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Project Management

Work Breakdown Structure Information

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In depth:

Advocating a deliverable-oriented work breakdown structure

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It is generally recognized by project management professionals that the work breakdown structure (WBS) is the foundation of planning, estimating, scheduling, and monitoring activities. Although the lower-level elements of a WBS need to be schedule-oriented, the upper levels can (and should) be deliverable-oriented. The upper levels of a WBS are often either resource-oriented or schedule-oriented, primarily because they are somewhat more convenient to create. Schedule- or resource-oriented structures are not as efficient in project monitoring, evaluation, and plan modification, when compared to work breakdown structures that are created with a deliverable structure in mind. The rationale and methods for modifying the traditional breakdown structure philosophy are presented in order to obtain a WBS that is focused on deliverables. A deliverable-oriented structure has the added advantage of providing project historical information that can be useful when planning future projects. Word count: 4252

ABSTRACT:

It is generally recognized by project management professionals that the work breakdown structure (WBS) is the foundation of planning, estimating, scheduling, and monitoring activities. Although the lower-level elements of a WBS need to be schedule-oriented, the upper levels can (and should) be deliverable-oriented. The upper levels of a WBS are often either resource-oriented or schedule-oriented, primarily because they are somewhat more convenient to create. Although it is more difficult and somewhat unfamiliar to develop a deliverable-oriented WBS that contains deliverables at the top levels, schedule- or resource-oriented structures are not as efficient in project monitoring, evaluation, and plan modification when compared to work breakdown structures that are created with a deliverable structure in mind. This article presents the rationale and methods for modifying the traditional breakdown structure philosophy in order to obtain a WBS that is focused on deliverables. A deliverable-oriented structure has the added advantage of providing project historical information that can be useful when planning future projects.

Key Words: work breakdown structure, deliverables, project management, organizational breakdown structure, resource breakdown structure.

It is generally recognized by project management professionals that the work breakdown structure (WBS) is the foundation of planning, estimating, scheduling, and monitoring activities. This article presents the rationale and methods for modifying the traditional breakdown structure philosophy in order to obtain a WBS that is focused on deliverables. A deliverable-oriented structure has the added advantage of providing project historical information that can be useful when planning future projects.

Before discussing the work breakdown structure (WBS), I want to provide the proper perspective for project structures. There are three separate structures that need to be created, defined, or modified for a project: the organizational breakdown structure, the resource breakdown structure, and the work breakdown structure.

The organizational breakdown structure (OBS) is the most readily available structure. Since companies frequently go through large organizational changes, care must be taken to use the most recent data and to make updates as changes continue to occur within the organization. For a project management system, the normal organizational chart must be augmented by unwritten responsibilities and by any “dotted-line” relationships that affect the execution of the project.

The resource breakdown structure (RBS) is a logical and useful classification of the resources needed to accomplish a project’s objectives. Rather than developing a new RBS for each project, it is more efficient to develop an RBS for a large group of projects. As each new project is planned, only those portions of the common RBS that apply to this project are selected and used. A project RBS is different from all other human resource or budgeting classification methods in that it reflects applicability to project management, as compared to cost accounting or personnel evaluations. An RBS is essentially a catalog of all of the resources available to a project.

The most difficult to define, and yet the most useful of these three project structures, is the work breakdown structure. The information for a WBS is drawn primarily from the project objectives statement, historical files of past projects,

project performance reports, or from any other files containing the original and final objectives of previous projects. Instead of developing a WBS for each project, sometimes it is appropriate to develop a general WBS for a group of projects; for each project, only the appropriate segments need to be selected and modified. This practice is appropriate in organizations that conduct projects that are similar.

THE WORK BREAKDOWN STRUCTURE

A work breakdown structure provides a framework of common reference for all project elements, for specific tasks within the project, and ultimately for better schedules and better estimates. A WBS facilitates the process of integrating project plans for time, resources, and quality. A good work breakdown structure encourages a systematic planning process, reduces the possibility of omitting key project elements, and simplifies the project by dividing it into manageable units. If the WBS is used as the common skeleton for the schedule and for the estimate, it will facilitate communication among the professionals working on the project.

A WBS is, or should be, a uniform, consistent, and logical method for dividing a project into small, manageable components for planning, estimating, and monitoring. A deliverable-oriented WBS facilitates and encourages the sharing of information. Ideally, there should be some uniformity and consistency in the WBS. In order to achieve uniformity, “all children of the same parent” must be developed based on the same basis. The ultimate goal is to achieve a WBS that highlights a logical organization of products, parts, and modules.

A WBS will provide a road map for planning, monitoring, and managing all facets of a project, including the following:

- definition of work;
- cost estimates;
- budgeting;
- time estimates;
- scheduling;
- resource allocation;
- expenditures;
- changes to the project plan;
- productivity; and
- performance.

As the project is conceived, defined, and fully developed, not only can summaries for the WBS be created for one project, but departmental and divisional summaries can be made for each WBS item. These summaries use the relationship between the RBS and the WBS, and can be quite useful for resource forecasting, personnel projections, priority definitions, and for general management purposes.

