

Engineering Project Management Work Breakdown Structures for Engineering Projects

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1 Introduction

1.1 Project Scope Definition

The project scope is all the products, services, and deliverables required to complete the project. The combination of the scope statement, work breakdown structure (WBS), and WBS dictionary is often considered the “scope baseline”:

Scope baseline = Scope statement + WBS + WBS Dictionary

The scope statement should describe the general quantity and quality of work that is required in the delivery of a product, system, or facility that meets the requirements of the client and/or project sponsor. A scope statement outlines deliverables, design objectives, boundaries, exclusions, and acceptance criteria. Unfortunately, the project scope does not simply present itself and must be thought through by the project manager and/or design manager, with input from the project team and project sponsor.

Even if all the alternatives have been evaluated and selected with a clear line of sight on the design elements (which is rare), there are likely unique tasks and deliverable details that still need to be flushed out in order to write a good scope statement.

Example questions to ask when developing a scope of work and writing a scope statement:

- How detailed should be design report be on technical requirements?
- What level of accuracy is needed for the class estimate?
- How detailed should the 3D model be?
- Should clash detection be done on 3D model?
- How many drawings are estimated for each discipline?
- How many specification sections are estimated?
- Should the topographic survey include a boundary survey, easement search, and title search?
- Should the geotechnical report include foundation options or a single recommendation?

Flushing out these questions further develops the scope definition. A correct scope definition ensures that all the parties involved in the project (PM, design staff, subcontractors, project sponsor and champion, client staff, contractors, and regulators) understand the results and roles of a project in a common way.

Scope creep is an occurrence in which new activities, functionality or requirements are introduced into the project without a corresponding change in time, cost, or resources.

1.2 Vulnerability of Engineering Projects

Although scope definition and scope management are important for all project, design projects and engineering projects need even greater attention. The nature of a design project involves creativity, undecided alternatives, ever-evolving arrangements, multi-discipline teams working in different software, need for technical precision, constructability issues, safety issues, code compliance issues, regulatory related changes, and value engineering to keep within a client budget. All this makes the project very susceptible to scope creep.

Unlike the repetitive construction or manufacturing work, all design projects are unique. For example, a pilot project of a new plant, system, or process. This kind of individuality will keep a PM on their toes. Clients usually polish their requirements after reviewing design submittals which demand additions or modifications. The various regulatory agencies may introduce new requirements in the project. The field conditions often change from record documents and preliminary surveys, which impact the design arrangement. Besides that, the engineering teams work in various fields, including civil, electrical, mechanical, process, and structural, which are interdependent and rely on the elements from one another, such that if one discipline makes an equipment selection change, the other disciplines need to adjust their designs and the entire arrangement reviewed to confirm the change has been fully coordinated.

Another contributor is design iterations. Initial conceptual steps are premised on assumptions and incomplete information. Better information is developed early in the design process which results in design changes. The battery limits shift as the design moves from what was originally assumed to what is actually needed. This process is normal in design and often not seen as a change in scope.

1.3 Gold Plating

However, in the process of progressing the design, staff may want to add features which have never been required but offer some benefit to the end user or owner. For example, a mechanical engineer can opt to add a redundant pump with associated piping, power supply and controls. Or an architect can add EIFS (Exterior Insulation and Finish Systems) to a structure which was originally scoped to have plain walls. This is called gold plating, which represents good intentions but results in unapproved scope creep.

Without proper approval and management, small design decisions like this add to the level of effort required which can impact the budget and schedule. Also, it raises the construction cost estimate which later can lead to value engineering to discover and remove the gold plating.

1.4 Work Breakdown Structures as a Tool for Managing Scope

To combat these challenges, PMs are increasingly relying on the Work Breakdown Structure (WBS) to create a hierarchical level of breakdown that divides a project into manageable and measurable activities. WBS transforms abstract objectives into physical deliverables, whereby all the elements of the design work are taken into consideration.

The WBS is a project breakdown map, indicating what will be in the project and what will not be in the project, based on the implications. It is not a substitute for a scope statement, which goes into technical details, but the two are complementary. Typically, a written scope statement is part of the initial project contract, agreement, or agreed scope of work, and the WBS is made based on the scope statement. A WBS can include internal processes which are not listed in the scope statement, such as quality reviews, internal team meetings, or draft documents which are not deliverables to the client.

By breaking down the work from deliverables to work packages, one is able to organize what needs to be done to complete the project and who will perform each task. Each level of the structure is further elaborated, and the scope definition is related to schedule and cost management. An organizational chart is helpful in preparing a WBS for assignments. If the WBS has sufficient breakdown, when a design modification arises, a PM can quickly determine which tasks and staff are impacted, which ultimately helps determine if the modification is a part the original scope of work, is gold plating which can be eliminated, or is a change in scope that requires a change request.

1.5 Purpose of this Course

The course seeks to demonstrate why the development and utilization of a WBS is an important part of an engineering project. The goal is to help project professionals and design leaders to develop a quality WBS that matches up with the scope statement, schedule and budget. A main benefit of this approach is to avoid scope creep.

2 Understanding Scope Creep

Project scope varies greatly depending on the nature of the work. Engineering projects can involve the addition of a new system, building, infrastructure, digital elements, or land development. Inevitable, a change in design occurs. This could be a new feature, a regulatory change, or a new deliverable. These changes should be captured through change management and a change order or change approval. Such changes are not scope creep, as they are managed through a formal change control process.

However, gold plating, as defined previously, is an example of scope creep. Uncontrolled scope growth is where such modifications multiply without proper approval and lead to a vague conception of what the project should offer. Change occurs in every project, but the difference would be that the change is either managed or creeping.

A PM may not be able to tell at a glance if a modification should go through a formal change approval process or if it is scope creep that should be stopped. The PM should review the relevant project documents such as the original agreed scope of work and WBS, consult with relevant coworkers, and/or consult with the project sponsor. When in doubt, the change should be listed on a change log as potential scope change and evaluated through the formal change process.

2.1 Causes of Scope Creep

Poor scope definition during proposal and planning is the most common cause of scope creep. Key initial documents include the project charter, feasibility report, design brief, proposal, contract, and project plan. If the scope is not clear in these documents, the goals of the assigned participants may differ based on their interpretation of what is needed. This vagueness generates assumptions that would be found out at a later stage as incompatibilities between the designs from each discipline or a construction cost estimate and schedule that is overbudget.

For example, when the project for a facility expansion does not specify upgrading the control system, engineers may program a new control system when the client would be satisfied with minor upgrades to the existing software. One way to prevent this is to have the design disciplines review and add details to the written scope statement during the proposal and planning phases. Exclusions and assumptions should be written, reviewed, and discussed. It is better to take the time early rather than later in the project when rework is required.

