AACE INTERNATIONAL RECOMMENDED PRACTICE

91R-16

SCHEDULE DEVELOPMENT

AACE INTERNATIONAL

AACE® International Recommended Practice No. 91R-16

SCHEDULE DEVELOPMENT

TCM Framework: 7.2 – Schedule Planning and Development

Rev. August 13, 2020

Note: As AACE International Recommended Practices evolve over time, please refer to web.aacei.org for the latest revisions.

Any terms found in AACE Recommended Practice 10S-90, *Cost Engineering Terminology*, supersede terms defined in other AACE work products, including but not limited to, other recommended practices, the *Total Cost Management Framework*, and *Skills & Knowledge of Cost Engineering*.

Contributors:

Disclaimer: The content provided by the contributors to this recommended practice is their own and does not necessarily reflect that of their employers, unless otherwise stated.

August 13, 2020 Revision:

Robert B. Brown, PE FAACE (Primary Contributor)
Larry R. Dysert, CCP CEP DRMP FAACE Hon. Life (Primary Contributor)
John P. Orr, PSP FAACE (Primary Contributor)
Abbas Shakourifar, PSP (Primary Contributor)
Dr. Stephen P. Warhoe, PE CCP CFCC FAACE Hon. Life (Primary Contributor)

March 20, 2018 Revision:

Dr. Maryam Mirhadi Fard, PSP (Primary Contributor)
Dr. Seyyed Amin Terouhid, DRMP PSP (Primary Contributor)
Brian Celeste, CCP PSP
Larry R. Dysert, CCP CEP DRMP FAACE Hon. Life
Ricardo Garcia da Roza
Saad Ishac
Vera Lovejoy, FAACE
Donald F. McDonald, Jr. PE CCP PSP FAACE Hon. Life
Dan Melamed, CCP EVP
Edward R. Mislavsky, CCP
John P. Orr, PSP
Richard C. Plumery, EVP
H. Lance Stephenson, CCP FAACE
Dr. Stephen P. Warhoe, PE CCP CFCC FAACE
Ronald M. Winter, PSP FAACE

AACE® International Recommended Practice No. 91R-16

SCHEDULE DEVELOPMENT

TCM Framework: 7.2 – Schedule Planning and Development

August 13, 2020

TABLE OF CONTENTS

1. INTRODUCTION

This recommended practice (RP) is to be used for schedule development. Schedule development is the process of translating the project scope into activities, contractual milestones, logical relationships, durations, resource availabilities, time constraints, and other schedule basis information into the project schedule model. It involves analyzing the technical and programmatic information about an asset or project to create the as-planned schedule model. This model presents a set of logically-sequenced activities that may be resource- and/or cost-loaded, and is presented in the form of a time phased action plan.

This document is intended to provide a guideline, not establish a standard.

The outputs of the schedule planning process are inputs for schedule development. Schedule planning translates work package scope into manageable activities and determines the manner and sequence (i.e., logic) in which these activities are best performed. Schedule development allocates the available resources to activities in the schedule model in accordance with cost and resource planning and alternative allocation criteria while respecting project constraints affecting the schedule (e.g., contract milestone dates).

Schedule development generally includes iteratively refining schedule planning outputs (e.g., planned durations, means and methods, workflow sequence, and/or preferential logic) in a way that realistically, if not optimally, achieves project objectives for time (e.g., milestones, overall project duration), cost (e.g., cash flow), and others (e.g., performance requirements) [1].

An effective schedule will integrate with project technical documents, scope of work, contracts, and other project attributes that have an impact on the project schedule. A well-developed schedule contains an appropriate level of detail to enable effective project management. The schedule development process may use various techniques such as Critical Path Method (CPM), Critical Chain Method, and Program Evaluation and Review Technique (PERT). These techniques will be reviewed briefly in this recommended practice and considerations for their use will be discussed.

August 13, 2020

Schedules provide a platform for communicating, executing (controlling and monitoring), reporting, and presenting a baseline for project progress and performance measurement. It also provides a means for collecting and recording project progress, a basis for processing payment applications to support work performed, and a platform for analyzing project alternatives and decision making. Budgets, costs, resources, risks, and other information logs can be integrated into a project schedule to provide a basis for an integrated project control system. Furthermore, courts use and rely upon schedules for assessing requests for equitable adjustments including delay and disruption claims.

2. RECOMMENDED PRACTICE

2.1. Different Types of Schedules

Schedules serve different purposes. A brief description of the most common types of schedules is provided. Identifying the purpose for each schedule is essential to guide its development process. Different types of schedules can be characterized based on criteria such as level of schedule, scheduling method, and end use.

From the level of scheduling perspective, schedules are differentiated by the degree of detail in the schedules. The main levels of schedules are as follows[3]:

Level 1: A Level 1 schedule is a high-level schedule that reflects key milestones and summary activities by major phase, stage or project being executed. This schedule level may represent summary activities of an execution stage, specifically engineering, procurement, construction and start-up activities. Typically represented in Gantt format and depending upon when and how developed, a Level 1 schedule may or may not be the summary roll-up of a more detailed CPM schedule. Level 1 schedules provide high-level information that assist in the decision-making process (go/no go prioritization and criticality of projects). Specifically, a project may be considered part of a program of projects (whether completed, in progress, or not yet started). The level 1 schedule assists in defining the necessity of implementing actions and course correction (if warranted, it may be necessary for high level management to intercede in the execution of the project). Audiences for this schedule Level include, but are not limited to client, senior executives and general managers.