WBS DEVELOPMENT STEPS

Simply stated, the development of a WBS involves grouping all project elements into several (between 3 and 9) categories, which are normally referred to as level one. Each of the level-one items are then divided into 3 to 9 level-two items, each of the level-two items are divided into 3 to 9 level-three items, and so on. It is crucial that, at each juncture, the basis of division is the same.

Ideally, a reasonable consistency in the degree of detail at the lowest-level elements should be maintained. Not all branches need to go to the same level, but the significance of all of the lowest-level items in the overall project should be similar. Therefore, depending on the nature of the project, some branches may go to level two, some to level three, and others to level five.

This process of dividing the deliverable items is continued until the project has been divided into manageable, discrete, and identifiable items that require simple tasks to complete. A rule-of-thumb is to keep dividing the project until the elements realistically cannot be divided any more. This point may vary from company to company and may vary among project managers within the same company. The contents of each level of detail are not only company-specific; they are also specific to the nature of deliverables involved in each project. The degree of detail must be in line with the size of the project and conform to the company’s operational philosophies.

THE DIVISION BASES

To put things in the proper perspective, the transition from each level of WBS to the next may be on any one of the following bases:

- deliverable-oriented;
- product;
- functional system;
- physical area;
- schedule-oriented;
- task or activity;
- sequential;
- resource-oriented;
- discipline;
- administrative unit; and
- budget account.

It must be noted that there is some overlap in definition and use between the subgroup items of these eight bases, i.e., between product, functional system, and physical location. It is possible that someone would divide the project on the basis of product, and depending on the nature of the project, someone else might view the division as having been made on the basis of physical location.

The product basis refers to cases where the project is divided into distinct components that ultimately comprise the entire project, such as hardware, software, physical structure, south wall, north wall, concrete foundation, or steel roof. The functional basis refers to the functional systems that provide a facet of the infrastructure for the project deliverable. Functional systems are usually interwoven into the product. Examples of functional systems include the electrical system, mechanical system, or the skeleton of a building. The physical-area basis highlights the geographical or physical locations of the deliverable (e.g.,the south side, north side, top floor, or entrance). It is an important point that the most useful, and admittedly the most difficult, procedure for developing a WBS is to use deliverables as the basis of breakdown.

Task or activity basis refers to things that project team members do toward the goals of the project, such as excavating, pouring, forming, polishing, programming, or testing. Sequential basis reflects the order in which activities are performed, such as phase 1, phase 11, and phase 111. The sequence is often dictated by administrative constraints and is somewhat arbitrary. Use of these two bases is akin to importing the project schedule into the WBS. It is my contention that the WBS should be used to develop the schedule, and not the other way around.

The discipline basis follows job classification, degree classification, or employee skill. Examples of discipline basis are chemists, programmers, test technicians, or engineers. The administrative unit basis is an infusion of the OBS elements into the WBS and indicates the administrative or organizational division lines. Examples of administrative-unit-basis items are work performed by employees of division A, division B, or the contract office. The budget account basis is an infusion of the RBS into the WBS and follows the organization's financial structure: activities paid by federal funds, state funds, charge account A, or fiscal account B. It is my contention that the WBS should be used to develop the costs and resource assignments, and that funding procedures should not influence the nature of the project.

Sample

A comparison between the deliverable-oriented basis and the schedule-oriented basis is given below. There is no question that the lowest level of a fully-developed WBS will be comprised of activities. However, it would be more useful if the deliverable-oriented bases were used for the majority of the upper portion of the structure.

Listed below is an example of a WBS for an industrial complex. For illustration, the division of elements at different junctures has been performed using different bases. It is an important point that if this project were to be implemented, a new all-deliverable WBS can and should be developed:

- power house;
- steam generation system;
- electrical generation system;

- electrical transmission system;
- factory;
- receiving equipment;
- processing equipment;
- packaging equipment;
- shipping equipment;
- office;
- first floor;
- second floor;
- penthouse;
- grounds;
- phase one, bushes and trees;
- phase two, seeding for lawn;
- phase three, walkways; and
- phase four, poking-lot.

In this example, the breakdown basis for level one is physical location. The breakdown basis for the powerhouse is the functional system. The breakdown basis for the factory can be viewed as product, physical location, or functional system. The breakdown basis for the office element is physical location; the breakdown basis for the grounds is sequential.

A COMPARISON OF THE DIFFERENT BASES

The most common and easiest method of developing a WBS is to use either the task, activity, or phase as the basis. The vast majority of the elements in most work breakdown structures fit this pattern. It has been my observation that project professionals who have a scheduling background tend to use this basis as the breakdown basis. It is fair to say that the transition from an activity-oriented WBS to a deliverable-oriented WBS is difficult for those who have developed task-oriented work breakdown structures for a significant amount of time.

One stated advantage of the schedule-oriented elements is that the resulting WBS can be used for many projects. Although this can be an advantage because the WBS is generic and not specific enough, the same feature also can be a disadvantage by not addressing the definitive features of the project in a clear fashion.