Failure to align the stakeholders is another common cause for scope creep. Projects have multiple stakeholders including project sponsor, project champion, other client staff, customers, operators, architects, engineers, construction contractors, regulators, cost estimators, procurement staff, etc. Each of them possesses their own priorities and opinions. Structured communication including an early review of project assumptions can clarify expectations and get any strong opinions out of the way early.

For example, a client assumes that site civil work encompasses landscaping, but the civil design team does not do landscaping design. This creates a gap in scope that will be identified at late stages when the client reviews the design documents and comments to add landscaping. If landscaping is not listed as excluded in the assumptions in the agreed scope of work, the PM may then argue that landscaping is not normally considered civil work and thus was not in the civil scope of work. The client may disagree.

A significant factor in the extent of the scope creep is the extent of client management by the PM. Clients are in a position to dictate expectations and approve deliverables, which can creep into a position to dictate changes. For example, the owner may decide mid-way into the project that the building needs to have provisions to allow future expansion. These requests are usually based on actual benefits, but without the formal control of change, the client requests may get out of control and impact the cost and timeline of the project. The PM needs to remind all parties of the original agreed scope of work and of unintended consequences to making major design changes late in a project.

2.2 Real-World Examples of Scope Creep

Consider the case of a wastewater treatment plant redesign with the original goal to improve the processing of sludge. New regulation requirements are introduced at the detailed design stage, with the need to have additional nutrient removal. To fulfil the attempt, the engineers must include the usage of a chemical dosing systems, change the hydraulic profiles, and redesign the logic of process control. With all the validity of the reason for compliance, the additional design work adds months to the schedule, thousands of dollars to the design schedule, and hundreds of thousands of dollars to the construction cost. This scope creep should be captured through a formal change approval process.

In another case, a manufacturing expansion project aimed at increasing production capacity suffers from midstream modifications. First, it involves the introduction of a new production line that was covered. When halfway through, the management decides to integrate a robotic packaging system to save on labor costs. Now, the mechanical and electrical design teams have to redesign layouts, revise control schematics, and change utility requirements. The result is an overbudget and a six-week unplanned postponement. Again, the scope creep should be captured through a formal change approval process.

2.3 Consequences of Scope Creep

Unchecked scope creep disturbs the delicate balance between meeting cost and budget goals versus using effort and resources needed to provide quality deliverables. Figure 1 depicts how extra product specifications (specs) tip up the cost and timeframe of the project.

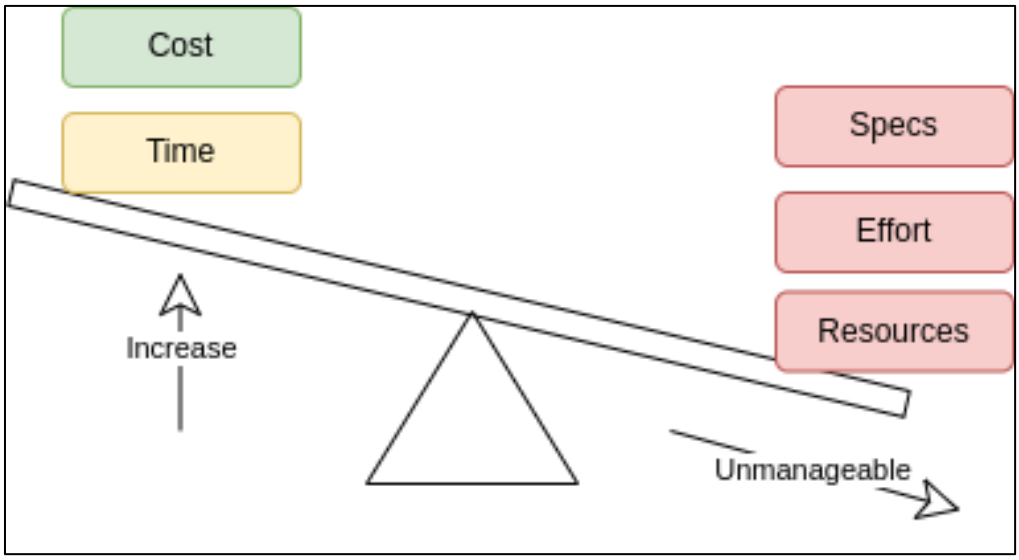


Figure 1: Consequences of Scope Creep

Source: Author

Budget overrun is an obvious effect of scope creep. Additional design time, new work and unexpected amounts of work cause costs to increase. Other types of budget problems include construction cost increase, lifecycle cost increase, return on investment decrease, and payback period increase.

Next come schedule delays. Every emerging requirement has a coordination, review, and redesign cycle across disciplines. Dependencies lead to delays, such as mechanical modifications must wait until structural engineers, models must be updated by drafters, and procurement schedules must be updated. The project delivery date is further shifted to the bottom which likely pushes out regulatory approvals, procurement, construction and startup dates.

Another risk of scope creep is a compromise of quality. In situations where the design is late and the budget is tight, the team may make shortcuts to quickly integrate the changes and complete design verification, but without the typical regulatory assessment, cross-discipline coordination, updated calculations, and clash detection. And when there is a case of constant revisions, there is a risk of losing sight of the original objectives. In addition, frequent changes introduce errors and inconsistencies.

Beyond these measurable effects, scope creep brings down the morale of the team as well as the confidence of the stakeholders. The leadership skills of the management team can be questioned by those involved in the project or end users. In extreme cases, the unchecked scope creep which is not kept in check leads to contractual difficulties or total project failure.

On a positive note, encountering scope creep can help a PM recognize where the scope statement is lacking details and better methods to gain client input.

2.4 Linking Scope Creep to the Need for Better WBS Practice

A root cause of all these issues is ineffective project scope control, that is, the inability to define and control the scope of work of the project. And to the rescue comes the Work Breakdown Structure (WBS). A WBS provides the framework that is required to break down the top-level objectives and deliverables and transforms them into specific and measurable work tasks. It is also advantageous in that it gives a pre-emptive list of all deliverables and responsibilities, hence establishing a benchmark of responsibility for the project team.

Once the cost and schedule information are appropriately added to the WBS, this then becomes a mechanism of control. One purpose of a WBS is to detect early deviations before they escalate into a full-scale scope creep. The next section provides background on the concept of WBS and how it can be applicable in the management of engineering projects.

3 Overview of WBS

The Work Breakdown Structure (WBS) is an element of the Planning performance domain in PMBOK® Guide, as it is a tool for organizing and controlling the total scope of work. The PMBOK® Guide defines a scope baseline as the collection of the approved scope statement, the work breakdown structure (WBS), and the WBS dictionary. All these together are what defines the work.