Management summary schedules generally include the timeline for and status of key project deliverables, phases, processes, gating, milestones, and constraints. They provide a graphical management summary of the overall project plan so project leaders can communicate concise schedule information and project status at a project management level [19].

Milestone schedules are among the least complex types of summary schedules, typically comprised of key events or milestones that depict the start or completion of key phases or tasks of a project, and can be presented in a tabular or time-scaled format for management level reporting and decision making. This schedule is typically included in management level progress reports and typically includes milestones and summary activities.

Level 2: Level 2 schedules are generally prepared to communicate the integration of work throughout the life cycle of a project. Level 2 schedules may reflect, at a high level, interfaces between key deliverables and project participants (contractors) required to complete the identified deliverables. Typically presented in Gantt (bar chart) format and rarely in CPM network format Level 2 schedules provide high-level information that assist in the project decision-making process (re-prioritization and criticality of project deliverables). Level 2 schedules assist in identifying project areas and deliverables that require actions and/ or course correction. Audiences for this type of schedule include, but are not limited to general managers, sponsors, and program or project managers.

These project level schedules are an activity and deliverable-centered plan that is typically comprised of the major project phases (e.g., conceptual design, detailed-design, procurement, construction, commissioning, and close-out phases) and features of work. They may be presented in a time-scaled network logic diagram or bar chart.

Level 3: Level 3 schedules are generally prepared to communicate the execution of the deliverables for each of the contracting parties. The schedule should reflect the interfaces between key workgroups, disciplines, or crafts involved in the execution of the stage. Typically presented in Gantt or CPM network format and is generally the output of CPM scheduling software. Level 3 schedules provide enough detail to identify critical activities. Level 3 schedules assist the team in identifying activities that could potentially affect the outcome of a stage or phase of work, allowing for mitigation and course correction in short course. Audiences for this type of schedule include, but are not limited to program or project managers, CMs or owner's representatives, superintendents, and general foremen.

Level 4: Level 4 schedules are prepared to communicate the production of work packages at the deliverable level. This schedule Level should reflect interfaces between key elements that drive completion of activities. Typically presented in Gantt or CPM network format Level 4 schedules usually provide enough detail to plan and coordinate contractor or multi-discipline/craft activities. Audiences for this type of schedule include but are not limited to project managers, superintendents, and general foremen.

Level 5: Level 5 schedules are prepared to communicate task requirements for completing activities identified in a detailed schedule. Level 5 schedules are usually considered working schedules that reflect hourly, daily or weekly work requirements. Depending on these requirements, the Level 5 schedules are usually prepared a day or week in advance. Typically Level 5 schedules are presented in an activity listing format without time scaled graphical representation of work to accomplish. Level 5 schedules are used to plan and schedule utilization of resources (labor, equipment and materials) in hourly, daily or weekly units for each task. Audiences for this type of schedule include but are not limited to superintendents, general foremen and foremen.

There are several methods for developing schedules. These may include the following: narrative schedule, Gantt or bar chart, CPM, critical chain method, linear schedule, and PERT. These methods are described in the *Tools and Techniques* section of this recommended practice.

Schedules can also be defined by their intended purpose:

- A master schedule is a consolidated schedule incorporating multiple related projects (e.g., program management), or unrelated projects (e.g., a portfolio management of unrelated projects), or parts, phases, or specialty trade schedules of a project, or any other combinations of the aforementioned.

- A baseline schedule: A static project schedule that reflects all formally authorized scope and schedule changes against which project performance is measured.

- A schedule update: A statused, dynamic version of the baseline schedule that reflects the most current information on the project. The most recent version is also known as the control schedule.

- A recovery schedule is a plan for recovering time lost on the project (i.e. slippage) [2] through means that typically involve resequencing schedule logic, adjusting available work time, and/or adjusting activity durations to align the project with the most recent schedule that pre-dated the slippage.

- A look-ahead schedule includes a select set of activities for a short time-period, typically within the upcoming two- to six-week timeframe. This schedule highlights the near-term tasks projected to be performed in a given period of time to identify upcoming priorities for each of the project team participants. Look-ahead schedules may break down the extracted activities into more detail to provide team members a daily list of tasks to be performed.

- Turn-around schedules are special schedules with short look-ahead time periods that are used to plan and monitor hourly or daily work at a detail level necessary to coordinate plant outages work or production for different trades and specialty crews [3].

A schedule is typically presented graphically in the form of a bar chart or a logic bar chart (e.g., time-scaled logic/network diagram). As the degree of project definition increases, the scheduling methodology tends to transition from development of bar charts to network logic diagrams [4]. A schedule may also be presented in a non-graphic format (e.g., narrative, tabular).

2.2. The Components of Schedule Development [1]

The components of schedule development can be broken down into inputs, tools and techniques, and outputs as shown in Table 1.