Another aspect of schedule-oriented work breakdown structures that has been perceived as an advantage is that a WBS is applicable when the project is not fully defined. Unfortunately, this advantage becomes a disadvantage when the project is fully specified but the estimating and scheduling of the project still depend on bundled estimates for design or testing.

Since projects ultimately are carried out when people do things such as develop, draw, print, fix, or fabricate, the elements at the lowest level always will be activity-based. However, using the deliverable methodology, the basis of division will change from deliverable-oriented to schedule-oriented, as low in the WBS as possible.

The second most common basis used to develop a WBS is the administrative basis. Project professionals who have a financial or administrative background tend to use disciplines, administrative units, or budget accounts as the basis of a WBS breakdown. Although this makes tracking funds very simple and straightforward, it may not help the project management objectives. The bases included in the third group should be used as little as possible, because they do not refer to the work but rather to the means by which the work is conducted and paid for.

I believe that the most preferable bases are deliverable-oriented bases, which are the first three items on the list. It is very important to make sure that the elements on the first several levels of the WBS, and certainly those on level one, are deliverable-oriented and not schedule- or resource-oriented. That is not to say that activities and costs are not important. On the contrary, when using a deliverable-oriented WBS that includes activities at the lowest levels, an analysis of the project's schedule and financing will be more meaningful.

For example, if the testing tasks are late, it would be possible to determine that complexity of testing item BB has delayed the overall testing results. Similarly, if the costs are significantly below budget, it would be possible to determine that an unexpected reduction in component costs for item CC has caused this unexpected and pleasant event.

By using a properly developed and fully utilized WBS, RBS, and OBS, you can develop summaries across the WBS and RBS lines, such as those listed below.

- What is the total number of work hours needed for module A?
- What is the total number of work hours of chemists needed for module A?
- How many programmers do we need to assign to this project during July?
- How much would the demand for client-side programmers be reduced next July if we postpone module B by three months?
- How many engineers would we need for module C during July?
- How many more analysts would we need next February if we double the scope of module D?
- What would happen to the project cost, project schedule, and resource requirements if the scope for module G were doubled?
- If module F were to be delayed by six months, what would the resulting cost and schedule look like?

SEMANTICS

Sometimes, simply using vague terms or words with multiple meanings as WBS titles can cause confusion and misunderstandings in the interpretation and planning of WBS items. For example, if a WBS item is labeled as procurement, it could refer to the people who buy things, to the department that employs them, or to the process of buying things. Similarly, if a WBS item is labeled as mechanical, it could refer to the mechanical engineering design process, to the mechanical portion of the deliverables, to the mechanical engineers, or to the department that employs them. If a WBS item is labeled as system, it could refer to the system that is delivered to the client, to the software portion of the system, to the people who write the software, to the department that employs them, or to the process of writing software.

Admittedly, the probability of confusion and misunderstanding is minimized if these words are interpreted within the appropriate context. However, it is incumbent upon a project planner to make every effort to eliminate all potential causes of confusion from the project plans.

As an illustration, consider a project that is described by the following WBS components: procurement, systems, civil, mechanical, and legal. These elements could be interpreted as uniformly referring to disciplines, administrative units, activities, or non-uniformly referring to a collage of the above.

If there is a possibility of ambiguity, in naming the WBS elements, one should use qualifiers such as mechanical engineering department, civil engineers, procurement phase II, software module, mechanical drawings, or contract documents. Using these qualifiers makes sure that there is virtually no chance that someone would misinterpret the meaning of the item labels.

CHANGING THE PARADIGM

Sometimes, it is possible to change a WBS from schedule-oriented to deliverable-oriented by modifying some elements and changing the wording of some of the elements. However, the transition from a schedule-oriented WBS to a deliverable-oriented WBS is not made by simply using non-action words, but involves looking at the project from the client's standpoint. Thus, the WBS should include the elements the client is interested in receiving and will pay for; consequently, as the client changes the scope and schedule constraint of various modules, it would be very easy to determine and justify the effect of such changes on the project's cost and schedule.

Therefore, as the WBS is developed, project management professionals should be careful not to infuse details of how the work will be delivered into the description of the deliverable itself. One way to achieve this is to develop a resource breakdown structure and an organizational breakdown structure before starting to divide the project objectives.

The transition from a schedule-oriented WBS (or from a resource-oriented WBS) to a deliverable-oriented WBS should be a reflection of the objectives, scope, and specifications of the project. In cases where the objectives are not fully developed at the time of WBS development, one can develop only the first two or three levels. Later, as more project information becomes available, the WBS can be expanded and refined.

Conceptually, the process of developing a deliverable-oriented WBS is relatively simple: divide the project into components that when recombined would produce the final project deliverable. Ideally you would avoid listing activities and

tasks until the last one or two levels of the WBS. The emphasis would be on describing the components that produce the project, the modules that produce the component, the units that produce the module, etc. Avoid listing the personnel responsible for delivery of reports, evaluations, or products. Such resource assignments can be created easily and systematically once the WBS and RBS are established (hopefully, independent of each other).

