The various WBS formats shown below can all be useful in describing the expansion project. We denote them as WBS based on technology, life cycle, geography, and so on, according to the focus of the second level in the WBS hierarchy. By choosing the focus of that crucial level, the WBS designer determines the fundamental structure of the project. Still, the designer has to make similar decisions at the third level, fourth level, and so on, but these are secondary choices compared with the second level.

4.2. A WBS Based on Technology

Projects that are characterized by a relatively high degree of specialization, especially those associated with the high-tech sector of the economy, typically require the assignment of a leading professional to lead all the project activities that are related to a particular technology. This professional is expected to maintain the same standards of quality and performance among the different facilities. Thus, this WBS format would fit especially well organizations that are structured in a functional hierarchy (see Section 1.2). This type of WBS will be a favorite for managers preferring strong central control of the project because every activity in the different locations is reported to the headquarters (where the professionals heading the various technologies are based). Figure 1 illustrates a WBS by technology in our case.

4.3. A WBS Based on Project Life Cycle

Organizing the WBS by the various stages of the project life cycle (or, more generally, by time) is not a particularly common practice. Still, it may fit certain organizations that elect to orchestrate their activities by timing. For example, the FABs construction project may be outsourced to a number of subcontractors, starting with a subcontractor in charge of preparing detailed floor plans and construction programs, followed by another contractor charged with all the infrastructure activities, and so on. This will lead to the WBS presented in Figure 2. The work content is first broken by the major stages of the project (from design to delivery). Then each stage is further broken down to its relevant categories. This process is repeated, sometimes to 7–10 levels or even more, until we reach the final level of the work packages.

4.4. A WBS Based on Geography

Breaking the work by geography lends itself quite easily to the assignment of five plant managers, each responsible for the entire work required for establishing his plant. In a way, this amounts to breaking the project into five identical subprojects, each duplicating the activities undertaken by the others. Obviously, this will be the preferred mode when the circumstances (culture, language, type of government, law system, etc.) are dramatically different in the different countries. This type of WBS will fit decentralized management practices in which local plant managers are empowered with full authority (and responsibility) for the activities relating to their respective plants.

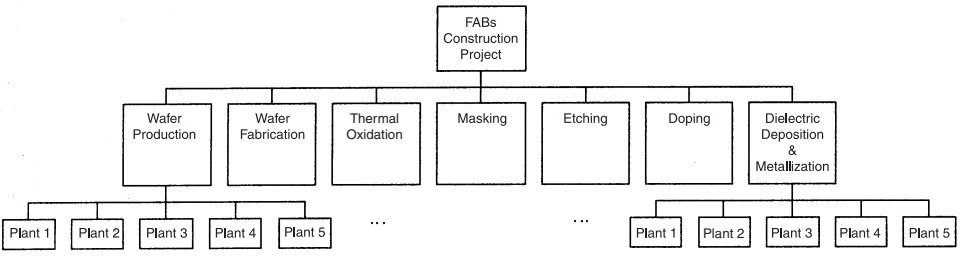

Figure 1 WBS by Technology.