Inputs	Tools and techniques	Outputs
1. Scheduling requirements 2. Plan for schedule development and monitoring (i.e., project controls plan) 3. Initial schedule model 4. Historical records 5. Technical documents 6. Work breakdown structure (WBS), work packages, and execution strategy 7. Trends, deviations, and changes 8. Estimated costs 9. Estimated resources 10. Information from project planning 11. Schedule submittals	1. Narrative schedule 2. Gantt chart (i.e., bar chart) 3. CPM 4. Critical chain method 5. Linear scheduling method (LSM) 6. PERT 7. Resource planning techniques 8. Scheduling tools / software 9. Simulation and optimization techniques 10. Collaboration techniques 11. Schedule review and validation	1. As-planned schedule model 2. Baseline schedule 3. Schedule basis document 4. Basis for schedule performance measurement and assessment 5. Refined scope development 6. Information for project monitoring and further detailing of the schedule 7. Trends, deviations, and changes 8. Schedule submittals 9. Historical schedule information

Table 1. Inputs, tools and techniques, and outputs for the schedule development process

Inputs include:

1. **Scheduling requirements:** The enterprise (i.e., any endeavor, business, government, group, individual, or other entity that owns, controls, or operates strategic assets) may establish requirements (including objectives, constraints, and assumptions) for schedule development and to determine if the project schedules are in alignment with the enterprise's requirements and with overall business strategy. The enterprise may also establish schedule budget and cost coding requirements to (i) ensure congruence with the enterprise and/or client's reporting or information systems (e.g., accounting system), (ii) enable productivity tracking and monitoring, (iii) distinguish between self-performed versus subcontracted work, and (iv) segregate costs and resources between subsidiaries.

August 13, 2020

Other sources for identifying scheduling requirements include technical documents, contract documents, and the project planning basis. Requirements to consider include stakeholder needs, resource and/or cost loading, structure (work breakdown structure and/or activity coding), constraints, reporting, updating, weather considerations, calendars, activity detail (durations, costs, resources), software, and application integration [5].

2. **Plan for schedule development and monitoring:** Schedule planning and development is performed in an integrated manner with other project control planning processes. Planning must consider the time, costs, resources, tools, methods, roles and responsibilities required for performance during the approved project or each phase. At the start of a project or any phase, the current documented scope basis and defining technical and contractual deliverables are the key inputs. Based on an assessment of these inputs, the project team further identifies activities, resources, and tools needed.

3. **Initial schedule model:** The initial schedule model is the primary input to the schedule development process. This model is the result of schedule planning by translating project scope into manageable activities and determining the manner and sequence (i.e., logic) in which these activities are best performed. The schedule model identifies the planned start and finish dates for project activities and milestones. Identification of project activities [7], developing activity logical relationships [8], and estimating durations [9] are three key processes that are required to develop a schedule model.

4. **Historical records:** Historical information gathered from prior projects (particularly in case of similar projects) is useful to support schedule development. Historical schedule metrics and benchmarks may be used to support schedule review and validation . Incorporating knowledge acquired from other projects is also important for effective schedule development and validation.

5. **Technical Documents:** Technical documents include specifications, drawings, and other documentation that define the work to be accomplished.

6. **WBS, work packages, and execution strategy:** The WBS provides the overall organization of asset investments or project work to be planned and scheduled. The project work package scope is defined with enough information to support decision making and appropriate control. The execution strategy identifies general approaches for planning consideration.

7. **Trends, deviations, and changes:** Trends, deviations, and changes are part of the change management process. Historical information from previous phases or projects may be inputs to the schedule planning and development processes. They should be evaluated for potential incorporation into the schedule. This information may also be useful during re-baselining.

8. **Estimated costs:** Cost data from the estimating and budgeting process in alignment with the WBS and work package activities are used for cost-loading the schedule as required by the project control plan. Attention should be paid to the validity of assumptions made for the budgeted costs, risks, resources and productivity, and their possible effects on activity durations. Spending and funding plans along with cash-flows may be prepared to support financial reporting.

9. **Budgeted resources:** Budgeted labor hours, material quantities, needed to perform the work, and other resources needed for each work package activity obtained from the estimating and budgeting process may be used for resource planning and management purposes.

10. **Information from project planning:** Resource planning, constructability analysis, value analysis and engineering, risk analysis and management, and procurement planning all may provide information to be considered in the schedule planning and schedule development processes.

11. **Schedule submittals:** If a contracted party develops its own schedule intended to be a part of the master schedule, that contracted party's schedule output becomes an input to the overall project master schedule upon acceptance by its client. Care should be taken to ensure that the external schedule aligns with the schedule model and other schedule inputs.

The schedule planning and development processes are applied in each phase of the project life cycle as the asset and project scope is defined, modified, and refined. Therefore, the specific tools and techniques used vary widely depending upon the lifecycle phase, the type of project, delivery method and the level of definition of scope information available.

Different methods are used to develop the schedule and determine a projected schedule completion date. The key methods are Gantt chart, CPM, critical chain method, LSM, and PERT. These methods can be used in conjunction with each other to address uncertainty from the scheduling perspective. This section describes these key methods, as well as other tools and techniques that are used for schedule development.

Tools and techniques include:

1. **Narrative schedule:** Narrative schedules provide a narrative description of the planned sequence of the project work and they are generally used in small projects that have only few activities.

2. **Bar Chart (i.e. Gantt chart):** Graphic representation of a project that includes the activities that make up the project and are placed on a time scale. Bar charts are time scaled, and show activity number, description, duration, start and finish dates, and an overall sequencing of the flow of work. Bar charts do not include the logic ties between activities.

3. **Critical Path Method:** CPM is a deterministic network model that uses a single duration estimate for each schedule activity to calculate the longest duration path for the project and to establish the earliest and latest dates for schedule activities by using forward and backward pass calculations, respectively.