Following is the first level of a WBS that was developed using the traditional schedule-oriented mind-set:

- level one;
- conceptual design;
- evaluation and approvals;
- design;
- installation and check-out;
- removal of old equipment; and
- project close-out.

To illustrate this example further, the level-two breakdown for the design branch is shown here:

- level two, design;
- system requirements;
- functional analysis;
- detailed design;
- resource requirements; and
- procurement specifications.

Because schedule-oriented work breakdown structures tend to be entirely activity-based, it is very difficult (if not impossible) to discern what the objective of the project is and what its deliverables are. Although not clearly identified in the WBS, the objective of this project is to deliver the following:

- two new emission stacks;
- a new emissions monitoring system; and
- an emergency power building.

By contrast, a deliverable-based WBS would be constructed along the lines of the following:

- level one;
- design documents;
- building structure;
- emergency generator system;
- stack monitors; and
- stacks.

This WBS clearly describes what the client should expect from the project manager or the contractor when the project is finished. Accordingly, tracking the project's progress would be relatively simple by noting the progress of the delivery of the project's components.

To illustrate this WBS further, the level-two items are given below:

- level two, design documents;
- conceptual documents;
- detailed design documents;
- level two, building structure;
- excavation cavity;
- poured-concrete substructures;
- precast-concrete elements;
- roof trusses;
- utilities;
- level two, generator;
- generator A;
- generator B;
- test equipment;
- level two, stack monitors;

- monitor for stack A;
- monitor for stack B;
- level two, stacks;
- standard footing;
- anchored footing;
- stack structure;
- exhaust fans;
- ducts; and
- heat removal system.

Depending on the size of the project and the traditions of this particular environment, the next level of activities might be schedule-oriented.

This example shows that with a deliverable-oriented WBS, you can easily and clearly follow the progress of the project components and get a clear idea of the project objectives and what is involved in achieving those objectives. A deliverable-oriented WBS is easier to schedule, estimate, and monitor because planning a project with a deliverable-oriented WBS is conducted by planning specific items that make up the project and is not based on planning generic activities involved in delivering them in a bundled fashion. When the time comes to make the inevitable changes to the project plan, they can be made more accurately and logically because changes are implemented only on those items that were affected by the change.

Successful project management depends on a well-defined and fully implemented organizational breakdown structure, resource breakdown structure, and work breakdown structure. With such planning tools, success depends on clear planning, accurate reporting, and regular updating. Deliverable-oriented elements can be developed for the top levels of the WBS for most projects. Using a deliverable-oriented WBS enhances the likelihood of success. This methodical approach may initially require some extra effort for those who have used schedule-oriented work breakdown structures in the past, but once this process becomes second nature, deliverable-oriented work breakdown structures can be developed easily.

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Work and Resource Breakdown Structures for Formalized Bottom-Up Estimating

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This article introduces the concept of a resource breakdown structure (RBS). Analogous to the traditional work breakdown structure, the RBS lists in a methodical fashion the resources with their specific cost rates that are available for the projects contemplated within an organization. Because proper use of the RBS requires precision and standardization in terms of units and dimensions, we review the basic nomenclature and present an example. When combined with a deliverable-oriented WBS, an up-to-date RBS greatly facilitates both initial project planning and the inevitable iterations on the original plans. In particular, the RBS enables simple, but accurate, calculations of the project's costs at the various levels of the WRS and as a function of essentially any variable that the project manager desires. It is a simple but valuable tool. [PUBLICATION ABSTRACT] Word count: 5723.

ABSTRACT

This article introduces the concept of a resource breakdown structure (RBS). Analogous to the traditional work breakdown structure, the RBS lists in a methodical fashion the resources with their specific cost rates that are available for the projects contemplated within an organization. Because proper use of the RBS requires precision and standardization in terms of units and dimensions, we review the basic nomenclature and present an example. When combined with a deliverable-oriented WBS, an up-to-date RBS greatly facilitates both initial project planning and the inevitable iterations on the original plans. In particular, the RBS enables simple, but accurate, calculations of the project's costs at the various levels of the WBS and as a function of essentially any variable that the project manager desires. It is a simple but valuable tool.

Key Words: work breakdown structure (WBS), resource breakdown structure, and estimating.

BREAKDOWN STRUCTURES

This article is not so much a research article as a practice article. That is, based on a combination of practical experience and academic study, the authors recommend a best practice: the creation and use of a resource breakdown structure. The authors know of few organizations that follow this method, but in those that do, even to a limited extent, project managers can plan with greater assurance of resource reliability. By reliability we mean that the project manager can depend on the reality of the existence of a resource at-hand and its estimated cost.

This practice falls at the interface between general management and project management. The project manager will use the RBS prepared previously by those charged with accounting for the organization's resources. To use it well, the RBS must be kept up to date. Its resource contents and their costs must be accurate. As is explained in the remainder of this article, the KBS has its analog in the well-known work breakdown structure.

Managers have a long history of dividing anticipated project work into smaller and smaller parcels and presenting the resulting schema graphically. This "breaking down" of the work facilitates better management in many ways. Similarly, in-house resources should be examined in a methodical manner, at the earliest opportunity, through the creation of the RBS. This structure will greatly facilitate the resource assignments and scheduling in projects that follow.