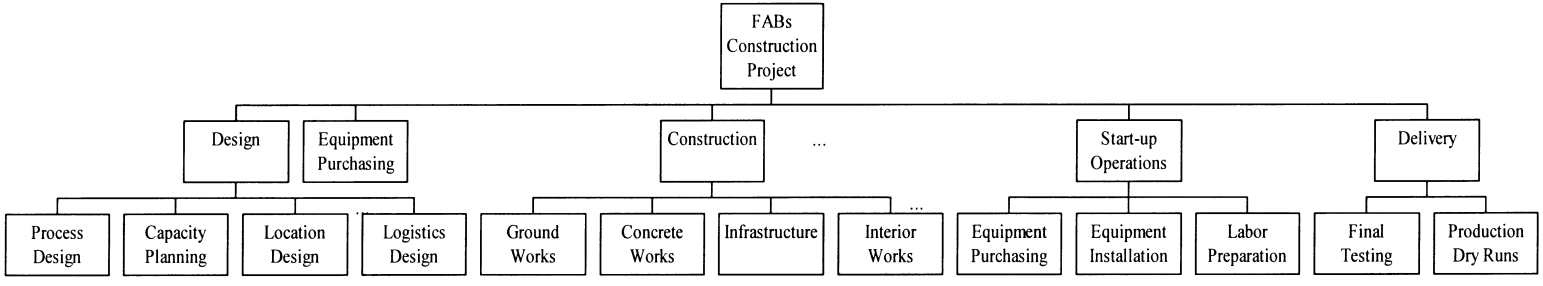

Figure 2 WBS by Project Life Cycle.

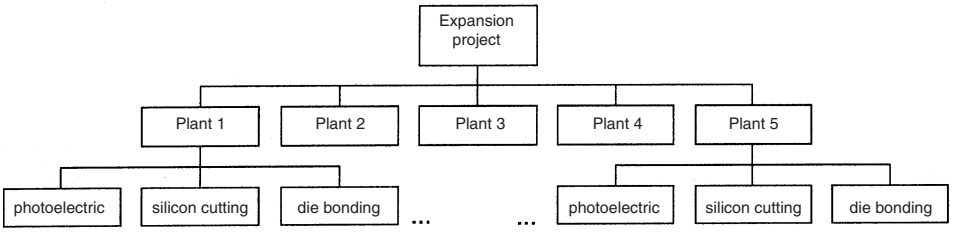

Figure 3 WBS by Geography.

4.5. Other WBS Designs

There are many other possible orientations in which a WBS can be designed. The choice among them depends on the organization charged with the project execution. For example, the growing recognition of the importance of supply chain management has caused some organizations to adopt structures that are logistics oriented. In such cases, we may find at the second level of the WBS a breakdown by logistics functions as illustrated in Figure 4. Other organizations favor structures oriented towards subsystems. That is, the entire system is divided into its major subsystems. In our case, a FAB can be divided into the warehouse subsystem (receiving and checking raw materials, packing and shipping finished goods), shop-floor subsystem (scheduling and dispatching jobs), quality control subsystem (testing components and finished units), and so on. These subsystems serve as the entities in the second level of the WBS.

4.6. Discussion

We conclude this section with a summary of the pros and cons in using a WBS to plan a project.

- *Advantages:*
  - The WBS reflects the project objectives. By listing all the activities required to accomplish these objectives, it prevents confusion and doubts as to the aim of the project.
  - The WBS creates a common database and a dictionary of common notation that serves as a reference point for all involved parties.
  - The WBS, in conjunction with the OBS, defines the way the project is to be managed. It relates each work activity to the corresponding organizational unit that is responsible for delivering the work.
  - The WBS enables smooth communications among the project team members and between them and customers, suppliers, regulators, etc.
  - The WBS serves as an archive that can later facilitate knowledge transfer to other projects or learning by new members of the workforce.
  - The WBS is an effective tool for resource management.
- *Disadvantages:*
  - The WBS requires a significant amount of effort to build and maintain.
  - The WBS encourages rigid structure for the project. Thus, it reduces managerial flexibility to initiate and lead changes during the project life cycle.

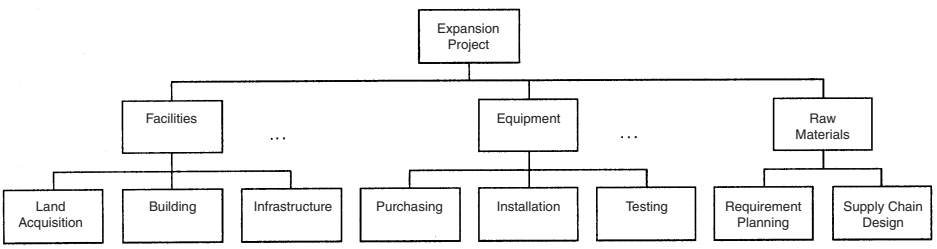

Figure 4 WBS by Logistics.