A WBS is also used to gauge progress and changes. The WBS includes all the deliverables and main tasks to complete them, which is then easily interconnected with the schedule and budget baselines. Thus, the WBS bridges the written scope with other planning documents.

Team members can utilize the WBS in case of a given change of a design to check whether the requested work can be compatible with the existing deliverables, or if it is a new component. For instance, if a client asks for “energy recovery analysis,” the PM or Design Manager can consult the WBS to see whether such analysis exists under a subtask like “Process Optimization Studies.” If not, the written scope statement should also be consulted. If it is not in either document, the request is a new scope item which should initiate a formal change request. The WBS traceability enables objective discussions about scope, avoiding misunderstandings and disputes.

3.1 Key Components of a WBS

Although there are different approaches to organizing a WBS, the following is one of the most common methods that fits most projects and especially engineering design projects. The highest level, Level 1, labels the overall project. Level 2 identifies all deliverables. Level 3 identifies disciplines and major tasks that produce those deliverables. Level 4 provides for a further breakdown into work packages or tasks. This multi-level approach provides clarity on how each task is associated with a deliverable. This WBS does not allow for tasks that don’t relate to the agreed deliverables.

3.2 WBS Dictionary

The WBS dictionary is an appendix to the WBS hierarchy. It provides detailed descriptions to each of the elements. The dictionary dictates the scope of work, the person in control, expected deliverables and acceptance criteria of each WBS code.

For example, let's say WBS 3.2.1 entails Mechanical Design, which includes pump selection. The dictionary description could read: Review pump options, perform hydraulic calculations, select pump, and update equipment schedule. Such a description adds clarity down to a reasonable level of detail. If reviewing pump options takes 10 minutes for each pump option, then there is little need to specify the number of pump options to review. However, if it takes 2 hours per pump option, then adding "review up to 3 pump options" would be more appropriate to avoid scope creep.

Each element in the WBS is assigned a unique code that can be easily tracked with the help of project management software. The coding hierarchy shows the echelons of breakdown, for example, 1.0 is Construction Documents, 1.1 is Civil Drawings, 1.1.1 is Site Grading Plan, and so on. Such codes are accompanied by cost control, scheduling, and reporting equipment, which gives traceability of all the management systems.

For example, staff should be able to enter hours on their timesheet to the codes in the WBS. Usually Level 2 (deliverables) codes are utilized to create phases/tasks for charging time, but sometimes Level 3 is utilized which provides greater insight into the budget status.

4 Developing an Effective WBS for Engineering Design Projects

4.1 WBS Creation Process

A well-constructed WBS ensures each drawing, each specification, each calculation, each meeting, each permit submittal is tied into an agreed deliverable under the scope of work. This leaves little room to make guesses as to what tasks make up the project or for what purpose tasks are being done. All tasks should be done to achieve specific deliverables (directly or indirectly).

4.1.1 Step 1 - Review Scope Documents and Client Requirements

It is crucial to review all the scope documentation available. Example documents include the business case, project charter, client brief, feasibility study, design basis report, proposal, and contract. These documents define what the project will provide and the purpose of the project. In particular, the agreed written scope statement (often referenced in the contract, proposal, or request for proposal) serves as the foundation of the decomposition of the work for the WBS. It is helpful to keep in mind the distinction between product scope (technical specifications and requirements) and project scope

(scope of services). The WBS needs to incorporate the entire project scope and can reference the product scope.

Technical experts should review the deliverables and product scope to help specify sufficient discipline work detail and to clarify assumptions and exclusions. For instance, a statement in the scope of work that “two geotechnical borings are included” should be reviewed by engineering staff to confirm two borings are sufficient. Then “perform two geotechnical borings” can be a task added to the WBS. These assumptions and design decisions should be reviewed with the client early to prevent a misunderstanding or disagreement later in the project.

4.1.2 Step 2 - Decision on Deliverables and Sub-deliverables.

Once the scope has been proved accurate, the next process will be to identify the major deliverables that make up the project outcome. Deliverables are tangible results that are submitted to the client, used for installation, or memorialized in some other fashion. Completing the set of deliverables completes the project. Thus, the deliverables should be physical or tangible (savable) outputs rather than activities.

Example deliverables include draft reports, final reports, cost estimates, permit submittals, documented regulatory approvals, specifications, drawings, sealed calculations, 3D models, bid packages, schedules, and meeting minutes.

Each of these deliverables can be subdivided into main elements that together make up each deliverable. These are typically called sub-deliverables. These are often internal documents that together make up a main deliverable document. Or each disciplines group or team can be a sub-deliverable. This is best done when combining the outputs from each team makes up the main deliverable. Like discipline sections of a drawing set that together make up the drawing set. The caution here is to not forget about general and common drawings that must be done by someone, usually either a drafting team, a BIM team, or the civil team, since they often manage the base plan.

For example, a deliverable “Site Layout Drawing” would be acceptable since it is a tangible drawing (digital or hardcopy) while “Civil Design” is not a tangible output and not an acceptable deliverable. “Civil Design” is an acceptable sub-deliverable that contributes to the civil layout drawing. Other sub-deliverables could include “Civil Drafting” (if done by a separate group), “peer review”, and “survey”. Since the survey is needed first, it should be listed first.

Simple WBS for the above example:

- Project 1.0: ACME Land Development
  - Deliverable 1.1: Site Layout Drawing
    - Sub-deliverable 1.1.1: Survey
    - Sub-deliverable 1.1.2: Civil Design
    - Sub-deliverable 1.1.3: Civil Drafting
    - Sub-deliverable 1.1.4: Peer Review

4.1.3 Step 3 - Work Package Breakdown.

The second step in the decomposition process is to create work packages (WPs), which are usually the smallest work units. A work package typically is an action that can be assigned to a specific individual (or small group) with specific results.

For example, the WPs of a sub-deliverable “Process Flow Diagrams” can be “Block Flow Diagram”, “Equipment List”, “Draft PFD”, “PFD Quality Review”, and “Finalize PFD”.

As another example, for sub-deliverable “Structural Drawings”, WPs could consist of “Foundation Calculations”, “Foundation Plan”, “Structural Details”, and “Drawing Quality Review”.

The WPs should be detailed to the extent that they can be easily managed but not too small so that the long list becomes an administrative nightmare. For a large multi-discipline design project, the level of breakdown is often in the 24 to 120 hour range (3 days to 3 weeks full time). However, some critical tasks like design reviews may only take a few hours but should get their own WP. Some longer tasks like building a 3D model may take many weeks but are better suited in a single WP.

Each WP must be mutually exclusive (work only identified in one WP), and the sum of all WPs must cover 100% of the scope.