At some point early in the planning stage, the project manager should be provided with a detailed listing of the resources available for the project, including whatever project-specific resources the manager might obtain from outside the organization. The term "resources" is used to mean everything that will cost money to obtain and is necessary for the completion of the project, (e.g., labor, equipment, licenses, taxes, and so forth).

If this initial resource estimate is prepared correctly, the cost of each component can be easily understood. Equally important, the continual improvements that this estimate must undergo can proceed formally. The estimate will be easy to review and improve as more information becomes available. Then, as the almost inevitable changes of scope occur, further modifications to the estimate can be made formally and clearly. They can be justified and defended.

NOMENCLATURE, DIMENSIONS, AND UNITS

To maintain a consistent nomenclature (and at the risk of being considered pedantic), let's pause briefly here to review the relevant concepts. The word "rate" carries its usual meaning of some quantity measured per unit time, e.g., a worker's cost rate could be measured in dollars per hour.

If there is a need to discuss the expense of singular items, (e.g., cans of paint), the cost is not a rate but simply so many dollars per can; the unit may be called “each.”

“Effort” equals the product of workers and time, measured in worker-hours, worker-days, worker-months, or worker-years. At any given point in the project, the effort divided by the appropriate unit of time gives the number of workers, e.g., if a project requires an effort of 100 worker-years, completion over a year’s duration would require 100 workers, but to be completed in six months (i.e., 0.5 years) 200 workers would be needed. This “instantaneous” worker need is implied when a project task’s “intensity” is discussed.

Because workers are paid, effort can be viewed as equivalent to cost. Units must be retained in such arithmetic, whether explicitly or implicitly, so the translation from effort to cost occurs through the cost rate per worker, (e.g., worker-hours times dollars per hour per worker yields dollars).

One makes “estimates” through this conversion, that is, if in shorthand notation one speaks of estimating an clement of the WBS, ultimately the cost is desired, but in the first, sometimes hidden (or skipped) step, one must estimate the effort.

Clarity is needed about the terminology because this article explains how to use the RBS in conjunction with the work breakdown structure to determine the total project cost by estimating the costs of all elements at the lowest levels of the WBS; the work follows. To begin, a proper work breakdown structure is described in detail.

WORK BREAKDOWN STRUCTURE

A good WBS simplifies the project by dividing the effort into manageable pieces. It encourages systematic planning and reduces the possibility of omitting key project elements. A good WBS provides a common framework for all project deliverables and for specific tasks within the project. It therefore smoothes communication among those implementing the project, which in turn improves the integration of project plans for time, resources, and quality; a good WBS ultimately produces better schedules and better cost estimates. In short, a good WBS anchors a project’s plans and improves planning, estimating, monitoring, and controlling.

The WBS provides a roadmap for all facets of the project, including the following:

- work definition;
- cost estimates and expenditures;
- time estimates and scheduling;
- resource allocation and budgeting;
- project plan changes; and
- performance and productivity.

To achieve the desired consistency in the WBS, in any branch of the hierarchy, lie transition from one level to the next level must follow similar criteria. That is, the characteristics that differentiate “parents” at one level from their “children” at the next lower level should be similar – if not identical – throughout the structure. Ultimately one wishes to create a WBS that highlights a logical organization of products, parts, or modules (or whatever the various project components are termed at the different levels) associated with each element of the WISS.

As project plans develop, not only can whole WBS summaries of resources be created, but departmental and divisional summaries can also be made for each WBS item. These summaries use the relationship between the RBS and the WBS to make resource use explicit (what, where, and in what quantity), and so can improve resource forecasting, personnel projections, priority definitions, and good management in general.

WBS DEVELOPMENT

The entire project sits at the top level of the WBS, which is referred to as level zero. Developing a WBS involves subdividing the project into three to nine deliverable elements at the next level, level one (the basis of the division is addressed below). Then each of the level one items will be divided into three to nine level two items, and each of the level two items will be divided into three to nine level three items, and so on. The WBS should emphasize real deliverables – e.g., “approval” requires a signature on a deliverable piece of paper – and as noted previously, at each juncture the basis of the division should be similar, if not identical, for all children at a given level.

This process of dividing the deliverable items continues until the planners have divided the project into discrete, manageable items that require relatively simple tasks to complete. This point may vary from company to company and among project managers within the same company.

The company's operational philosophy and the size of the project also influence the degree of detail in the WBS, but the specific contents at each level are determined by the nature of the deliverables involved. Ideally, one would maintain a reasonable consistency in the details at the lowest-level elements. Not all branches need go to the same level, but the lowest-level items in the project should possess similar significance. Therefore, depending on the type of project, some branches may go to level two, some to level three, and some to level five or greater.

DIVISION BASES

Any given project can be subdivided from various perspectives that often reflect the different mind-sets of different managers. For example, the transition from each level in a WBS to the next level may be oriented around schedules or resources, but the most useful (and admittedly the most difficult) WBS will use deliverables as the breakdown basis. Nevertheless, in the interest of completeness, in the list below two other techniques are outlined.