- There are many legitimate ways to view a project, and occasionally, depending on circumstances, one approach may be preferred to others. Yet the WBS forces the project designer to choose one approach and remain with it throughout the project life cycle.

5. WORK PACKAGES: DEFINITION AND USE

5.1. Introduction

At the lowest levels of the WBS and OBS, integration between the two hierarchical structures takes place. The assignment of specific work content (project scope) to a specific individual or organization creates the building bocks of the project-management framework: the work packages. In the following section, a detailed discussion of the definition and meaning of work packages is presented along with a discussion of the cost accounts that accompany each work package, translating its work content into monetary values for the purpose of budgeting and cost control.

5.2. Definition of Work Packages

The PERT Coordinating Group (1962) defined a work package (WP) as ''The work required to complete a specific job or process, such as a report, a design, a documentation requirement or portion thereof, a piece of hardware, or a service.'' PMI (1996) states: ''[A] work package is a deliverable at the lowest level of the WBS.'' Unfortunately, there is no accepted definition of the WPs nor accepted approach to link them with other related structures (foremost among them the OBS). In most cases, the WPs are defined in an informal, intuitive manner and without proper feedback loops to verify their definition.

One of the difficulties in defining the WPs is the trade-off between the level of detail used to describe the WPs and the managerial workload that is involved. On the one hand, one wishes to provide the project team with an unambiguous description of each work element to avoid unnecessary confusion, overlap, and so on. On the other hand, each WP requires a certain amount of planning, reporting, and control. Hence, as we increase the level of detail, we also increase the overhead in managing the project. To overcome this problem, some organizations set guidelines in terms of person-hours, dollar-value, or elapsed time to assist WBS designers in sizing the WPs. These guidelines are typically set to cover a broad range of activities, and therefore they ignore the specific content of each WP. Hence, they should be applied with care and with appropriate adjustments in places where the work content requires them.

Planning the work by the WPs and structuring it through the WBS is closely related to another important planning activity—costing the project. By dividing the project into small, clearly defined activities—the WPs—we provide a better information basis to estimate the costs involved. For example, consider the activity of design of the FAB processes. It is much easier to estimate its components when they are considered separately (designing the silicon melting and cooling process, silicon cutting, grounding and smoothing, etc.). Furthermore, the separate components may require different cost-estimation procedures or expertise.

Another consideration is related to the statistical nature of the cost-estimation errors. The estimation of the cost for each WP involves a random error that, assuming no particular bias, can be either positive or negative. As the cost estimates are aggregated up the WBS hierarchy, some of these errors cancel each other and the relative size of the aggregated error decreases. This observation holds as long as there is no systematic bias in the estimation procedure. If such a bias exists (e.g., if all the time and cost estimates were inflated to protect against uncertainties), then further decomposition of the WPs may eventually have a negative effect on the overall cost estimate.

In practice, in many scenarios there are limits to the precision that can be achieved in time and cost estimations. Beyond these limits, the errors remain constant (or may even grow). Thus, from the precision perspective, division into smaller WPs should be carried out as long as it improves the estimation accuracy, and not beyond that point.

5.3. Definition of Cost Accounts

Cost accounts are a core instrument used in planning and managing the financial aspects of a project. Three fundamental processes depend on the cost accounts: costing individual activities and aggregating them to the project level for the purpose of preparing project cost estimates; budgeting the project; and controlling the expenses during the project execution.

