WHITE PAPER

Factors Affecting Construction Labor Productivity

Managing Efficiency in Work Planning

INTERGRAPH®

Contents

1. Introduction

The measure of the rate at which work is performed is called “productivity”. It is a ratio of production output to what is required to produce it. The measure of productivity is defined as a total output per one unit of a total input.

In construction, the output is usually expressed in weight, length, or volume, and the input resource is usually in cost of labor or man-hours. There are many standards available in the construction industry for contractors as reference values for purposes of construction cost estimation. These standards may vary in values but most are similar in principle.

This white paper will explore labor factoring and how advances in technology are making management of labor productivity more predictable. The use of technology can expose inefficiencies, enable visualization of problem areas, and improve construction planning accuracy, as well as provide documentation and visualization to support or defend change order requests and construction claims.

2. Labor Impacts on Construction Planning

The American Association of Cost Engineers defines productivity as a "relative measure of labor efficiency, either good or bad, when compared to an established base or norm." This white paper focuses on the ability to create, change, and manage labor factors affecting productivity in construction planning.

While trying to benchmark productivity is difficult as an absolute value, many sources are available for benchmarking trends from historical data collected, which are made available from many trade and professional associations. These include the US Department of Labor, US Bureau of Labor Statistics, Contractors Associations, independent contractors, universities, and other organizations. Although there are numerous lists of labor factors from different groups, most are very common to many lists and carry a similar range of impacts on labor productivity.

Every year, owner operators, engineering, procurement, and construction (EPC) companies, and contractors are hit with billions of dollars in construction claims as a result of inefficiency factors impacting labor. Good construction planning should consider and track labor factors in the original work scope to accurately reflect all the conditions that were used to estimate and fund the project, as well as to eliminate or minimize the impact on productivity, which will directly affect the construction costs. It should also include changes in work scope that look at labor impacts as part of the sequence and planning of any work.

Technology such as Intergraph® SmartPlant® Construction can help work planners manage and control labor impacts by providing users the ability to add and adjust labor factors for their project. It also allows users to visualize and animate work packages with the ability to change the sequence of work packages in order to eliminate or reduce labor factoring. In addition, SmartPlant Construction can create work package documentation to support or defend construction claims associated with labor factoring.

3. Unique Projects

No two construction projects are exactly the same and vary in many ways such as design, size, capacity, utilities, location, orientation, and so on. When projects are planned and budgeted based on historical data, it is important to consider the differentiators and variables unique to the project and factor them accordingly. All projects are unique and have some variables. Even those with the exact same design will have some differentiators, including:

- Design or capacity
- Varying site conditions such as soil, drainage, and so on
- Weather conditions such as climate and temperature
- Season changes
- Manpower and labor conditions, such as union versus open shop, and skilled versus unskilled labor
- Experience factors such as learning curve and legacy data from previous projects
- Intangible factors such as morale, fatigue, and attitude, which leads to absenteeism, turnover, and crew size inefficiency
- Site access
- Unplanned errors and omissions, work stoppages, delays, and so on
- Source and location of power and utilities
- Governmental or regulatory requirements
- Material source, supply, and codes
- Different project team and supervision
- Proximity to transport and logistics

4. Methods of Measuring Inefficiency

Measuring inefficiencies on construction projects has been done numerous ways over the years:

- Measured Mile
- Comparison to other projects
- Comparison to contractor's bid, estimate, or plan
- Use of expert testimony to establish inefficiency
- Published inefficiency factors or studies
  - Bureau of Labor Statistics
  - Business roundtable
  - National Electrical Contractors Association
  - Mechanical Contractors Association of America
  - The U.S. Army Corps of Engineers Modification Impact Guide
- Practical exercises and case studies

Many of these have been used for construction claims, such as the "Measured Mile". It gauges inefficiency loss by comparing a measurable period of time on a project impacted with inefficiencies against a period of the same length with no inefficiency impact.

It is important to use known and accepted industry sources whenever possible to establish and build inefficiency tables. Reliable industry standards, practices, surveys, historical data, and case studies can all prove to be excellent sources for developing a table of factors for labor inefficiency for use in construction planning.

Another consideration in developing a table of factors with reliable and known sources is the established credibility in helping to support or defend a construction claim and change orders as a result of impacts caused from inefficiencies.