- Deliverable Basis - Product, functional system, physical area;
- Schedule Basis -Task or activity, sequential;
- Resource Basis - Discipline, administrative unit, budget account.

The so-called product basis refers to those cases where the project is divided into distinct components that ultimately come together to create the project, such as hardware, software, a physical structure, a concrete foundation, a steel roof.

A functional basis references the functional systems that are usually interwoven through the product and provide the infrastructure for the project deliverable. Examples of functional systems include the electrical system, the mechanical system, or the skeleton of a building.

The physical-area basis highlights the geographical or physical locations of the deliverable, (e.g., south side, north side, top floor, or entrance).

A task or activity basis refers to actions taken by project team members in executing the project, such as coding, excavating, pouring, forming, polishing, programming, testing, and so forth. A sequential basis reflects the order in which activities are performed, such as Phase I, Phase II, and Phase III. The sequence is often dictated by administrative constraints and can be arbitrary. Using these two latter bases is akin to importing the project schedule into the WBS. Managers should not use the schedule to develop the WBS, but instead should use the WBS to develop the schedule.

A discipline basis follows job classification, degree classification, or classifications of the skills of employees. Examples of personnel subdivided on a discipline basis are chemists, programmers, test technicians, engineers, and so forth.

An administrative-unit basis puts organizational elements into the WBS and indicates the administrative or organizational division lines. Examples of administrative-unit basis items are work done by employees of division A, division B, or the contract office.

The budget-account basis infuses the RBS into the WBS and follows the organization's financial structure, with items such as activities paid by US federal funds, state funds, charge account A, or fiscal account B. Again, the authors contend that funding procedures should not influence the fundamental nature of project plans, and the WBS should be used to develop the costs and resource assignments, not the other way around.

These orientations can certainly overlap in definition and usage. One person might divide a project on the basis of product, and depending on the type of project, another might view the division as having occurred on the basis of physical location. For example, a given wall inside some physical structure might be viewed as being at a particular place (location) or fulfilling a deliverable requirement (a product). Despite this different perspective, a deliverable basis presents much less opportunity for confusion because all understand the actual object being considered: in this case, a wall.

This common understanding also encourages communication and forecasting in canned-value types of calculations. Consider the following hypothetical example. Tasks A1 (a subset of deliverable A1) have just been completed in 109 percent of their estimated time, using 82 percent of their estimated resources. The essentially identical tasks A2 are scheduled for later in the project. Assume that learning and experience curves do not apply and that cost expenditures vary uniformly and linearly with progress. The estimate for A2 must be modified to reflect an 18-percent decrease in resource use with a 9-percent increase in time, that combine to change (presumably) the cost estimate in some way. This calculation rests on the clear identification of the tasks as "essentially identical," with similar elemental representations on a consistent, well-defined WBS. With a deliverable basis, the tasks are tied to a particular object, allowing much less variation than when assigned independently of that object.

FINALLY, CONSIDER A POSSIBLE RESOURCE-RELATED CORRECTION TO THE WBS.

As a base of reference for scheduling the project, the duration of any element is the longest duration of the resources required for it. If some of the resources for a WBS element need to be applied serially, then it is generally more advisable to divide this element into several serial elements. The rule here is, then, that within a given element, resources may be used in parallel, but not serially.

RESOURCE BREAKDOWN STRUCTURE

An RBS classifies and catalogs the resources needed to accomplish project objectives. As the work breakdown structure does for the deliverable elements of a project, the resource breakdown structure provides a consistent framework for dividing the resources into small units for planning, estimating, and managing. Therefore, in many ways, the RBS is analogous to the WBS and claims similar advantages in improving communication, integration, planning, and estimating; monitoring and controlling will be addressed in a subsequent article.

An RBS differs from other human resource or budgeting classification methods because it applies directly to project management, not to, for example, cost accounting or personnel evaluations. Rather than developing a new RBS for each project, the organization can develop various RBSs for families of projects. As managers plan each new project, they select only those portions of the common RBS that apply to the project. Here the WBS and the RBS work together: mapping a project's WBS onto the family RBS then links project activities with specific available resources.

RBS DEVELOPMENT

One does not plan a project while developing the RBS. Instead, the RBS tabulates the resources available to projects of a certain type. Developing the RBS starts with dividing the pool of resources into entities specific enough so that one can use this structure as a shopping catalog for resources necessary to accomplish project activities developed in the WBS.

As with the WBS, developing an RBS involves grouping all resources into between three and nine categories in level one. Then, each of the level one items is subdivided, and so forth, as described above for the WBS. Consistency in the division bases again remains a crucial component of the structure. Ideally, the rationale that divides one level from the next should be consistent across all children, but at a minimum the division basis at any juncture must be the same for all children of the same parent.

One maintains a reasonable consistency in the degree of detail of the lowest-level elements. Here the nature of the resource pool and its administrative environment determine the depths of the levels.

Again, as in the WBS, the division process continues until one has identified discrete, manageable resource items. A useful guide here is to keep dividing the project until the lowest level items reflect the resource details that interest the estimators and schedulers. Again, this level of detail varies among companies and project managers.