The first issue, costing the project and its activities, requires the project planner to choose certain costing procedures as well as cost classification techniques. Costing procedures range from the traditional methods to state-of-the-art techniques. For example, absorption cost accounting, a traditional method that is still quite popular, relates all costs to a specific measure (e.g., absorbing all material, equipment, energy, and management cost into the cost of a person-hour) and cost new products or services by that measure. An example of a more advanced cost accounting technique is activity-based costing (ABC), which separately analyzes each activity and measures its contribution to particular products or services.

Cost classification can be done in many ways. Each organization builds its own hierarchy of cost accounts, which is also known as the cost breakdown structure (CBS). In many cases, the CBS is closely linked to the OBS. This means that each organizational unit at the bottom level of the OBS is associated with a cost account. All the expenses planned for the various activities are accounted for through these accounts. Often we find that these cost accounts are further broken down along general accounting principles (e.g., variable vs. fixed costs or manpower, material, equipment, and subcontracting costs). Some organizations prefer to construct the CBS according to the WBS. That is, each WP is associated with a unique cost account. The latter method enables easier control over the individual activities, therefore lending itself more easily to project structure. The former approach might fit better functional structures because it is geared to maintain control over functions rather than activities. It is possible to combine these two approaches by defining the cost accounts at the lowest level of the OBS–WBS level. Then one can aggregate these accounts either by the OBS or by the WBS structures and still obtain consistent estimates at the project-wide level.

Other organizations create the CBS according to the project life cycle. Each of the major life-cycle stages (conceptual design, detailed design, production, operation, divestment) is a major cost account that is further broken down into finer accounts according to secondary criteria (e.g., detailed schedules, functional association). This form of CBS allows the most straightforward control of cost accumulation over time.

The second process, budgeting, uses the cost accounts as a vehicle to generate the project budget. A popular way to generate a budget is through a bottom-up aggregation. The cost accounts associated with individual WPs are aggregated towards a complete budget. Along the way, management may intervene in many ways that may alter the original cost estimates. For example, a ''crashing'' policy may be adopted in order to expedite certain activities as a result of exogenous considerations. This will make the respective budget line larger than the original estimate stated in the cost account. Similarly, a decision to hold certain amounts as ''management reserve'' (a common practice) will also inflate the budget above the original cost accounts. Thus, gaps may exist between the budget and the cost estimate of WPs and the WBS as a whole. However, even with these gaps, the cost accounts are the basis for building and maintaining the budget for every project.

Based on cost estimates, allocated budget, and other considerations (primarily competitive pressure), the pricing of the project is established. The project price may be above or below its cost or its budget, depending on management policies and extraneous constraints.

The third process, financial control of the project, is again based on the cost accounts. The basic control method is an ongoing comparison between actual and planned cost accumulation. Methods such as the earned value technique develop ratio measures that help the controller to analyze the schedule and cost deviations over time and employ control limits as triggers for corrective action. The control is usually performed at the WP cost account level.

6. USING THE WORK BREAKDOWN STRUCTURE: EXAMPLES

6.1. R&D Projects

Managing R&D projects is among the toughest areas in project management. These projects are characterized by a high degree of uncertainty, and consequently a large proportion of them is never completed. The importance of careful planning in this environment cannot be overstated.

The diagram in Figure 5 illustrates a WBS planned for an R&D project aimed at developing a new product. The second level of this WBS is organized by the project life cycle, and the third level corresponds to functional departments that are involved in the project.

6.2. Equipment-Replacement Projects

Every technology-intensive firm is challenged from time to time with equipment-replacement projects. This type of project is especially common in the high-tech sector, where the frequency of such projects is now measured in months rather than years. The WBS presented in Figure 6 focuses at its second level on the division among activities related to the facility and its infrastructure (requiring civil engineering expertise), activities related to the equipment itself (requiring mechanical engineering expertise), and activities related to manpower (requiring human resource expertise).

Unlike the previous example, the third level is not identical across the three entities of the second level. A greater level of detail is needed to describe the equipment-related activities, and so the corresponding WBS branch is more developed.