4. **Critical chain method:** The critical chain method, developed based on the CPM concept, uses time buffers on schedule paths to account for resources that constrain the work. This method identifies the longest-duration sequence of resource-constrained activities through a project network to determine the shortest-possible project duration based on the constraints applied to the schedule.

5. **Linear Scheduling Method:** LSM schedules are typically used on projects wherein the majority of the work is made up of highly repetitive tasks (e.g., pipeline, tunnel, runway, highway, or rail projects). LSM schedules use velocity diagrams representing each activity. The schedule format typically provides the planned and actual production rates on a time scaled format. It is also important to note that the LSM is sometimes referred to as Line of Balance, Vertical Production Method, Time-Space Planning, Repetitive-Unit Construction, or Time Couplings Method despite minor differences that may exist between these methods.

6. **Program Evaluation and Review Technique:** PERT is a probabilistic (i.e., stochastic) network model that allows for randomness by introducing uncertainty to activity duration estimates. This method uses three duration estimates (i.e., optimistic, most likely, and pessimistic) to calculate the expected time for schedule completion.

7. **Resource planning techniques:** Resource planning identifies future resource requirements for an organization or a scope of work. By assigning (loading) resources to each activity, resource requirements can be estimated and available resources can be scheduled in accordance with consumption limitations (e.g., money, labor hours) by resource leveling, smoothing, or balancing. Resource planning also allows

the project stakeholders to determine if the schedule is forecasting reasonable and realistic resource levels at various periods of the project duration (e.g., to prevent trade stacking or congestion).

Any form of network analysis in which scheduling decisions are driven by resource management concerns (e.g., limited resource availability or difficult to manage changes in resource levels) is referred to as resource leveling. Smoothing is a type of resource leveling in which activities are rescheduled such that the project completion date remains unchanged and the requirement for resources does not exceed resource limits [2].

Schedules are used as analytical tools to assess resource efficiencies. Incorporation of resources into the project schedule provides a baseline for efficiency, delay and disruption analyses, and may be used to support claims for delay, disruption or acceleration from changed conditions [10].

8. **Scheduling tools/software:** Scheduling software incorporates basic algorithms for schedule development and provides the tool used to calculate schedules and generate reports. Schedule development is not an automated process. It relies on a variety of duration, logic and other information from multiple sources requiring decisions and analyses that need a human interface.

9. **Simulation and optimization techniques:** Value analysis and risk assessment use what-if scenarios to optimize scope decisions in terms of cost and schedule. During the schedule optimization phase, the duration of activities may change to keep resource usage or expenditure rates within planned limits or budget constraints. Schedule compression (i.e. crashing) is one of the schedule optimization methods that tries to shorten the duration of the critical path by adding more resources to selected critical activities while considering cost/schedule tradeoffs.

10. **Collaboration techniques:** Team input regarding activities, approaches, and investment or work sequencing logic may be obtained through workshops, interviews, executability reviews, and similar methods. Obtaining these inputs and incorporating them into the schedule is important to ensure that not only is consensus achieved, but to also define the needs and expectations of the team and stakeholders.

11. **Schedule review and validation:** Schedule review seeks to ensure that the schedule reflects the defined scope, is suitable for control purposes, is sequenced properly, meets the stakeholders' milestone requirements and commitments, and that all parties agree on and understand its content, including its probabilistic nature in relation to various agreements and contractual requirements. Additionally, the schedule should be benchmarked or validated against or compared to schedule metrics to assess its appropriateness, competitiveness, areas of risk, and to identify improvement opportunities.

Outputs include:

1. **As-planned schedule model:** This model is the primary outcome of the schedule development process and includes a list of activities with their planned date information (e.g., early and late start and finish dates). This model, once approved, becomes the basis for the baseline schedule. It can be used to test alternate criteria, approaches, resource scenarios, and risk factors.

2. **Baseline schedule:** The baseline schedule is the approved time-phased, logically linked detailed interpretation of the project execution plan. It may be resource loaded and includes the entire project scope of work reflected by activities, summary activities, milestones, and interfaces, in a structured way. During project execution, the project's baseline schedule may be revised to reflect major changes in the execution plan (i.e., establishing a new schedule baseline) if the project team determines that a revision is

necessary due to significant project events. A revision to the baseline (or re-baselining) typically requires owner approval.

3. **Schedule basis document (i.e., baseline narrative):** At the close of the initial schedule development, the baseline schedule shall be thoroughly documented in the schedule basis [14] and communicated to the project team. The schedule basis provides a high level summary of the schedule, a statement of the schedule purpose, and a comprehensive description of the schedule contents including description of the critical path, other high risk activities, resources, methodologies, standards, references, deliverables, assumptions, inclusions and exclusions, key milestones and constraints, calendars, and indications of the level of risk and uncertainty used to establish schedule contingency. The schedule basis becomes the reference for the change management process to understand changes, deviations, and trends.

4. **Basis for schedule performance measurement and assessment:** Schedule development is aligned with the project control plan that establishes how project performance will be measured and assessed, including rules of credit for measuring progress, and the procedures for evaluating progress and forecasting remaining durations [15, 20].

5. **Refined scope development:**: Results from the schedule planning and development processes may lead to modifications and refinements to the WBS, work package definitions, and execution strategy.

6. **Information for project monitoring and further detailing of the schedule:** Results from the schedule planning and development processes may lead to modifications and refinements in the cost estimates and cash flow analysis, resource plans, value engineering analyses, risk analyses, and procurement planning.