The RBS contains both the unit of measurement for each resource explicitly (e.g., foot, pound, cubic-yard, equipment-hour, labor-hour) and the cost of a single unit of the resource (e.g., $10,000 per equipment-hour). Items that get used entirely in a project can be measured as "each," for example installed motors, doors, computers, hard disks, and so forth. The RBS may list either direct costs or total costs, (i.e., including overhead), but all resource costs should be measured identically, with or without overhead.

Resource Breakdown Structure - A Schematic Representation of a Resource Breakdown Structure. The George Washington's Represent Generally Available Personnel, and the Bulldozers Represent Equipment Resources.

To remind us of the importance of this consistency in the measurement units (and many other consistencies), look at the example of the Mars Climate Orbiter, which failed in September 1999, because one navigating group worked in English units and the other in Metric units [1].

Moreover, a tighter consistency is recommended than this minimum requirement of working in the same system. For example, the measurement for all time related elements can be one of hours, days, months, or years, but the chosen unit should appear in all appropriate quantities (unless the numbers become unreasonably large or small). The same statement can be made about all other dimensions and combinations of dimensions involved in the project, e.g., length (inches, feet, yards, centimeters, meters, kilometers) or volume (gallons, cubic yards, cubic centimeters, cubic meters).

Limited resources may be indicated as part of the RBS. For example, one would mention that 14 civil engineers are available for a new project; or two cranes; or 35 brick layers; or four programmers; or three photographers; and so forth. On the other hand, for high-priority projects some resources may be limitless. The project environment may be such that it would allow, for example, as many CAD operators as demanded by the project; or contract officers; or safety engineers; and so forth. As with the WBS, the RBS can be presented graphically, in a tabular fashion, or using indented text.

THE PRIMARY DIVISION BASIS

The best (though not necessarily the only) lines of demarcation among the elements at the first level of the Resource Breakdown Structure are the following:

- people (labor);
- tools, machinery;
- materials and installed equipment; and
- fees, licenses.

The labor category is often referred to as human resources. It includes, for example, skill categories, professional disciplines, and work functions. All possible human resources should be listed here, regardless of their physical location, administrative attachment, or contractual circumstances.

Tools and machinery are those physical items needed by project team members to perform their duties successfully. When the project ends, the project team will remove the tools and machinery from the project environment. Examples of items in this category are testing equipment, hand tools, equipment to install project deliverables, and computers to monitor and evaluate the installation process. These items are usually leased or rented. Purchasing this type of item can be more cost effective for lengthy projects, but these items will still be removed from the project site.

When tools and machinery are rented or leased, the leasing agency sometimes rolls the wages of the operator into the rental fee of the equipment, this practice blurs the line between the human and physical resources. For planning and cost estimating, however, some organizations treat the operators as an integral part of the physical equipment.

Installed equipment and materials are purchased for the project and ultimately installed, integrated, and embedded in the project deliverables. Examples include fiber-optic cables, furniture, tape drives, monitoring equipment, pumps, ducts, and computers.

Fees and licenses refer to those cost items that do not involve any implementation or installation but are required for the execution of the project. Examples include insurance policies, bond agreements, permit fees, license charges, and taxes.

Complications arise when the client provides some combination of equipment, funding, and personnel. Although in such cases the detailed solution varies depending on the nature of the project and the priorities of the organizations involved, the most general approach still lists all of necessary project resources in the RBS regardless of how they

will be funded. Once the total project cost estimate is prepared, the client-furnished equipment and labor costs can be subtracted from the resources requested by the project manager or the contractor.

From our perspective, money is not a resource in this breakdown structure. Money represents the primary means by which resources are provided. To illustrate the validity of this concept, consider that for internal projects, money is often not the exchange medium. Although resources such as worker hours or equipment may then be granted directly, the project manager should still perceive them as resources to be husbanded.

After the mapping of the WBS onto the RBS, the money necessary for the project can be estimated through the sum of the products of two numbers: the resource quantities demanded by the WBS and the corresponding RBS unit costs.

That is, for each element at the lowest level of the WBS, one multiplies the desired quantity of the resource by its cost per unit of appropriate measure to yield cost. Because one often considers the multiplication implicitly, the sum of the resource estimates from the WBS is equivalent to the total cost estimate.

Lower-Level Division Bases, With a Concentration on Human Resources
One can categorize equipment, supplies, tools, and material by size, function, cost, or technical area. Fees can be divided by type or by cost. Aside from the above general guidelines, equipment, materials, and fees are highly discipline dependent and must be dealt with on a project-by-project basis. The categorization of people deserves a bit of amplification, however, because it is common to all projects, and because people are the most important resource in any project.

Ideally, the project manager plans, estimates, and manages all tasks and resources independent of where the resources reside, administratively or physically. But if a human resource item is part of an outside organization that the project manager intends to hire for an individual task, then that task and its associated resources should not be regarded as part of the project at hand. If the project manager does not manage a certain resource, he has no major influence in the use of the resource; aptly named, the resource and the resulting product are “outsourced.”