6.3. Military Projects

To demonstrate the wide-range applicability of the WBS concept, we close this section with an example of a military operation. An army unit (say, a brigade) is faced with a mission to capture a riverbank, construct a bridge, and secure an area (bridgehead) across the river, thus enabling the movement of a larger force in that direction. Figure 7 illustrates how this mission can be planned through WBS principles. The second level of the WBS is arranged by the major military functions

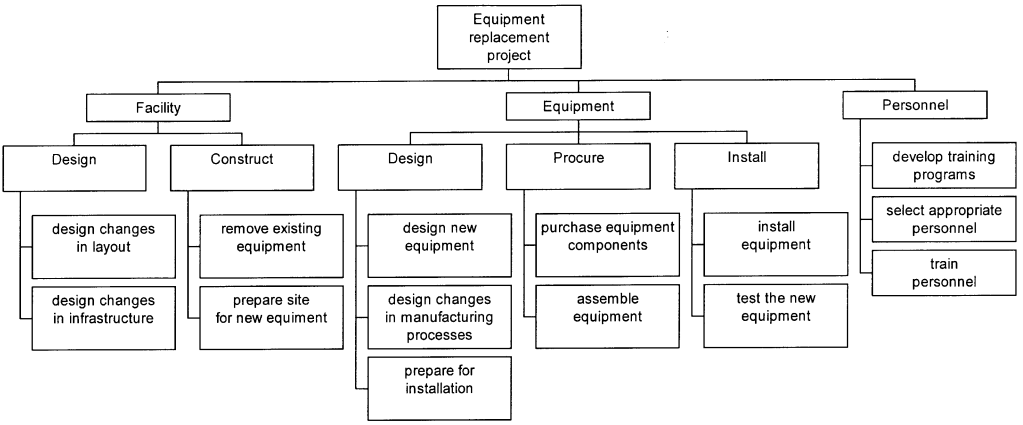

Figure 5 WBS for an R&D Project.

that are involved, and the third level is arranged by the life-cycle (illustrated here with a basic distinction between all precombat activities and during-combat activities).

7. CHANGE CONTROL OF THE WORK BREAKDOWN STRUCTURE

7.1. Introduction

Projects are often done in a dynamic environment in which technology is constantly updated and advanced. In particular, projects in high-tech organizations go through several major changes and many minor changes during their life cycle. For example, the development of a new fighter plane may take over a decade. During this time, the aircraft goes through many changes as the technology that supports it changes rapidly. It is quite common to see tens of thousands of change proposals submitted during such projects with thousands of them being implemented. Without effective control over this process, all such projects are doomed to chaos. Changing elements in the WBS (deleting or adding work packages or changing the contents of work packages) belong to an area known as configuration management (CM). CM defines a set of procedures that help organizations in maintaining information on the functional and physical design characteristics of a system or project and support the control of its related activities. CM procedures are designed to enable keeping track of what has been done in the project until a certain time, what is being done at that time, and what is planned for the future. CM is designed to support management in evaluating proposed technological

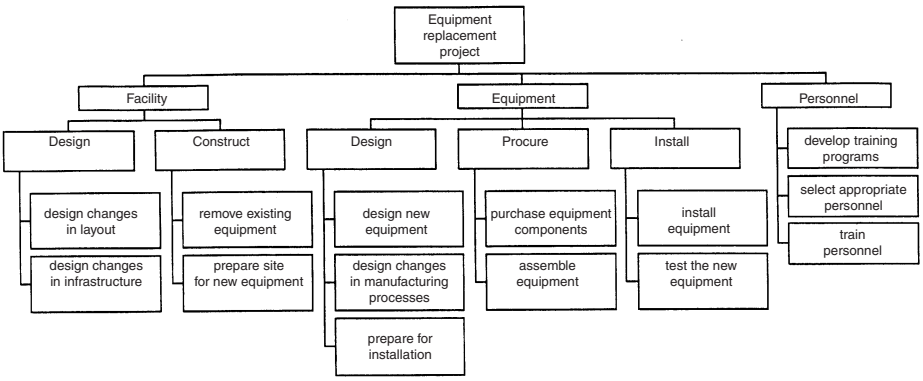

Figure 6 WBS for an Equipment-Replacement Project.