7. **Trends, deviations, and changes:** The results of trend, deviation, or change evaluations are inputs to the change management process.

8. **Schedule submittals:** Often, contracted parties are responsible for the detailed schedule planning and development of the activities within their contract scope. If so, their schedule deliverables, as required by the contract, are their process outputs that become an input to the overall or master schedule developed and maintained by the party responsible for maintaining the overall or master schedule.

9. **Historical schedule information:** The as-planned schedule, baseline schedule, schedule basis, and other plan information provide inputs to the project historical database.

2.3. Proper Level of Detail

Project stakeholders require different levels of detail, reports, and types of information from the schedule; AACE provides recommendations as to the number of schedule levels and their formats [3]. Project schedules should be developed such that they provide the appropriate level of detail for use by the stakeholders, and for reporting progress. The approved baseline and update schedules must be flexible to meet various reporting requirements (e.g. organized by activity codes, WBS, COA, and OBS). Reporting requirements may have a direct influence on schedule design [10]. For example, if an owner needs reports for the financial institution that provides project funding, the schedule should support this level of reporting. If field project management needs look-ahead schedules for short-term planning, then the level of detail must be sufficient to allow frequent updates and significant task information by discipline/trade. Business stakeholders are likely to be most interested in milestone and final completion metrics that they will monitor. Contractors, on the other hand, may want to also monitor and control their labor and equipment requirements at a more detailed level. Subcontractors and vendors may monitor and control their own work at a more granular level, but they also must make provisions to interface with the prime contractor and other subcontractors or vendors.

Lower level schedules should allow for the roll-up of similarly grouped or defined activities to higher schedule levels. For example, the level of detail presented in an engineering, procurement, and construction (EPC) model schedule may be directly aligned with particular phases of development for the project. The level of detail for an EPC schedule would depend upon the available scope definition. As the project moves into subsequent phases and more scope information becomes available, the schedule is revised to reflect this additional detail. This is sometimes referred to as a form of "rolling wave" method of scheduling [2]. The rolling wave concept involves iterative planning steps in which the work to be executed in the near future is known and planned in detail. The future work may be unknown and is planned at a higher level of detail or summary level. Therefore, schedules are progressively elaborated with more detail. This breakdown of the scope of work into smaller duration activities helps to plan and monitor the work with higher precision of resource and time requirements.

Schedule development at a summary level may be carried out by using a simple model of estimated duration versus cost. Such a schedule will support rudimentary cash flow and resource loading analysis and provide reasonable assurance that milestone date requirements can be met. When limited scope information is available during strategic asset planning or early project scope development phases, schedule planning and development may be limited to manually developing lists of the major activities and milestones and/or simple bar charts. It is common to have summary activities included early in the schedule. Then, as a specific phase of the project approaches, these activities are expanded into further detail in a type of rolling wave schedule. When scope definition is advanced, software tools are almost always used and the schedule planning and development outputs may include extensive activity lists, logic diagrams, time-line graphics presented in alternate views to suit various needs (e.g., by different levels of the WBS, different responsibilities, and reporting requirements).

The level of detail in the schedule also depends on the nature, size, duration, and complexity of the project [3]. For example, power plant outages often use short interval scheduling in which there may be several thousand of activities measured in hours or even fractions of hours. The level of detail may be contractually stipulated, where limits may be set for the activity's minimum and/or maximum duration, the progress monitoring and reporting requirements, funding categories, or other requirements. The schedule needs sufficient activities to reflect schedule interdependencies. Too few activities may create difficulties for schedule analysis. A high level of detail may make updates more time-consuming but may make analysis easier and more accurate. A trade-off comes in the capability to monitor and update the work.

Before initiating schedule development, it is important to determine whether the method of schedule development is a bottom-up or top-down approach, or a combination of the two. Using a bottom-up approach may be easier to develop for those who have detailed information available but carries the risk of overdeveloping portions of the project schedule, requiring more time to develop. Using a top-down approach generally is quicker and simpler but it is more difficult to obtain the accuracy of the details than would be developed in a bottom-up approach. Using a combination approach will often allow the top-down portion to be used to guide the efforts during the bottom-up phase of the development.

Once the approach is determined, the next step is identifying functional stages, followed by reviewing the areas within the functional stages, and grouping those areas into common groups based on the predicted rate of progress. If stages are chosen appropriately, then each stage may progress somewhat independently of the other stages. Examples include: underground utilities that may run concurrently but not in the same sequence as foundations; exterior façade work that may progress independently and concurrently with interior rough-ins; and earthwork on a roadway project that may proceed independently from utilities but will partially precede and partially succeed the utilities work. It is important to review the utilization of the schedule. This helps establish the update frequency that is an important consideration for the level of schedule detail. Establishing the smallest activity duration range based on the frequency of schedule updates will make the transition to bottom-up detail schedule development easier [10].

August 13, 2020

2.4. Development of Project Schedules

The primary outcome of the schedule development process is the as-planned schedule model, which may integrate time, cost, resource, and risk planning. This integration occurs by loading cost, resource, and risk attributes of schedule activities into the schedule model to form control baselines. The approved baseline schedule becomes the basis for measuring actual and forecast progress, and for assessing change and delay.

The following provides a methodology for developing project schedules:

Collect inputs required: The previous section specifies the list of inputs required for developing the schedule. Since schedule development is an iterative process, it may commence even without some of the inputs. However, a well-developed schedule cannot be prepared until all the inputs are collected and processed in a timely and an appropriate manner.