4.1.4 Step 4 - Assign Codes and Ownership

Once the breakdown is complete, each element of the WBS must be assigned a unique code and an owner. The coding structure should follow a numerical hierarchy. See the numbering system in Figure 2. Note that some organizations have their own project phase and task numbering system for planning, budget tracking, purchasing, expense reports, and timesheet entries. A PM may have to work within that system while still achieving the goals of a WBS.

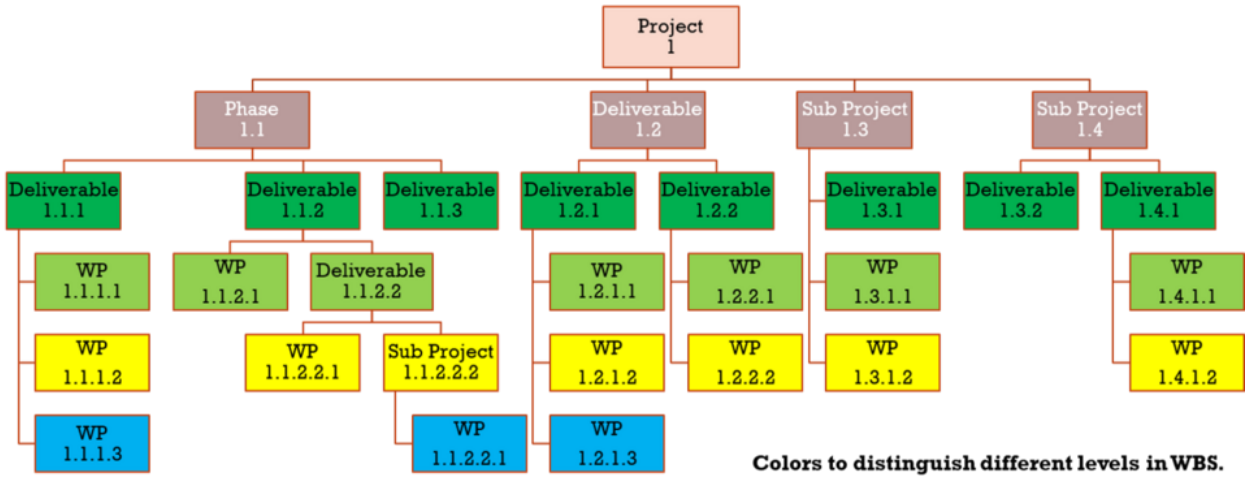


Figure 2: Generic WBS with Work Packages (WP) and codes
Source: commons.wikimedia.org/wiki/File:Workbreadown_structure_sample.png

Assigning responsibility is equally important. Each work package should have a designated staff member responsible for its completion, such as a design lead. This accountability ensures that no scope elements fall through the cracks. Responsibility also facilitates communication between disciplines when interface issues arise. When multiple staff from different groups are involved, the PM can take responsibility to coordinate.

Simple WBS example with initials on right for responsibilities:

- Project 1.0: ACME Land Development PM
  - Deliverable 1.1: Site Layout Drawing TRE
    - Sub-deliverable 1.1.1: Survey SED
      - WP 1.1.1.1: Subcontractor Topographic Survey SED
      - WP 1.1.1.2: Subcontractor Boundary Survey SED
    - Sub-deliverable 1.1.2: Civil Design TRE
      - WP 1.1.2.1: Concept Layout Sketch TRE
      - WP 1.1.2.2: Concept Review Meeting TRE
      - WP 1.1.2.3: Drawing Markups TRE
    - Sub-deliverable 1.1.3: Civil Drafting BYG
      - WP 1.1.3.1: Concept Layout Drafting BYG
      - WP 1.1.3.2: Final Site Layout Drafting BYG
    - Sub-deliverable 1.1.4: Quality Reviews PM
      - WP 1.1.4.1: Civil Peer Review POE
      - WP 1.1.4.2: Cross-discipline Review GAM

4.1.5 Step 5 - Validate Completeness Against Project Scope

The final process is validation, wherein the WBS has to cover 100% of the project, nothing more and nothing less. This is called the 100% rule. In other words, the WBS must only contain all the work required to produce the agreed project deliverables and nothing beyond.

The process of validation involves reviewing the WBS with the project team and other stakeholders, sometimes including the client or end users, to make sure it is complete. The PM should not assume to know the tasks and steps required to produce the deliverables. Instead, a lead from each team/group/discipline should provide input on work elements needed and the PM incorporates this into the WBS. Often the written scope statement also requires updating, so usually both of these documents are produced at the same time.

Items missing in the WBS indicate a gap in scope which will be realized in the future. Additional items in the WBS may be unauthorized or unnecessary work.

4.2 Example 1

For an example, there is a Water Treatment Plant (WTP) Expansion design project. It is a project that will enhance the capacity of the plant, modernization of both the mechanical and electrical systems and efficiency of the processes. The output is to be final drawing sets for civil, process mechanical, and electrical disciplines. A WBS in table format is in Table 1, and in hierarchical format in Figure 3.

Table 1: WBS Items for Water Treatment Plant Expansion Design

Level	Code	Description	Main Tasks and Outputs
Level 1	1	WTP Expansion Design	Overall Project
Level 2	1.1	Civil Drawings	Civil discipline work
Level 3	1.1.1	Site Survey and Geotechnical	Subcontracted work
Level 4	1.1.1.1	Topographic Survey	Survey basemap and benchmarks
Level 4	1.1.1.2	Geotechnical Report	Borings, analysis and report
Level 4	1.1.1.3	Civil Design	Stormwater, engineering, drafting
Level 2	1.2	Process Mechanical Drawings	Process mechanical discipline work
Level 3	1.2.1	Hydraulic Profile	Hydraulic calculations
Level 3	1.2.2	Process Flow Diagrams	Engineering, drafting
Level 3	1.2.3	Mechanical Drawings	Plans, sections, details
Level 4	1.2.3.1	Mechanical Layouts	Engineering sizing, layout, and markups
Level 4	1.2.3.2	Mechanical Drafting	CAD drafting
Level 4	1.2.3.3	Pump Selection	Pump hydraulics, sizing, and selection
Level 2	1.4	Electrical Drawings	Electrical discipline work
Level 3	1.4.1	Power Distribution	Power design
Level 4	1.4.1.1	One-Line Diagram	Concept, load calculations, drafting
Level 4	1.4.1.2	Panelboard and MCC Design	Selection and layout of equipment
Level 3	1.4.2	Controls Design	Controls design
Level 4	1.4.2.1	Controls Architecture Drawing	Controls scheme layout, drafting
Level 4	1.4.2.2	P&ID Drawings	Engineering, drafting, instrument list