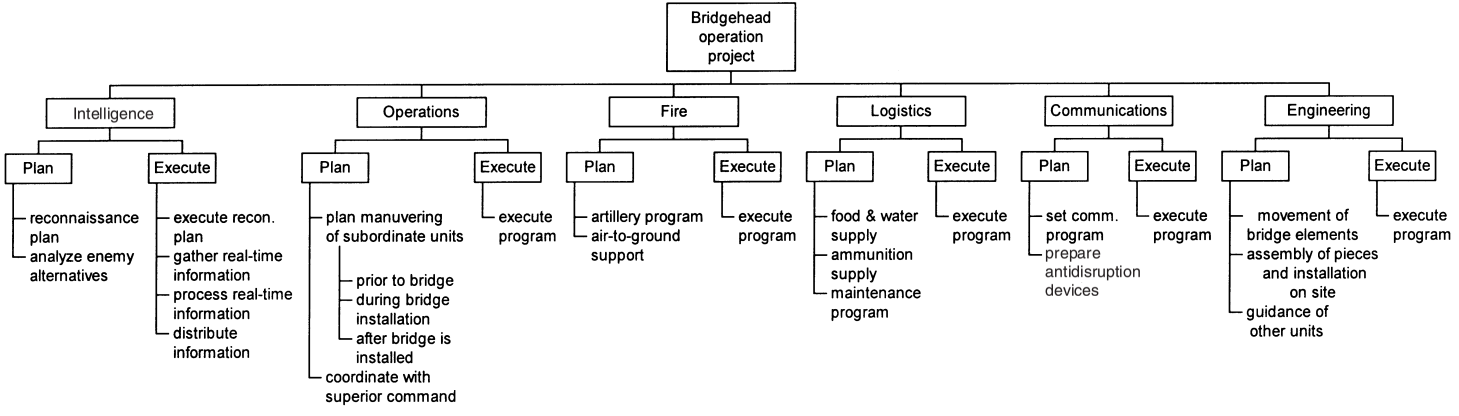

Figure 7 WBS of Military Operation.

changes. It relies on quality assurance techniques to ensure the integrity of the project (or product) and lends itself easily to concurrent engineering, where certain activities are done in parallel to shorten time-to-market and secure smooth transitions among the design, production, and distribution stages in the project life cycle. Change control involves three major procedures, which are outlined below.

7.2. Change Initiation

Changes can be initiated either within the project team or from outside sources. Either way, to keep track of such initiatives and enable organizational learning, a formal procedure of preparing and submitting a change request is necessary. A complete change request should include the following information:

- *Pointers and identifiers:* These will enable the information system to store and retrieve the data in the request. Typical data are request i.d.; date, name or originator; project i.d.; configuration item affected (e.g., work packages i.d., part number i.d.).
- *Description of change:* A technical description (textual, diagrammatic, etc.) that provides full explanation on the content of the proposed change, the motivation for the proposal, the type of change (temporary or permanent), and suggested priority.
- *Effects:* A detailed list of all possible areas that might be affected (cost, schedule, quality, etc.) along with the estimated extent of the effect.

7.3. Change Approval

Change requests are forwarded to a team of experts who are capable of evaluating and prioritizing them. This team, often known as the change control board (CCB), evaluates each proposed change, taking into account its estimated effects on the various dimensions that are involved. Foremost among these criteria are the cost, schedule, and quality (or performance) issues. However, other criteria, such as contractual agreements and environmental (or collateral) effects, are also considered. The review is done both in absolute and relative terms. Thus, a proposed change may be rejected even if it leads to overall improvement in all relevant areas if there are other changes that promise even better effects. If the board approves a change, it needs to specify whether the change is temporary or permanent. Example of temporary changes are construction of a partial pilot product for the purpose of running some tests that were not planned when the project was launched, releasing an early version of a software to a ''beta'' site to gain more insights on its performance, and so on. It can be expected that approval of temporary changes will be obtained more easily and in shorter time spans than the approval of permanent changes.