Select time unit: Depending on the contract requirements, project and schedule type, and the required level of detail, an appropriate time unit (e.g. weeks, days, or hours) is selected for project activities to be expressed in that time unit. Although the day is the most common time unit used in project schedules, hours are commonly used for schedules depicting work to be performed during a plant outage or turnaround. The same time unit should be used consistently throughout the schedule.

Establish the schedule outline: The schedule outline is the means by which project activities are classified. The schedule outline forms the schedule structure and a basis for producing schedule layouts.

Enter WBS and coding structures: The WBS and other coding structures should be used as the framework for the schedule, defining activity codes, and classifying project activities. It is good practice to incorporate a deliverable-oriented WBS (i.e., hierarchical decomposition of the total project scope into project deliverables), a process-oriented WBS (i.e., hierarchical decomposition of the total project scope into process steps, also known as functions or stages of the work [11, 12]), the OBS. It may include other coding structures that correspond to activity attributes, such as the COA, work areas (e.g., area, location, zone, or floor), project stage gates, phases, contracts, disciplines (e.g., civil, mechanical, electrical, instrumentation), and trades, in the schedule.

Define activity coding structure: Activity code dictionaries should be established after planning the organization layout of the schedule to define the coding structure for activities. Activity codes are a means of tagging each activity systematically to allow for effective and quick schedule monitoring, as well as to provide customizable filters, layouts, and organized reports. Activity codes are used to sort, select, filter, and group activities. Activity codes should support a variety of reporting needs to effectively manage the project. Project planning and scheduling professionals may choose to consider activity codes that are composed of characters set to correspond to deliverable and process-oriented WBS, OBS, COA, work area, project stage gates, phases, contracts, disciplines, and trades, or any other codes required by the contract.

Define and assign project and resource calendars: If the schedule is to be resource loaded, work days and shifts that are available for scheduled activities and resource availability dates denoting when a resource or resource pool is available for work on the project must be identified and documented in project and resource calendars, respectively. Workdays, holidays, rest days, rotations, seasonal and operational non-work periods, and working shifts are considered when developing these calendars. Project planning and scheduling professionals may need to define different or customized calendars for different project teams or resources depending on their availability or working conditions. Anticipated or contract-stipulated adverse weather days may be accounted for in defining these calendars [16]. After calendars are defined, they are then assigned to individual schedule activities.

Add activities and assign activity attributes: Project activities are added into the schedule and assigned previously-defined activity codes. Activity attributes (e.g., WBS, location, or responsibility identifiers) are added to the project schedule either at the same time as activities are entered into the schedule or at a later stage. One of these attributes is the activity ID, which may provide a unique identification string (i.e., numeric or alphanumeric) that involves multiple code components in a structured manner. Each of these code components represents a separate attribute. In assigning activity codes to generate unique activity identification numberings, it is good practice to use directional numbering (i.e., numbers increasing in magnitude from the start to the finish of the project) and numbering gaps (to allow for inclusion of additional activities into the schedule in later stages of the scheduling process). [13]

Choose scheduling options: Commercially available scheduling software applications usually allow the users to choose any of end-of-day, beginning of day, or a combination convention [13] for performing schedule calculations. Planners and schedulers should make an informed decision about the proper activity start/finish convention that addresses the project scheduling needs.

Generate the computerized logic network: All available planning and scheduling data is incorporated in building a computerized logic network. Activity logic development is iteratively refined and improved as needed. It is important to ensure that the schedule is free of logic deficiencies (e.g., incorrect logic, logic loops, missing logic, excessive or improper use of time lags/leads, redundant activity relationships). Every activity, except the first and last ones, must have at least one predecessor and one successor. It is recommended that the schedule starts with a start milestone and ends with a finish milestone. Planners and schedulers should use logic relationships to address considerations such as: [13]

a) Physical relationship: A physical relationship (i.e., causal relationship) exists between two activities when one activity cannot start until the other activity is either partially or totally complete.
b) Safety relationship: A safety relationship is defined when executing two activities at the same time may cause a safety hazard.
c) Resource relationship: A resource relationship is defined when sequencing decisions are driven by resource management concerns (e.g., limited resource availability or difficult to manage changes in resource levels).
d) Preferential relationship: A preferential relationship is a discretionary and non-causal relationship that represent the way that the scheduler or the project team preferred to sequence the work.

A proper combination of sequential, concurrent, multiple successor, and multiple predecessor should be used to establish activity sequences. However, it is recommended to refrain from using resource relationships and use resource leveling techniques to address resource management concerns.

In developing the schedule logic, proper date and float constraints should be incorporated into the schedule if a restraint takes precedence over a logical activity relationship. Constraints should be held to a minimum, and only used where required by contract, regulations, or when proper logical activity relationships cannot create the required or intended results. Common constraints include: as soon as possible, as late as possible, start no earlier than, start no later than, finish no earlier than, finish no later than, must start on, and must finish on.

It is good practice to not rely on automated solutions or cloned schedule models; each schedule model must be carefully vetted so that the product accurately represents the current project plan. The process used to select a specific scheduling software should take place during schedule design (i.e., prior to schedule development). The main criteria for selecting an appropriate scheduling software application include specific scheduling requirements, contractual requirements, compatibility and integration considerations, budget and other required features.