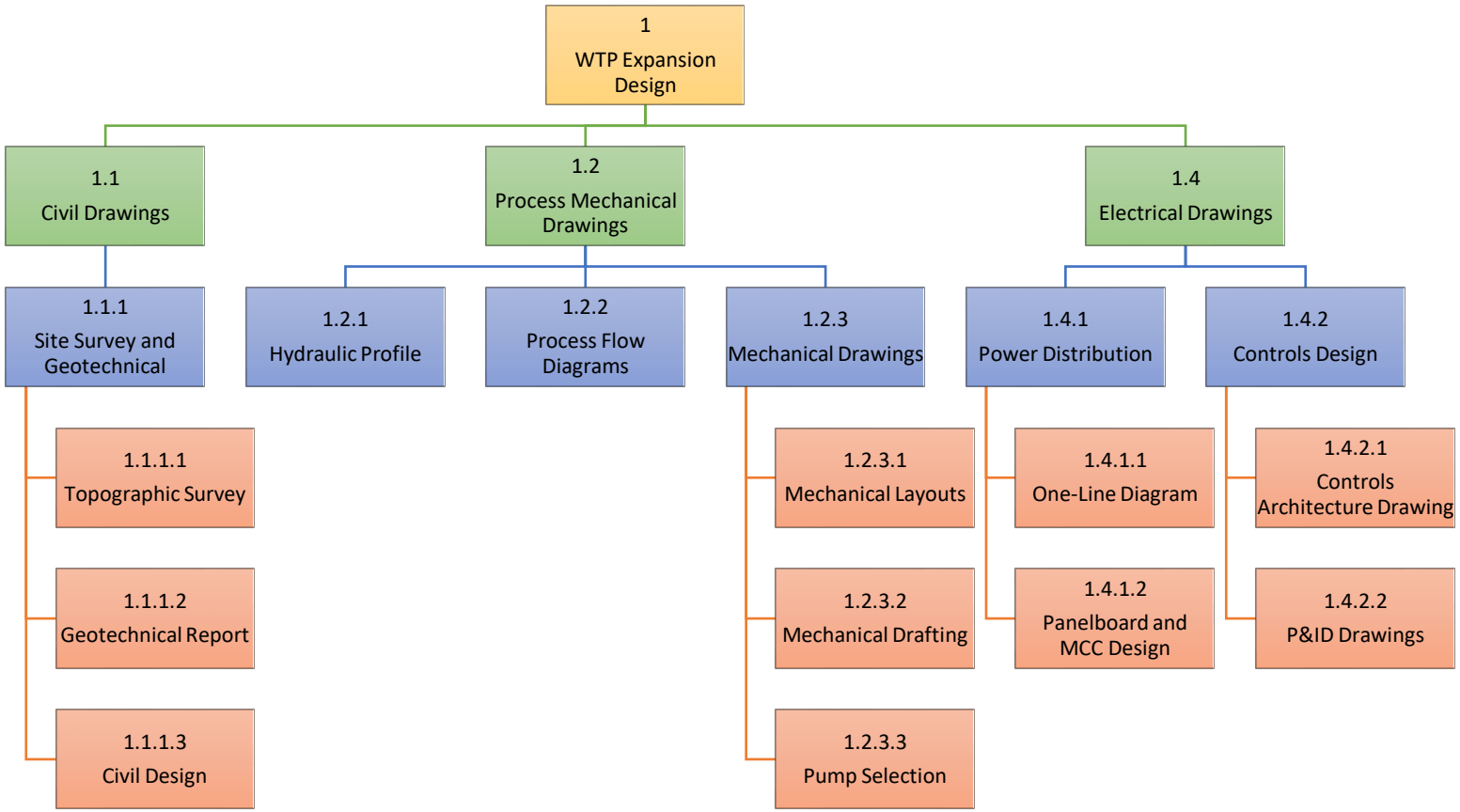


Figure 2: WBS For WTP Expansion Design Project

Source: Author

4.3 Example 2

The following is an example WBS in list format for a simple project with two deliverables: a report and a presentation. Here the term “task” is used instead of “sub-deliverable”. Also, the project number is 100 instead of 1 in previous examples.

- Project 100: New Building
  - Deliverable 100.1: Report
    - Task 100.1.1: Draft Report
      - WP 100.1.1.1: Setup and General Sections
      - WP 100.1.1.2: Site Layout Section
      - WP 100.1.1.3: Building Design Section
      - WP 100.1.1.4: MEP Section
      - WP 100.1.1.5: Regulatory Section
      - WP 100.1.1.6: Cost Estimate Sections
      - WP 100.1.1.7: Recommendations Sections
    - Task 100.1.2: Report Quality Review
    - Task 100.1.3: Submit Draft Report
    - Task 100.1.4: Revise and Submit Final Report
  - Deliverable 100.2: Presentation
    - Task 100.2.1: Draft PowerPoint
    - Task 100.2.2: Presentation Quality Review
    - Task 100.2.3: Client Presentation

4.4 Accounting for Overhead

Projects typically have general tasks that apply to multiple deliverables. A big overhead item is project management, which can be 5 to 15% of a project budget. Another is project meetings. Project management, meetings, and other overhead efforts can be integrated into a WBS in one of these ways:

1. Add PM as a separate “deliverable”
2. Add PM tasks under each deliverable
3. Add PM tasks to a single deliverable

The first approach is very common and simple. However, the second or third approach is recommended as it keeps the focus of the WBS on achieving deliverables. Once you start adding deliverables to the WBS that are not actual deliverables, scope creep is more likely to happen. Also, the cost breakdown presented to the project sponsor and project champion will show the cost for each deliverable with overhead included, which helps to make intelligent governance decisions, such as eliminating or delaying a

deliverable due to budget constraints. Common items, like a kick-off meeting, can be covered under the main deliverable.

4.5 Challenges in WBS Development

The development of a WBS can appear as a relatively easy exercise. However, each project is unique, and each organization's numbering system is unique, making the WBS creation challenging. Also, linking it to the budget and schedule takes skill.

One of the pitfalls is an over-detailed WBS with too many WPs. The system becomes cumbersome as the work is broken down more than necessary. For example, listing all the individual calculations or all the individual drawings. A WBS is geared towards providing adequate detail to enable a PM to control the work. A PM shouldn't need to track excessive details like each structural calculation. Grouping the calculations together into a single WP is usually sufficient. Tracking each calculation individually, including asking for percent completes on each calculation each week is adding effort without value.

On the flip side, too abstract or vague breakdowns can be equally problematic. A WBS where Civil Work or Electrical Design are listed but does not have sub-elements would be challenging to determine the schedule and budget status. Especially if the efforts are more than 100 hours or more than month time in any task. This ambiguity provides a space to be interpreted and weakening control over the work, leading to scope creep.

Another issue that is recurrent is the absence of interfaces across disciplines. Multi-disciplinary projects often have interfaces between the discipline WBS elements, such as piping penetrations through structural walls or electronic connections to the mechanical equipment. These elements require collaboration which should be verified by the PM as having been done.