5. Contractor Productivity Loss Claims

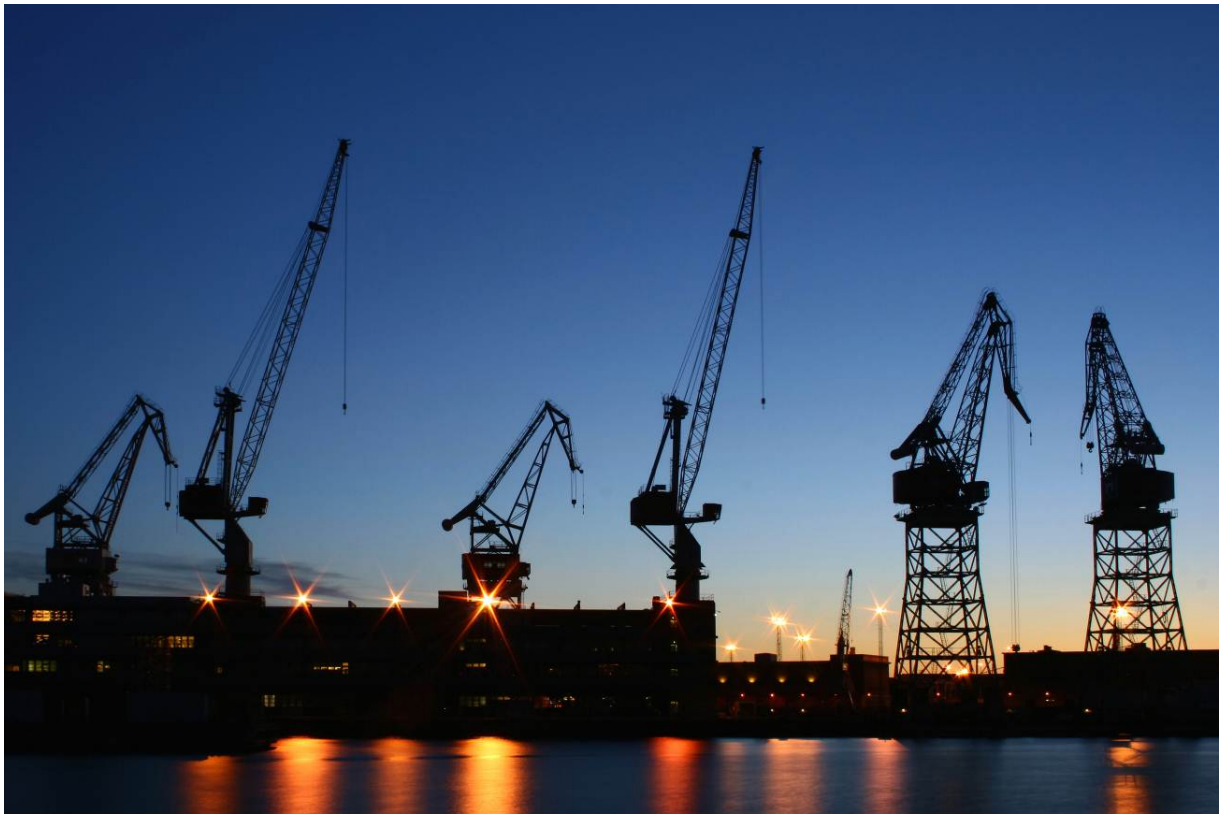
According to the Independent Project Analysis Group, an average of over 35 percent of all construction projects will have a major change. A change in a project of any kind usually means there will be associated productivity impacts that can be attributed to inefficiencies as well.

EPC companies, contractors, and subcontractors usually have contracts with a defined work scope, duration, start date, and other parameters to base their estimate. Often, the design is incomplete or changes are made that will impact the original estimate. The original project may have been planned for partial execution in cold weather and other inefficiencies; however, the changes will probably constitute additional impacts and inefficiencies.

One key example is owners will very often demand the same completion date, despite the added work scope. This may require overtime, second shift work, rework, additional crafts, and many other impacts to the original plan and estimate. This increase in man-hours, constraints, and other resources would impact the cost and schedule.

Another impact that may occur is the need for new or additional material, constraints, and equipment, which affect the sequence, duration, and schedule of work packages. There could also be an increase in idle time of workers waiting on material.

Such changes may cause manpower increases and work areas to be overcrowded with workers who now need to share and occupy the same work space, scaffolding, or equipment with other crafts, causing a further drop in productivity.