The CCB is responsible for accumulating and storing all the information on the change requests and the outcomes of the approval process. Maintaining a database that contains all the relevant information on the changes usually facilitates this process. The database should enable easy access to future queries, thus facilitating continuous organizational learning.

7.4. Change Implementation

Changes that were approved, on either a temporary or a permanent basis, are to be integrated into the project. The information on approved changes is usually disseminated to all involved parties through an engineering change order. This form contains all the information that might be required by the various functions (engineering, manufacturing, quality assurance, logistics). Proper change implementation requires the creation of feedback loops that will provide information on the impact of the implemented change. There is a need to verify that this impact is consistent with the estimated effects that were analyzed during the approval stage. These feedback mechanisms alert the system to any departure from the planned effects and help management to identify potential troubles before they actually occur. As before, the information that flows in these loops is recorded in the CM database to support further learning and improvement.

8. THE WORK BREAKDOWN STRUCTURE AND THE LEARNING ORGANIZATION

8.1. Introduction

In addition to supporting division of labor and integration, the WBS–OBS framework is an effective tool for the accumulation, storage, and retrieval of information at the individual and organizational levels. By using templates of work breakdown structures as the project dictionary, it is possible to accumulate information about the actual cost duration and risks of project activities and work packages. This information is the basis for a continuous learning process by which, from one project to the next, a database is developed to support better project planning and management as well as the training of individuals and groups. The next section discusses individual and organizational learning in the project environment.

8.2. WBS as a Dictionary for the Project

The division of labor among the parties participating in a project supports specialization. It is also an answer to the need to finish the project work content within a predetermined schedule, which is not determined by the amount of work to be performed. Due to the division of labor, it is possible to perform each part of the work content of the project by the best experts within the required time frame.

These benefits of the division of labor do not come for free—they carry the risks associated with integration. Integration of information, knowledge, and deliverables produced by the different work packages must be based on a common language to ensure a smooth and fault-free process. This common language is based on the WBS.

A well-planned WBS serves as a dictionary of a project. Because each work package is defined in terms of its work content, its deliverables, its required inputs (data, information, resources, etc.), and its relationship to other work packages within the WBS, all the stakeholders have a common reference or a common baseline. Furthermore, careful management of changes to the WBS throughout the project life cycle provides a continuous update to the project dictionary.

Learning a common language is easier if the same language is used over a long period of time and becomes a standard. Thus, organizations involved in similar projects should strive to develop a WBS template that can serve most of the projects with minor modifications. This is easier if the projects are repetitive and similar to each other. However, if there are major differences among projects, the WBS representing the project scope (as opposed to the product scope) can be standardized if the processes used for project management are standardized in the organization. Thus, by developing a standard set of project-management processes and supporting these standards by appropriate information technology tools, it is possible to standardize the project part of the WBS and make it easier to learn. A standard WBS ensures that project-management knowledge and practices are transferred between projects and become common knowledge in the organization.

8.3. Information Storage and Retrieval

The flow of information within and between projects is a key to the organizational learning process. Information generated in one project can serve other projects either by transferring people between the projects, assuming that these people carry information with them, or by a carefully planned method of information collection, storage, and retrieval. A library-like system is required to support the transfer of information, which is not based on human memory. A coding system that supports an efficient search and retrieval of information or data for the estimation of cost, duration, risks, and so on. is required. In the extreme, such a system can help the planner of a new project to identify parts of historical projects similar to the new project he or she is involved with. Such subprojects that were performed in past projects can serve as building blocks for a new project. A carefully planned WBS is a natural coding system for information collection, storage, and retrieval. Work packages performed on past projects can serve as templates or models for work packages in new projects if the same WBS is used.