It is important to take note of the data date is a key piece of information for network calculations. For a baseline network, the data date coincides with the starting point of the network. During the schedule update process this date is a specific date on the schedule signifying the demarcation line between work completed up to that date and remaining work.

August 13, 2020

Cost and resource load the schedule: Estimates of costs (i.e., budgeted costs) and resources required for each activity (i.e., workforce, consumable material, equipment, or other physical resources) may be assigned to scheduled activities. Costs and resources are identified and added to the project schedule either at the same time as activities are entered into the schedule or at a later stage. Resource loading the schedule allows for resource tracking, optimization and leveling of resources and adjusting the schedule based on resource constraints. Cost loading the schedule allows for the development of funding plans, spend plans, cash flows, and may aid in establishing earned value management.

Activity duration types: Activity duration types (i.e., fixed duration and units, fixed duration and units/time, fixed units/time, fixed units) should be defined as necessary to determine how resource allocations should adjust activity durations [9].

Schedule review: The schedule is reviewed and validated by assessing the schedule details including, the level of detail, cost, resource, and duration estimates, dependencies, work and resource distributions, overlapping/concurrent work, and critical and near-critical paths to ensure that the schedule meets project objectives [17,18].

Optimize the schedule: The initial project schedule can then be optimized by iterative modification of the plan and schedule inputs until the most satisfactory schedule is obtained. Simulation methods or what-if analysis are used to find optimum or near-optimum outputs by changing key schedule inputs such as activity durations, sequences, and cost/resource assignments. Schedule risk analysis identifies the likely range of estimated activity durations (optimistic, most likely, and pessimistic estimates); the results may be used to adjust the schedule. Methods such as decision tree analysis and Monte Carlo simulation can be used for what-if analysis to facilitate the decision-making process involved in schedule optimization [21].

Approve the project schedule: Necessary approvals are obtained to ensure that the project sponsor, project team, and stakeholders approve the project schedule as the baseline schedule and as a basis to proceed with implementation. Even if not formally required, obtaining the acceptance of the project schedule from the project sponsor, project team, and stakeholders is recommended to ensure that all concur with the schedule.

Establish schedule control basis: The project baseline schedule provides a basis for control and is established once the project team and stakeholders are in agreement with the project schedule. It should be confirmed that changes are contractually permissible and, if so, a change management process should be in place to track changes to the project control basis via a set of revisions. Any change to the project control basis can be made by issuing a new control basis with an approved revision number enumerated on a revision log. This log identifies the revision, describes the latest changes; and it records who requested the changes, who approved the changes, and addresses disposition. It is good practice to designate a copy of the baseline schedule as the target schedule against which actual performance can be measured. Scheduling software usually permits the addition of multiple target schedules to the schedule so that users can track changes and compare the schedule control basis as the project progresses. The control schedule is to be used for progress and performance measurement, analysis, and what-if scenarios to determine the ramifications of delay events or project management decisions on the completion dates [3].

Communicate the schedule: Stakeholders may require different levels of detail and types of information from the schedule. Therefore, more than one type or version of the same schedule may be issued. Each type or version of the schedule must identify the source schedule and the status date upon which these schedules are based. The planned baseline schedule and its documented basis (including assumptions on how project performance is measured and assessed) needs to be communicated to and understood by all stakeholders.

The project schedules should be communicated properly with internal and external stakeholders through methods such as workshops, review meetings, project meetings, and schedule reports to ensure that they are engaged and informed and have the opportunity to express their needs and expectations. The schedule reports should be developed in such a way that their content and format satisfy reporting needs. If the project schedule is provided to the project team as a schedule report, the following activity attributes may be included: activity ID, activity name, duration, remaining duration, percent complete, responsible party, early start, early finish, actual start, actual finish, and total float. It is good practice to group activities based on a structure that corresponds with the deliverable or process oriented work breakdown structure, or a hybrid of both, or any other activity attributes. Project activities should be sorted using a stakeholder desired criteria. Common activity sorts include activity codes, early start, criticality status/total float, user-defined activity priorities, or a combination of these criteria.

2.5. Roles and Responsibilities

Multiple stakeholders are involved in schedule planning and development. When services are contracted much of the schedule planning and development detail may be undertaken and be the responsibility of contractor(s). The product of the contractor's schedule planning and development process is often a submission of the requested bid or tender schedule, or contracted schedule deliverable to another contractor, and/or to the owner as appropriate. The deliverable typically includes a planned schedule for activities within the contractor's scope of work and activities of outside parties that interface with the contractor's work. A contractor's schedule is generally an input to the overall or master schedule, which is developed and maintained by the project owner or their designee.

Typically, contracts specify the schedule requirements for a project; however, understanding who needs to be involved with the schedule development process assists in effective schedule design. On the owner side, identifying the reviewer(s) of schedules is important because they may establish requirements that may differ from the schedule specifications. The schedule reviewer(s) might allow minor adjustments to logic or may require approval for all changes to the schedule. The process for schedule submission, revising, and approval, including any lessons learned, should be established and communicated. This process should also include the establishment of the change management process so the project starts out with an organized approach to handle changes that may occur during the project.

Identifying all schedule stakeholders and defining their roles is important. Constant engagement of the stakeholders helps to ensure that all project needs have been properly addressed. During schedule development, all major responsibilities and the roles to fulfill those responsibilities need to be identified.[10] It is important that the project team assigns roles based on the type of schedules needed. For instance, look-ahead schedules are developed with the relevant superintendent and field engineers for each trade or craft discipline and ultimately would integrate all of the crafts' work schedules. These schedules are periodically reviewed at site meetings so responsibilities can be confirmed, actual dates and progress assigned, and potential conflicts and interferences prevented.