6. Factors Affecting Labor Productivity

There are many factors that affect the productivity of labor in construction. These are generally set forth in publications or manuals made available through associations like the Mechanical Contractors Association of America (MCAA) and other organizations. For example, the MCAA has a list called *Impacting Factors on Construction Crew Productivity*, and this list highlights 16 factors affecting labor productivity.

6.1 Labor Factors

Here are some of the most recognized factors affecting labor productivity in the industry:

1. **Overtime**

   Scheduling of extended work days or weeks exceeding a standard eight-hour work day or 40-hour work week lowers work output and efficiency through physical fatigue and poor mental attitude.

2. **Morale and Attitude**

   Spirit of workers based on willingness, confidence, discipline, and cheerfulness to perform work or tasks can be lowered due to a variety of issues, including increased conflicts, disputes, excessive hazards, overtime, over-inspection, multiple contract changes, disruption of work rhythm, poor site conditions, absenteeism, unkempt workspace, and so on.

3. **Fatigue**

   Fatigue can be caused by prolonged or unusual physical exertion.

4. **Stacking of Trades**

   This occurs when operations take place within physically limited space with other contractors, resulting in congestion of personnel, inability to use or locate tools conveniently, increased loss of tools, additional safety hazards, increase visitors, and prevention of crew size optimum.

5. **Joint Occupancy**

   This occurs when work is scheduled utilizing the same facility or work area that must be shared or occupied by more than one craft, and not anticipated in the original bid or plan.

6. **Beneficial Occupancy**

   This is a result of working over, around, or in close proximity to other crafts, owner's personnel, or production equipment, which may cause noise limitations, dust, or other hazardous risk. This may also prevent or cause access restrictions.

7. **Concurrent Operations**

   This is the effect of adding operations to any sequence of operations that has already been planned, without a gradual and controlled implementation of additional operations.

8. **Absenteeism and Turnover**

   There is a great deal of time and money lost associated with high turnover and absenteeism on projects. Construction projects in certain areas with low manpower and high demand for labor will usually be more impacted than others. Extreme weather conditions (such as extreme heat or cold) will also increase absenteeism and turnover. Replacement workers are usually not familiar with the work or area, and require experienced workers to stop work and show them what to do. The impact can be up to four days of lost work for each worker.

9. **Mobilize/Demobilize**

   This relates to moving resources on and moving off to projects as a result from changes or delays, causing work disruptions. Productivity may drop during these periods as time is lost when crews move from one area or work assignment to another.

10. **Errors and Omissions**

    Increases in errors and omissions impact on labor productivity because changes are then usually performed on a crash basis, out of sequence, cause dilution of supervision, or any other negative impacts.

11. **Start/Stop**

    This results from a work stoppage or suspension of work, which may cause a break in the schedule, usually triggering a start/stop of work activity. Stop-starts can have an impact on productivity and cost of a project. Work scheduled or reassigned during holidays such as Thanksgiving, Christmas, New Year's, and so on are often impacted with stop-starts. Workers tend to discuss the time off and lose previous momentum with a drop in productivity before they get back in routine.

12. **Reassignment of Manpower**

    When workers are reassigned, they experience unexpected or excessive changes, losses caused by move-on or move-off, reorientation, and other issues that result in a loss of productivity.

13. **Late Crew Build-up**

    This is caused when the planned project manpower loading is altered and causes manpower loading to build up slower than planned due to availability, shortage of resources, or competition from resources. Impacts can be in excess of 10 percent.

14. **Crew Size Inefficiency**

    This is when the optimal crew size is altered by adding or deleting crew members. When workers are added or deleted from a crew, it breaks up the original team effort and rhythm of the crew and results in loss of productivity.

15. **Site Access**

    This is a result of interferences to the convenient or planned access to work areas. This can be due to blocked stairways, roads, walkways, insufficient man-lifts, or congested work sites.

16. **Logistics**

    Insufficient or poor material handling, owner-furnished material, procurement practices, or a lack of controls can cause procurement or delivery problems, as well as other issues. This then prevents, delays, or disrupts the normal material workflow to a work area, warehouse, or lay-down yard. This can also be a result from the additional replacement or substitution of material due to contract changes, defects, or delays at the work site.

17. **Security Check**

    This could be caused by workers entering or leaving the area, or from "brassing" in and out, toolbox checks, transport of labor to secure area, and so on.