Developing WBS templates for the types of projects performed by the organization enables a simple yet effective information storage and retrieval system to be developed. Even if some of the projects are unique, a good coding system based on WBS templates can help in identifying similar parts in projects, such as parts related to the project scope. The ability to retrieve complete work packages and use them as building blocks or parts of work packages and as input data for estimation models enhances the ability of organizations to compete in cost, time, and performance.

8.4. The Learning Organization

The transfer of information within or between projects or the retrieval of information from past projects provides an environment that supports the learning organization. However, in addition to these mechanisms, a system that seeks continuous improvement from project to project is required. This can be done if the life cycle of each project is examined at its final stage and conclusions are drawn regarding the pros and cons of the management tools and practices used. Based on a thorough investigation of each project at its completion, current practices can be modified and improved, new practices can be added, and, most importantly, a new body of knowledge can be created. This body of knowledge can, in turn, serve as a basis for teaching and training new project managers in how to manage a project right.

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ADDITIONAL READING

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APPENDIX
Table of Contents for a SOW document

- Introduction: project scope and general description
- Type of project (development, production, construction, maintenance, etc.)
- A description of final deliverables, intermediate deliverables and delivery schedule
- Main phases in project life cycle: a short description of each phase, its deliverables and its work content
- Applicable documents
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- Technical specifications
- Applicable standards
  - Applicable laws and regulations
  - Applicable procedures
  - Other applicable documents
- Development
  - Conceptual design
  - Functional design
  - Detailed design
  - Prototypes required
  - Deliverables of development phase
- Production and construction
  - Quantities to be delivered and delivery schedule
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- Markings and signs
  - Mechanical markings and signs
  - Electrical markings and signs
  - Other markings and signs
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  - Purchasing in state
  - Purchasing abroad
  - Subcontractors management
  - Suppliers management
  - Purchasing of critical and long-lead items
- Testing
  - Master plan for testing
  - Detailed plans for each test
  - Performance approval testing
  - Functional tests
  - Environmental conditions testing
  - Commercial production testing
  - Acceptance testing at the supplier's site
  - Acceptance testing at the customer's site

- Prototypes
- Reliability and maintainability
  - Anticipated reliability (calculations of MTBF)
  - Fault tree analysis (FTA)
  - Anticipated maintainability (calculations of MTTR)
  - Maintainability analysis and level of repair
- Adaptability
  - Electromagnetic (RFI/EMI) requirements and tests
  - Adaptability requirements to existing hardware and software systems.
- Integrated logistics support (ILS)
  - Engineering support (maintenance plans, maintenance during warranty, engineering support after warranty period)
  - Spare parts (during warranty period, recommended spare parts list, spare parts supply after warranty period)
  - Training (initial training in maintenance and operation, training literature and other aids, training during system life cycle)
  - Documentation: description of documentation to be supplied for training, maintenance, operation, and logistic support.
  - Project documentation: design reviews test documents, etc.
  - Data and its storage: means for data storage and retrieval during and after the project
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  - Packaging and shipment
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  - Packaging and shipping requirements
  - Permissions, export and import licensing
  - Constraints in the installation site
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  - Logistical, technical, and operational responsibility for installation
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  - Maintenance during installation and commissioning
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  - Quality procedures
  - Quality and reliability analysis
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  - Quality control and reviews
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  - Technical specifications
  - Engineering reports
  - Testing procedures
  - Test results
  - Product documentation
  - Production documentation
  - Drawings
  - Definition of interfaces
  - Operation, maintenance, and installation instructions
  - Software documentation (in the software itself and in its accompanying documents)
- Warranty
- Customer-furnished equipment