To account for cross-discipline collaboration, the WP descriptions can highlight elements needing cross-discipline coordination and which disciplines are involved. Having a WBS in a table form allows adding columns for notes such as this.

4.6 Linking WBS to Schedule and Budget Baselines

Once approved, the WBS is to be used to create the schedule and budget baselines (or update them if those documents are already started). All items within a WBS should become activities on a schedule. Scheduling software includes Microsoft Project, Microsoft Planner, or Primavera. Such a relationship allows tracking the progress by

WBS code, which will allow the PM to understand which areas of the scope are ahead or behind schedule.

Similarly, project budgets should be organized by WBS code. When the expenses or labor hours are to be recorded, they are charged to the corresponding element of the WBS. This correlation, along with knowing the percent complete of each WBS element, allows for earned value management (EVM).

For example, if a WP is at 80% spent, and the actual progress is 40% complete, then the PM can identify that the WP is tracking overbudget. Next, the PM looks at the schedule which says the WP should be 50% complete, which is more than the 40% actual completion, so the WP is also behind schedule.

A WBS allows linking the triple baseline: scope, time, and cost. Any change to be implemented can be more easily examined on its effect on all three baselines and this will be a sure way of making an informed decision.

5 WBS for Prevention and Control of Scope Creep

The major benefit of an advanced WBS is that it quickly identifies changes. Any work request that cannot be matched to a WBS element should trigger a formal change review which can allow the work to proceed (also check the written scope statement). A WBS is a straightforward yet effective mechanism to control changes The WBS is called a “scope firewall”, and only authorized or well-defined tasks are allowed to proceed.

Each part of the WBS structure justifies the work to be done as well as the people who are supposed to lead the effort. The team members who are assigned to lead the WPs are expected to report on the progress of each WP in progress meetings and report any potential new tasks encountered. This communication will assist in preventing scope creep.

5.1 Preventive Strategies Using WBS

One of the reasons why the WBS facilitates the control of the scope is the clarity and definition. When planning a new project, it is important to create a list of tangible and distinct deliverables so that ambiguity is minimized, and then breakdown the work required to achieve the deliverable. The WBS dictionary stipulates the WP details and acceptance requirements.

For example, a WP is for a 3D Structural Model and the dictionary refers to the main tank and foundation, but not to the piping in and out of the tank. During work, the designer questions if the piping and pipe supports should be modeled. A quick check of the WBS and dictionary reveals that piping is not required and would be a change to the scope. The designer requests that the PM inquire about proceeding with this extra work through formal change control. The PM finds previous correspondence on this topic during planning, when the project sponsor made a decision to only model the tank and foundation, so the request to model piping is denied and the issue is closed.

5.2 RACI Matrix

WBS is also very compatible with a RACI Matrix. This is whereby Responsible, Accountable, Consulted, and Informed (RACI) people are established for each deliverable and/or WP. Clarity and ownership are enhanced by linking the RACI matrix to the WBS items.

See Table 2 for an example RACI matrix. In these cases, the lead engineer is Responsible for completing the work, the PM is Accountable to task completions, other engineers are Consulted, and the project sponsor is Informed of all work being done. This congruency will minimize miscommunication and ensure that any change is enacted by the responsible person.

Table 2: Example RACI Matrix

WBS Code	Description / Deliverable	Project Manager	Civil Engineer	Process Engineer	Mechanical Engineer	Electrical Engineer	Project Sponsor
1.1.1.1	Perform Topographic Survey – Produce survey maps and coordinate data	A	R	I	I	I	I
1.2.1.1	Calculate System Head Curve – Generate flow and head loss calculations	A	I	R	C	I	I
1.3.1.1	Select Main and Standby Pumps – Prepare equipment specification sheets	A	I	C	R	C	I
1.4.1.1	Design New MCC Panel – Develop electrical drawings and specifications	A	I	I	C	R	I

Legend:

R = Responsible (does the work)
A = Accountable (owns the deliverable, approves)
C = Consulted (provides input/expertise)
I = Informed (kept up to date on progress)

5.3 Example Scenario - Detecting and Managing Scope Creep

In the case of a design project currently at 60% design completion, the project sponsor requests including a backup pumping system for Process Line. The PM reviews the WBS dictionary and finds that WP 1.3.2 Pumping System Design has a description "Design standby pumps to Process Line A" but no mention of Process Line B. The written scope statement also lacks reference to Line B. Therefore, designing a backup pumping system for Line B is not a part of the approved scope.

The PM opens Change Request (CR-07). The PM finds WP 1.3.2 in the budget and examines the cost impact which is estimated as 60 hours and $12,000. Next, the PM finds WP 1.3.2 in the baseline schedule and estimates the schedule impact to the critical path as one (1) week. The project sponsor is presented with a change proposal, which is accepted. Next, the PM adds a new WP element in the WBS, for Line B Backup Pump Design, updates the budget and schedule, and informs the staff they can proceed with the work.

This logical process demonstrates how the WBS becomes a point of reference for determining what is in the scope of work versus a change, and the numbering helps quickly find the involved WPs in the budget and schedule to determine the impact.

5.4 Integration with Change Management Process

The WBS can be integrated into the change management system (such as change logs) in a similar way the WBS is integrated into the budget and schedule. Altogether, this creates a comprehensive project management system.

When there is a potential change, the workflow process is typically performed through four phases.

- Identification - The change is logged against a specific WBS element (for example, 1.4.2.1 - Control Wiring Diagrams).
- Evaluation - The PM and project team assess the impact on scope, cost, and schedule.
- Approval - Authorized parties decide whether to proceed (as defined in the project RACI matrix, project plan, or change management plan).
- Update - If approved, the WBS, schedule, and budget baselines are revised accordingly.

Potential and approved changes are tracked on a change log, as shown in Table 3.

Table 3: Example of a Simple Change Log

Change ID	Date	Affected WBS Code	Description	Impact (Cost/Time)	Status
CR-07	3/15/2025	1.3.3	Add backup pump design for Line B	+$12,000 / +1 week	Approved
CR-08	3/20/2025	1.2.2	Extend hydraulic study to include storm bypass	+$6,000 / +3 days	Under Review

The requirement to place all changes under a new WBS code allows the project to be fully traced on how and why the scope changed. This facilitates control in the implementation of the new work, and easier tracking of lessons learned, and can be used in future planning.

5.5 Best Practices for WBS Updates and Version Control

WBS is supposed to be living document and must be maintained in order to be effective. There should be a baseline WBS. Then the PM can utilize version control in which future revisions are saved separately with a new date, reason for change, and initials. Many organizations use controlled registers or project management software containing audit trails as a means of ensuring that there is transparency with each change.