18. **Learning Curve**

    When crew turnover causes new workers to be added to a crew or additional manpower is needed within a crew, a period of orientation occurs in order to become familiar with changed conditions. They must then learn work scope, tool locations, work procedures, and so on.

19. **Ripple Effect**

    This is caused when changes in other trades' work then affects other work, such as the alteration of schedule.

20. **Confined Space**

    When work is in a confined space with limitations on egress and ventilation, this can result in non-productive labor to provide hole watch, along with other issues. Time is also lost when getting to and from the work area.

21. **Hazardous Work Area**

    This is caused when working in an area that is classified as hazardous, requiring special safety equipment and clothing. Restrictions may limit time and exposure of workers to the area, resulting in less time on tools in the area.

22. **Dilution of Supervision**

    This occurs when supervision is diverted from productive, planned, and scheduled work to analyze and plan contract changes, expedite delayed material, manage added crews, or other changes not in the original work scope and schedule. Dilution is also caused by an increase in manpower, work areas, or project size without an increase in supervision.

23. **Holidays**

    If workers work on holidays, there is not only a cost factor for holiday pay, but there is usually a loss of productivity as well. It may be addressed as a morale factor since workers are away from families and working instead of enjoying the holidays, or it can also be factored separately. Either way, there is usually a productivity loss to consider.

24. **Shorter Daylight Hours**

    Delays can cause work to be deferred from one time period to the next, which may involve seasonal changes. Different regions and locations around the world also have different amounts of daylight hours, depending on the season.

25. **Weather and Season Changes**

    Performing work in a change of season, temperature zone, or climate change resulting in work performed in either very hot or very cold weather, rain or snow, or other changes in temperature or climate can impact workers beyond normal conditions.

26. **Rain**

    Most crafts do not work in the rain, but many do, especially those who live in wet regions of the country and must work or risk losing too much in wages. Work can, and does occur in the rain, but not without inefficiencies due to rain gear, visibility, safety, morale, discomfort, hazards, and other issues.

27. **Shift Work**

    This is when work is performed at any time other than the first shift or the morning shift of a work day. Work on second and third shifts are less efficient and may even be based on a shorter work period. The reduced daylight hours and problems trying to pick up where the last shift left off results in less productivity.

28. **Working in Operating Area**

    Inefficiencies can result when work is in close proximity to operating units such as heat from boilers, smoke from emissions, explosion zones, and so on. This can cause work stoppages, need for protective clothing, work permits, or other requirements.

29. **Over-manning**

    This is caused when work planners hire too many workers for the estimated work scope and duration. Sometimes, when labor in certain areas or regions is scarce or hard to get, work planners may overcompensate for potential absenteeism and turnover, which creates overstaffing. Another cause is the false assumption that increased manning will always result in increased work productivity.

30. **Tool and Equipment Shortage**

    This is caused when there is insufficient quantity or quality of tools and equipment to meet the needs of the project.

31. **Area Practices**

    This can be the result of added or extended coffee breaks, unique observance or custom, or other practices unique to the craft, owner, country, project location, or other customary practices in the area.

32. **Proximity of Work**

    This is caused by working in a remote area, proximity of tools, break areas, material laydown yard, or other resources causing a loss of time for access.

33. **Alternating, Staggered, or Rotating Work Schedules**

    This usually results in unusual or unique scheduled work periods designed to optimize craft hours worked, attract labor to remote sites, compete for labor resources, and minimize fatigue. Examples include allowing half the work force to take every other Friday off, or staggered crews of 4-12s (working on four days and then four days off), or rotating crews to work a week and then take a week off.

6.2 Severity of Inefficiencies

The severity of the factors on construction crew productivity can vary according to the location, cause, region, duration, and other factors contributing to the severity of the factor. A couple of examples are provided in Table 1 below.

Table 1: Severity of labor factors can vary depending on other factors.

Construction Labor Productivity Factors		Factor Percentage Range (%)		
Factor	**Cause**	**Low**	**Average**	**High**
Shorter Daylight Hours	Two weeks of work planned for June must be rescheduled to December. The location of work has a great impact on daylight hours. If work is in Texas vs. Alaska, the difference in daylight could be severe.	1 (Texas)	5	10 (Alaska)
Morale and Attitude	Crew is scheduled to work five weeks over three consecutive holidays (Thanksgiving, Christmas, and New Year's Day) due to rework caused by owner design changes.	1	15	30 (Severe)

6.2 Severity of Extended Inefficiencies

Inefficiencies impact labor productivity, but can also intensify if continued for prolonged periods. Using overtime as an example, the impact on productivity dramatically increases each week if no break occurs. The primary reason for overtime intensity is the compounding effect of workers on the job week after week with limited or no days off.