The level of detail with which a human resource is defined in an RBS naturally depends on the organization, the project, and to some extent on the individual project manager. But with that obvious caveat stated, now it’s time to consider further the transition from one human-resource RBS level to the next, which should occur on one of the following bases.

1. Administrative unit
2. Physical location
3. Credential (in a particular discipline)
4. Work function
5. Position hue
6. Skill level

Managers sometimes divide human resources on the basis of their administrative affiliations, such as company A, Contractor X, or Organization D.

In other cases, one might prefer to catalog the resources into groups based on physical location, especially as it relates to proximity to the project site, (e.g., human resources from Los Angeles, Boston, Southern Plants, or Western Contractors).

The credential-discipline basis is used when people need to be identified with their degree specializations, their certifications, or by other recognized credentials. Examples of these divisions are: those with a degree in chemistry, those who hold a professional engineer’s license, those who hold a CPA certification, or those with master’s degrees.
A work function basis is used when, independent of the credentials people hold, managers must know workers’ functions. Examples of such divisions are programmers, test technicians, supervisors, team leaders, equipment operators, designers, estimators, project control specialists, and so forth.

Position title basis is required when, independent of credentials or job functions, people's places in the organizational hierarchy determine their duties in the project. Examples of such divisions are contract officers, program directors, department chiefs, divisional VPs, and so forth.

When it is appropriate to classify project personnel by their degree of effectiveness and skill, project managers can use the skill basis, e.g., expert, skilled, and semi-skilled.

Again, it is suggested that one maintains a reasonable level of consistency in grouping the resources. For example, whether labor items are categorized by degree, job title, or job function, the categorization should be consistent across all labor items at that level of the RBS.

ESTIMATING COSTS

For example, if a project needs three brick layers for four days to build a wall, then the category is brick-layer, the intensity is three workers, the duration is four days, and the effort is 12 worker-days. At a unit cost of $300 per worker per day, the cost is $3600.

One could find the total cost of the project by adding all these costs together, but so many numbers are somewhat unwieldy, and such a calculation hides the additional information that will subsequently be easily obtained. In the next step, one moves up a level to determine – by simple addition – the total quantity of resources necessary for all elements at level N-I, grouped by resource-category. The process repeats, proceeding from bottom to top, until each element of the WBS shows the total resources it requires, grouped by resource category. Ending at level zero, you have now estimated the project's total resource expenditure, as well the costs of all substitutes defined in the WBS.

As in any method of estimating, one must check the estimate against experiential data and the subjective knowledge of management professionals. The first key question to ask at this point is: is the estimate for the total cost of the project reasonable? Poor overall estimates often result from inadvertent omissions in the WBS and the RBS. Therefore, correction primarily comprises filling the holes of the WBS. Correction may also include improving elemental estimates at the lowest levels, but one should not change an elemental estimate arbitrarily from what one believes is the best estimate. Further, one should not change the estimate values for those items above level N, (i.e., those items that are parents of lower-level items). Remember that all parents' estimates are derived from sums of lower-level estimates, not from direct input.

Project planning should evolve continually. As more information becomes available, the WBS, the estimates, and the schedule must be updated and (one hopes) refined. Ideally, these enhancements should be conducted frequently rather than only for specific administrative milestones and budget deadlines. At every update opportunity, the enhanced WBS (and if necessary, an enhanced RBS) should be used to refine the elemental estimates.

Using a good WBS with an accurate RBS, one can ask detailed cost and resource questions about the project, such as: What is the total number of worker-hours needed for module A? How many worker-hours of chemists are needed for modules A, B, and C?

When these tools are combined with good temporal estimates to produce a valid schedule, one can then ask questions that involve detailed time and resource issues together, such as:

- How many programmers are needed across the entire project in July?
- How many engineers are needed for module C during July?
- Would the demand for client-side programmers be reduced next July if module B is postponed by three months?
- How many more analysts would be needed next February if the scope of module D is doubled?
- How would doubling the scope of module CJ affect project cost, schedule, and resource requirements?
- If module F were to be delayed six months, what would the resulting cost and schedule look like?

Among other factors, project success depends on clear planning, good communication, and regular updating. In this article the focus has been on the importance of well-defined, accurate, consistent, and complete work and resource breakdown structures. With these two planning tools, a manager can make a systematic and accurate estimate of the project's required resources – and therefore its cost.

Once deliverable-oriented WRS elements have been developed for a project, producing a cost estimate becomes a simple matter of mapping the WBS onto the RBS and assigning the appropriate resources to individual WBS elements. This methodical approach may initially require some extra effort, but if an organization regularly produces and maintains its RBS families, the process becomes second nature. The project manager's anxiety about cost estimating will decrease, and the organization will achieve significant efficiencies in planning, scheduling, and monitoring.

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Technical Articles - Each month, Cost Engineering journal publishes one or more peer-reviewed technical articles. These articles go through a blind peer review evaluation prior to publication. Experts in the subject area judge the technical accuracy of the articles. They advise the authors on the strengths and weaknesses of their submissions and what changes eau be made to improve the article.

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