The PM should periodically perform WBS validation by reviewing each WP in the WBS. This is often done after each major deliverable is completed and at the end of the project, to confirm it is truly complete. When changes do take place, the new WBS should be reshared (or at least accessible) to the stakeholders to ensure that all team members are on the same page.

The other practice that is helpful is the association of WBS codes to digital document management systems. Project documents should contain the WBS code in the title block, heading, or other place within the document. The file name can also contain the WBS code. This allows tracking of documentation and association with the WP of the project, to prevent confusion with another part of the project or another project altogether.

6 Example Problem and Solution

An example of a Work Breakdown Structure (WBS) as a control mechanism in practice is for a wastewater lift station design project. The objective of the project is to design a new lift station at a specified pumping capacity to collect and convey wastewater from gravity sewers in a growing city district. The design work consists of civil, mechanical and electrical design deliverables including drawings, technical specifications, and a cost estimate.

The client introduces new requirements during the 60% design review, which includes a system to manage odors, a telemetry system, and an automated monitoring system. These are reasonable requests that improve the design. However, they were not originally planned and would bring about significant upheavals to all the disciplines. The state of the engineering team has become a typical example of potential scope creep, which, unless handled effectively, can lead to cost overruns, schedule setbacks, and strained relations with clients.

6.1 Step 1 - Identifying the Issue within the WBS

The first step towards approaching the scope change was to establish where the issue was reflected within the existing WBS. The lift station project's original WBS comprised the top-level deliverables which are impacted by the potential change:

- 1.1 - Civil Drawings
- 1.2 - Mechanical Drawings
- 1.3 - Electrical and Instrumentation Drawings
- 1.4 - Technical Specifications
- 1.5 - Cost Estimate
- 1.6 - Project Management

To check if the requested changes are in the scope of work, the PM reviews the WBS dictionary for the WP elements related to odor control, instrumentation, and monitoring:

- WP 1.2.4 states to be compatible with a future odor control system
- WP 1.3.3 describes the controls, with nothing concerning a telemetry system
- WP 1.3.5 lists a simple manual monitoring system

6.2 Step 2 - Assessing the Impact on Cost, Schedule, and Deliverables

Once the scope gap had been identified the second net step consists in establishing the impact of the changes. The PM has a meeting with civil, mechanical and electrical design leads. The PM requests the tasks, estimated hours, and estimated weeks to integrate the changes.

To determine the impact, each lead reviews the changes as follows:

- The lead mechanical engineer identifies that new ducting, a carbon filtration system, and an auxiliary blower should be supplied for odor control. This modifies the general arrangement, changes several drawings, and adds items to the equipment schedule.
- The lead electrical engineer analyzes the power required, controls changes, instrumentation additions, and telemetry locations and components.
- The lead civil engineers review the impact to the site layout, equipment slab, and drainage system.

In total, including extra PM time, the change is estimated to add 220 hours of work for a cost of approximately $45,000 as well as a 3-week delay to project completion.

The findings are recorded in a Change Impact Form which includes a breakdown of cost per deliverable in the WBS. The impacted WBS codes are also listed. The evaluation did not lead to ambiguous generality but offered the client facts, which he could operate with.

6.3 Step 3 - Documenting the New Elements with WBS Codes

The proposed new scope was then documented by the project team, which developed new WBS codes after determining the impact. Some of the new elements are as follows:

Mechanical Drawings:

- 1.2.4 Odor Control System Design
    - 1.2.4.1 Equipment Selection
    - 1.2.4.2 Duct Layout and Detailing
    - 1.2.4.3 Odor Control Plan and Sections

Electrical and Instrumentation Drawings:

- 1.3.4 Instrumentation Expansion
    - 1.3.4.1 Modified Instrumentation List
    - 1.3.4.2 Telemetry system drawings
    - 1.3.4.3 Automated monitoring system drawings

A before-and-after snippet of the WBS structure for Mechanical Drawings:

Before Change (Excerpt):

- 1.2 Mechanical Drawings
    - 1.2.1 Pump Selection
    - 1.2.2 Piping and Valves Layout
    - 1.2.3 Equipment Data Sheets

After Change (Excerpt):

- 1.2 Mechanical Drawings
    - 1.2.1 Pump Selection
    - 1.2.2 Piping and Valves Layout
    - 1.2.3 Equipment Data Sheets
    - **1.2.4 Odor Control System Design**

The RACI matrix is updated and assignments added for each WP added.

The PM provides a brief communication update to the entire team and stakeholders with the new WBS structure.

6.4 Step 4 - Revising the Baseline and Communicating Through RACI Roles

The client provided approval for the new WBS items which incorporated the changes from the baseline WBS. The PM enters the new WBS in the project management software which automatically updates the project budget and schedule.

Following the RACI matrix, the engineer leads are responsible for making the design changes, the PM is accountable, all engineer leads are informed of the work done by other disciplines, and the client is informed of the work. The RACI provides clarity such that no overlaps and miscommunication arise in the completion of the work.

6.5 Step 5 - Capturing Lessons Learned in the WBS Dictionary

A post-project review was conducted by the team after deliverables were completed. Some of the key lessons that were acquired in the process of participation in the WBS dictionary included having discussions with the client on optional systems, such as odor control, telemetry, monitoring, and automation. It was a decided that the need for an odor controls system should be evaluated for all future wastewater lift station projects. Also, it was decided that future lift station projects should review this project's WBS to identify potential scope elements to be considered. The WBS documents the final scope which will be reviewed to reduce the possibility of repeating scope gaps in future projects.

6.6 Outcome and Measurable Improvements

In the end, the project was completed a week later than initially planned, which was much lower than approved three week extension. The client was very appreciative of incorporating the requested improvements fairly late in the design process. The application of an organized WBS allowed the project team to achieve project goals while taking on significant changes. The changes were done amicably with formal client approval to minimize contractual risks.

Internally the changes were handled with minimal stress. Team members were self-assured about the use of the WBS as an instrument of not only planning but also living out the complexity with a sense of order and logic. Having the WBS linked with the budget and schedule allows consistency in the documents and gave the PM confidence to quickly move forward with the changes.

7 Practical Takeaways for Project Managers

7.1 Establish the WBS Early

WBS should be established during project planning, preferably during the proposal stage when the budget is developed, so the two can have the same organization. Some budget files have integrated WBS features so the two are in one document. The WBS dictionary is based on the scope statement (written scope of work) and can be created upon project approval, such as when the project plan is developed and kick-off meeting scheduled.

Early development of the WBS helps ensure that all the team members understand the scope limits before the design momentum sets in. A late WBS will mostly result in retroactive reconstruction of the project without leading the team with clarity.