When workers continue to work seven days a week with no time off, each week they get more fatigued, morale declines, judgment is impaired, absenteeism increases, and errors and other problems occur. The National Electrical Contractors Association (NECA) did studies, and in one case, it charted a dramatic decline in performance with extended work weeks of over 65 percent after 16 weeks.

Scheduling heavy overtime for extended periods can not only double or triple the cost of the work of standard 40-hour work week, but actually produce less completed work due to productivity loss. Owners could easily pay for over 100 hours of work and get less than 40 hours of productive work. Extended work weeks drop productivity after only a few weeks, and continue to diminish rapidly after a few months.

7. Manage Labor Factors with Planning Tools

It is a fact that known factors impacting labor in construction exist. Good work planning will help identify and quantify them upfront in the estimate and the work packages. By identifying them early, the estimate will be more accurate, and work planners can concentrate on reducing and eliminating these labor factors. Work planning with smart tools using visualization and work packaging in a 3D model will enable work planners to identify, quantify, reduce, and eliminate these factors, thus improving productivity and staying on budget.

7.1 Selectable Labor Factors

SmartPlant Construction allows users to create a set of labor factors and values for factoring labor productivity of work packages. Users can load their own factors or use industry tables from trade groups or associations. They can also drag and drop components from the 3D model into a work package and let SmartPlant Construction automatically calculate man-hours based on preconfigured rules of progress, along with drawings and materials. Users can then add labor factors by selecting from a table of values that they can set and apply a labor factor to the entire work package.

Using Figure 1 as an example, if a work package will be executed during extreme hot weather, users can select a “hot weather” factor to be applied to the man-hours of 1.2, which will add an extra 20 percent to the man-hour calculation.

Figure 1: SmartPlant Construction enables users to add relevant labor factors and apply them to the work package accordingly.

7.2 Filter to Find Material and Equipment Availability

As shown in Figure 2, users can filter materials in the 3D model in SmartPlant Construction to visualize if area material is needed or available. This helps work planners to eliminate and manage impacts of owner-furnished materials and problems of dealing with storehouse people, who have no control over material flow to work areas.

Figure 2: Filters in SmartPlant Construction enable users to find material and equipment availability.

Work planners can also view availability of material or generate a material request in SmartPlant Construction (as shown in Figure 3) to find materials on site, in the warehouse, or in transit. They can then manage contract changes causing problems in procurement and delivery of materials, as well as re-handling of substituted materials at site.

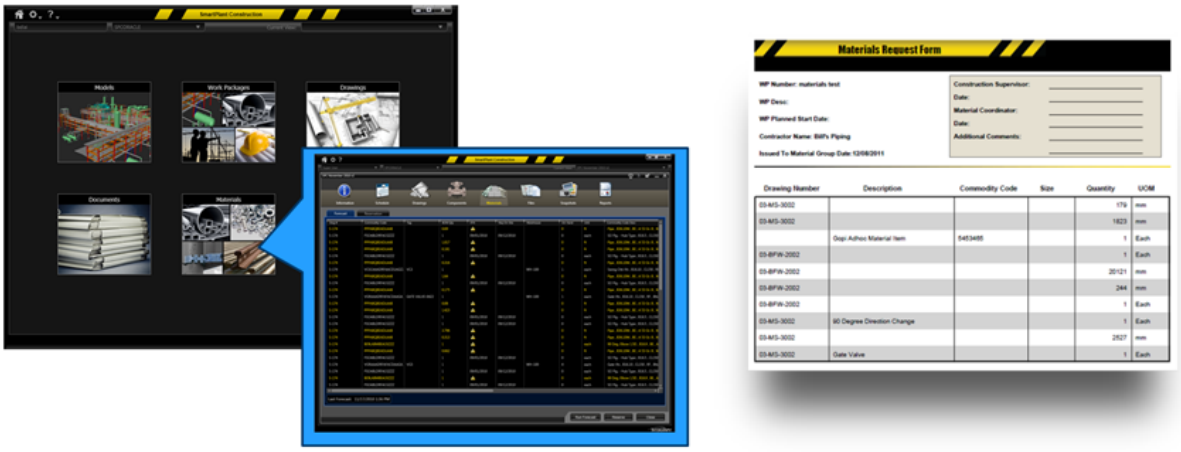


Figure 3: SmartPlant Construction enables users to view material availability or generate a material request.