3. CONCLUSION

Schedule development is the process of translating project scope, activities, contractual milestones, logical relationships, durations, resource availabilities, time constraints, and other schedule basis into the project schedule model. As a guideline, this recommended practice described the components, characteristics, and the steps of the schedule development process.

REFERENCES

1. Stephenson, H. Lance, CCP, Editor, *Total Cost Management Framework: An Integrated Approach to Portfolio, Program and Project Management,* Morgantown, WV, AACE International, (latest revision).
2. AACE International, Recommended Practice 10S-90, *Cost Engineering Terminology*, AACE International,

Morgantown, WV, (latest revision).

3. AACE International, Recommended Practice 37R-06, *Schedule Levels of Detail – As Applied in Engineering, Procurement, and Construction*, AACE International, Morgantown, WV, (latest revision).
4. AACE International, Recommended Practice 27R-03, *Schedule Classification System*, AACE International, Morgantown, WV, (latest revision).
5. Schumacher, Hannah E., PSP, and C. Jackson, *Lessons Learned – Schedule Development Using Primavera P6*, 2010 AACE International Transactions, AACE International, Morgantown, WV, 2010.
6. AACE International, Recommended Practice 60R-10, *Developing the Project Controls Plan*, AACE International, Morgantown, WV, (latest revision).
7. AACE International, Recommended Practice 23R-02, *Identification of Activities*, AACE International, Morgantown, WV, (latest revision).
8. AACE International, Recommended Practice 24R-03, *Developing Activity Logic*, AACE International, Morgantown, WV, (latest revision).
9. AACE International, Recommended Practice 32R-04, *Determining Activity Durations*, AACE International, Morgantown, WV, (latest revision).
10. AACE International, Recommended Practice 61R-10, *Schedule Design — As Applied in Engineering, Procurement, and Construction*, AACE International, Morgantown, WV, (latest revision).
11. Golpayegani, S. Alireza Hashemi and Emamizadeh, Bahram, *Designing Work Breakdown Structures Using Modular Neural Networks*, Decision Support Systems, Elsevier, Oxford, UK, 2007
12. AACE International, Recommended Practice 33R-15, *Developing the Project Work Breakdown Structure*, AACE International, Morgantown, WV, (latest revision).
13. Glavinich, Thomas, *Construction Planning and Scheduling 2nd Edition*, The Associated General Contractors of America, Arlington, VA, 2004.
14. AACE International, Recommended Practice 38R-06, *Documenting the Schedule Basis*, AACE International, Morgantown, WV, (latest revision).
15. AACE International Recommended Practice 82R-13, *Earned Valve Management (EVM) Overview and Recommended Practices Consistent with EIA-748-C*, AACE International, Morgantown, WV, (latest revision).
16. AACE International, Recommended Practice 84R-13, *Planning and Accounting for Adverse Weather*, AACE International, Morgantown, WV, (latest revision).
17. AACE International, Recommended Practice 53R-06, *Schedule Update Review – As Applied in Engineering, Procurement, and Construction*, AACE International, Morgantown, WV, (latest revision).
18. AACE International, Recommended Practice 78R-13, *Original Baseline Schedule Review – As Applied in Engineering, Procurement, and Construction,* AACE International, Morgantown, WV, (latest revision).
19. AACE International, Recommended Practice 89R-16, *Management Summary Schedule,* AACE International, Morgantown, WV, (latest revision).
20. AACE International, Recommended Practice 90R-17, *Statusing the CPM Schedule – As Applied in Construction,* AACE International, Morgantown, WV, (latest revision).
21. AACE International, Recommended Practice 70R-12, *Principles of Schedule Contingency Management – As Applied in Engineering, Procurement, and Construction,* AACE International, Morgantown, WV, (latest revision).

CONTRIBUTORS

Disclaimer: The content provided by the contributors to this recommended practice is their own and does not necessarily reflect that of their employers, unless otherwise stated.

August 13, 2020 Revision:
Robert B. Brown, PE FAACE (Primary Contributor)
Larry R. Dysert, CCP CEP DRMP FAACE Hon. Life (Primary Contributor)
John P. Orr, PSP FAACE (Primary Contributor)
Abbas Shakourifar, PSP (Primary Contributor)

August 13, 2020

Dr. Stephen P. Warhoe, PE CCP CFCC FAACE Hon. Life (Primary Contributor)

March 20, 2018 Revision:
Dr. Maryam Mirhadi Fard, PSP (Primary Contributor)
Dr. Seyyed Amin Terouhid, DRMP PSP (Primary Contributor)
Brian Celeste, CCP PSP
Larry R. Dysert, CCP CEP DRMP FAACE Hon. Life
Ricardo Garcia da Roza
Saad Ishac
Vera Lovejoy, FAACE
Donald F. McDonald, Jr. PE CCP PSP FAACE Hon. Life
Dan Melamed, CCP EVP
Edward R. Mislavsky, CCP
John P. Orr, PSP
Richard C. Plumery, EVP
H. Lance Stephenson, CCP FAACE
Dr. Stephen P. Warhoe, PE CCP CFCC FAACE
Ronald M. Winter, PSP FAACE