7.2 Maintain a Living WBS with Revision Control

A WBS cannot be a fixed plan. The initial WBS is the baseline WBS. As design progresses, slight modifications may be necessary without an approved change to scope due to the introduction of new internal reviews, staff changes, design optimization, scope clarifications, or to fix errors discovered. It is recommended that a living WBS document be under a formal revision control, to ensure that all of the stakeholders are referring to the same version of the WBS.

All the versions should be documented with the version number, date, and description of the changes. All revisions of WBS can be automatically saved and managed in a digital collaboration system such as Microsoft Project, Microsoft Planner, Primavera, or enterprise resource planning (ERP) systems. These systems can also trace between the WBS items, budget items, and schedule activities, and provide full alignment of project information.

7.3 Integrate WBS with Scope, Schedule, and Cost Tracking

The full strength of a WBS is achieved when it is integrated within the project control documents. Each of the components of the WBS should be linked to the line item of the budget and to an activity in the schedule. Through such integration, the earned value can be analyzed, progress measured, and deviations can be detected quickly and efficiently. Modern software tools can readily facilitate this for the PM.

It is also possible to associate WBS codes with 3D representation elements such as Building Information Modeling (BIM). Adding WBS numberings to file names is also helpful as part of advanced document management system.

7.4 Periodic WBS Reviews

The WBS should be periodically reviewed when evaluating percent completes and when deliverables are being completed. In each of the reviews, the WBS should be checked against the actual work being completed, and any changes should be documented and considered for a formal change request. Although the PM takes responsibility for the WBS management, it is helpful for the deliverable leads to review the WBS for their respective items to confirm tasks have been completed without a scope change.

7.5 Train Team Members on WBS Use and Change Control

A culture of scope discipline through the use of a WBS takes leadership, encouragement, and training. Many engineers regard the WBS as an administrative exercise for PMs and accountants, and not a design management tool. PMs and organization leaders should raise awareness to team members regarding the importance of reviewing and using the WBS. It should be pointed out that the WBS integrates with cost and schedule management tools, for a comprehensive means to avoid scop creep and meet project objectives. Everyone wins when a project meets the objectives.

Workshops, onboarding, and on-job training can be used to demonstrate the WBS creation, navigation, and application to real world situations. Knowledge of the dictionary is of particular importance to design team members to confirm the work they do matches the agreed scope. A general agreement of the WBS allows team members to recognize the scope instead of asking the PM to figure it out.

7.6 Encourage Ownership

An organizations culture is a crucial element for a successful WBS management. A good culture leads to a sense of shared ownership of an accurate WBS that is used by everyone. Rewards can be granted to PMs and project teams that setup and utilize and accurate WBS. New employees should have WBS training as part of their orientation.

7.7 Client Collaboration

If an organization and the PM have confidence in the WBS, the client can be invitation to review the WBS to help establish a mutual understanding of the scope and provide transparency in change processes. Clients and other stakeholders will likely view the organization in a positive light upon seeing the effectiveness of a WBS.

7.8 Key Performance Indicators (KPIs)

Key performance indicators (KPIs) are used to quantify project performance. KPIs from projects with and without a WBS can be compared to quantify effectiveness of the scope control with a WBS. Examples of KPIs are as follows:

- Percentage of scope changes identified at early stages versus late stages of a project
- Percentage of work packages deployed without scope problems
- Percentage of change requests linked with valid WBS codes
- Percent of deliverables without changes
- Change costs as percent increase to original budget
- Change delays as percent increase to original schedule
- Quantity of quality review comments (internal and external)

The monitoring helps to build a culture of continuous improvement and helps organizations to enhance their WBS practices over time.

8 Course Summary

A WBS is not only a tool for planning, but a moving control system, which unites the scope, the schedule, and the cost. A thorough WBS ensures that every task is described, assigned, and being tracked. A PM can use the WBS to manage and control scope changes throughout a project.

A WBS that is used by the project team is likely to prevent scope creep before it starts. Projects with a disorganized scope and no WBS are often firefighting events as deliverable dates get closer. This is contrary to projects built on the disciplined practice of a WBS, which have fewer changes and accommodate changes systematically.

Defining scope limits with a WBS dictionary will allow a team to reduce, as well as serve as a framework by which new requirements can be evaluated on objective terms. The WBS dictionary, RACI matrix, and change log can be harmonized with each other in order to ensure transparency and accountability throughout the project lifecycle.

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Work Breakdown Structures for Engineering Projects - Quiz

Updated: 12/27/2025

1) **A scope statement and a Work Breakdown Structure (WBS) are complementary.**
    a. True
    b. False

2) **What does WBS stand for?**
    a. Work Breakdown Structure
    b. Written Breakdown of Scope
    c. Work Break Summary
    d. Work Building Structure

3) **Which is true of a WBS?**
    a. Includes costs
    b. Includes due dates
    c. Includes risk ranking
    d. Breaks down the work

4) **What is gold plating?**
    a. Premium coating systems
    b. Scope creep with good intentions
    c. Change orders
    d. Gilded products

5) **What is the most common cause of scope creep?**
    a. Poor scope definition
    b. New team members
    c. Lack of meetings
    d. Management change

6) **Which is NOT assigned to each WBS element?**
    a. Unique code
    b. Responsibility
    c. Dictionary entry
    d. Author

7) Which is the normal hierarchy in a WBS?

a. Project > Deliverables > Sub-deliverables > WPs
b. Project > Disciplines > Sub-disciplines > WPs
c. Project > Critical Tasks > Non-Critical Tasks
d. Portion > Disciplines > Sub-disciplines > WPs

8) What should the sum of all WP's equal?

a. Majority of the scope
b. 100% of the scope
c. Scope minus overhead work
d. Zero

9) What WBS level is 1.1.1?

a. 1
b. 2
c. 3
d. 4

10) What does WP stand for?

a. Work Package
b. Waterfall Project
c. Whole Package
d. Work Portion

11) A WBS allows linking scope, time, and cost?

a. True
b. False

12) What is the budget status if a WP is at 40% spent, and the actual progress is 50% complete?

a. Underbudget
b. On budget
c. Overbudget
d. Unknown

13) What is the schedule status if a WP is at 50% complete, and the schedule says it should be 80% complete?

a. Ahead of schedule
b. On schedule
c. Behind schedule
d. Unknown

14) What does RACI stand for?

a. Responsive, Actionable, Consulted, and Informational
b. Representative, Accountant, Champion, and Informal
c. Responsible, Accountable, Consulted, and Informed
d. Related, Accountant, Consultant, and Informed

15) Which are phases in change workflow?

a. Review Meeting, Management Input, Stakeholder Input, Execute
b. Identification, Evaluation, Approval, Update
c. Identification, Root Cause Analysis, Risk Review, Lessons Learned
d. Discovery, Discussions, Costing, Scheduling