7.3 Use Filtering to Visualize Congestion

Figure 4 shows that after successful volumes publishing, SmartPlant Construction is able to highlight zones (rooms or areas) with different densities in a nuclear plant. This makes it easier to visualize congestion and optimize the erection and construction process.

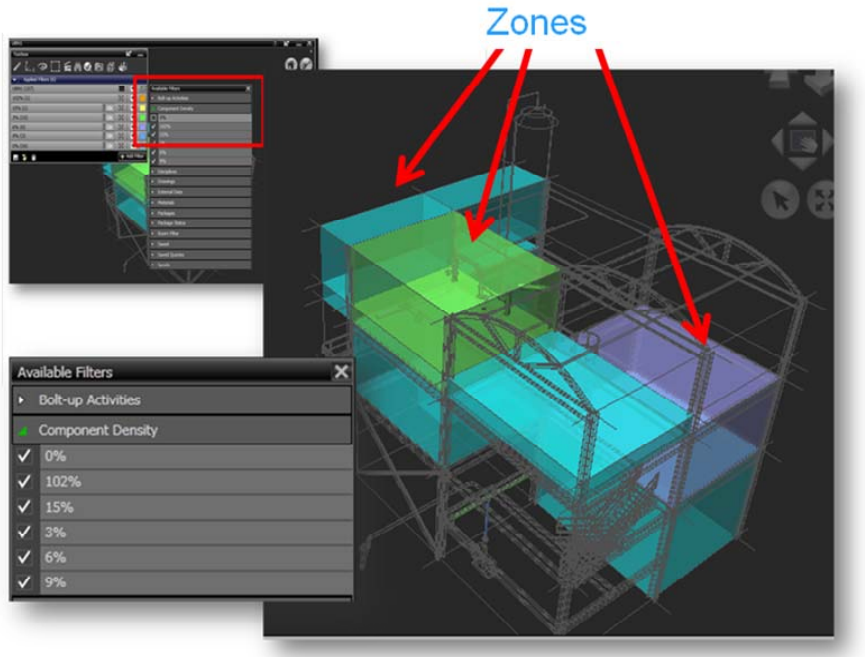


Figure 4: Upon successful volumes publishing, SmartPlant Construction highlighted zones in a nuclear plant with different densities.

7.4 Visualize and Eliminate Need for Labor Factors

In SmartPlant Construction, the 3D model can be filtered to see congestion due to two work packages planned in the same area at the same time. Work packages have different disciplines with different crafts working at the same time. SmartPlant Construction allows users to filter or animate work packages to visualize congestion of beneficial occupancy, and change the work package schedule to eliminate the need to have a labor factor.

In Figure 5, the 3D model in SmartPlant Construction has been filtered to show the electrical and piping work packages that are going to be worked at the same time in the same location. By clicking on either of the highlighted work package, the user can go straight to the work package and see the labor factor of 25 percent added for “Beneficial Occupancy”.

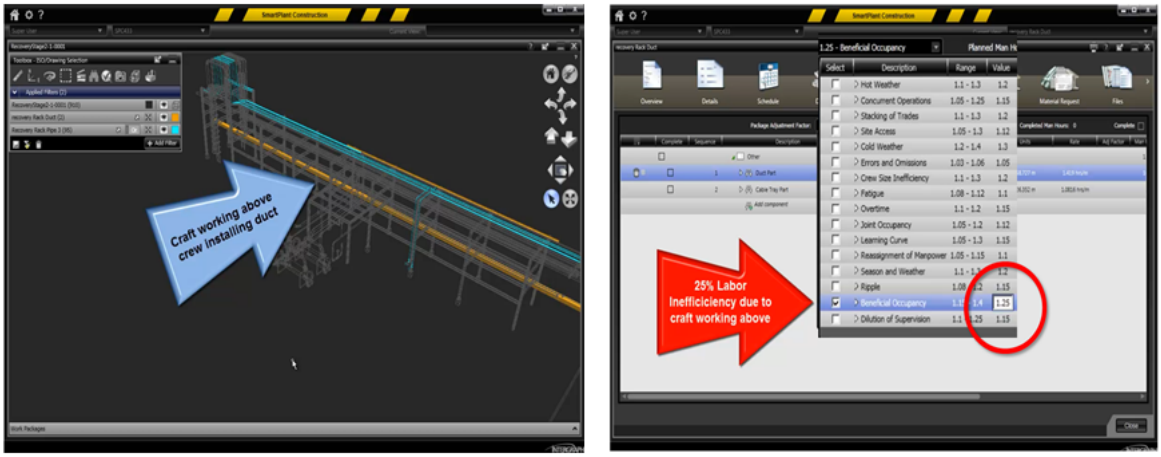


Figure 5: The 3D model can be filtered in SmartPlant Construction so work planners can visualize congestion due to two different work packages occurring in the same area at the same time, highlighting any labor inefficiencies.

The work package can then be rescheduled for a different date (as shown in Figure 6), and this eliminates the congestion of multiple work packages in the same area at the same time. Users can adjust the labor factor of the work package immediately, eliminating the beneficial occupancy problem and the need for a labor factor. This efficient work planning feature reduces the man-hours with a 25 percent saving.

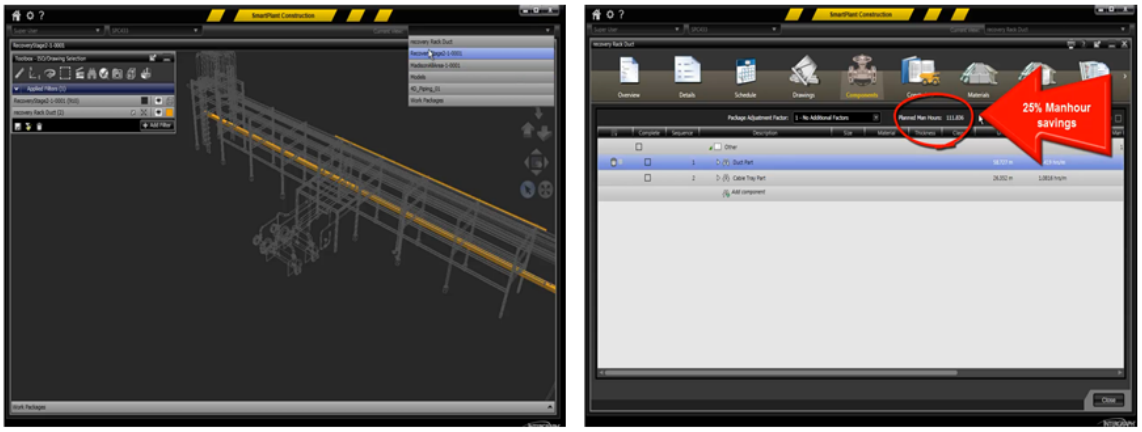


Figure 6: Using SmartPlant Construction, users can reschedule work packages to eliminate any labor inefficiencies.

7.5 Manage Constraints

SmartPlant Construction has a Constraints feature (as shown in Figure 7) to manage resource requirements and constraints for work packages. Resource requirements are planned and managed for construction activities in a project. Required resources for work package activities such as equipment, labor, and permits can be added to work packages as constraints to plan and manage based on schedule, availability, and other factors.

Figure 7: SmartPlant Construction enables users to manage resource requirements and constraints for work packages.

8. Enhancing Construction Planning

According to a study of over 12,000 projects conducted by the Independent Project Analysis group, on average, over 35 percent of all construction projects will have a major change:

- 25 percent of projects slip by over 20 percent
- 25 percent of all projects grow in the field by over 30 percent

Project growth and change will not only have direct impacts on the project schedule and budget, but will also compound the problem with labor inefficiencies. Inefficiencies are a problem in construction and one of the biggest contributors to project overruns.

Technology cannot eliminate inefficiencies entirely but tools like Intergraph SmartPlant Construction can improve productivity by giving users the resources to identify inefficiencies in the planning stage for more effective construction planning. Work planners can then incorporate any identified labor inefficiencies into the budget, and SmartPlant Construction will provide the tools to manage their impacts on productivity, as well as help support, document, track, and defend any construction claims.

For more information about Intergraph, visit our Web site at www.intergraph.com.