DCL.2

The Effect of Resource Constraints on Project Schedules

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INTRODUCTION

The AACE Cost Engineers' Notebook defines schedule as "the plan for completion of a project based on a logical arrangement of activities, **resources available** (emphasis added), and imposed dates or funding budgets" [1].

Although most would agree that this is a good definition, many schedules are developed without considering available resources, resulting in a plan that may be misleading or impossible to achieve. When project schedules are developed without considering available resources, the resulting schedule may be misleading or impossible to achieve. Although resource-loading and resource-leveling techniques have been available for many years, most project schedules fail to consider resource constraints. This can lead to poor management decisions when the project schedule is used for decision making. The difference between resource constrained schedules and schedules that are not resource constrained can be significant. Float times and critical paths can change. In fact, the traditional critical path concepts can even break down [3]. If resource considerations are ignored during the project, and schedule slippage occurs, resources should certainly be considered after project completion when explaining poor schedule performance. This paper will illustrate the importance of resource-loaded and resource-constrained schedules by showing the effect of resource constraints on project float and critical path.

WHY IS RESOURCE LOADING IMPORTANT?

In many projects, schedules are developed without considering resources. This, in effect, assumes that these resources are unlimited. Resources such as labor, equipment, and materials are not unlimited and require close management attention. The basic objective of resource management is to supply and support the project so that established time objectives can be met and costs can be kept within the project budget [2].

In most situations, resources are limited or constrained in some way. Resource constraints include site constraints, competition for resources among projects, and geographical constraints. Resource constraints can often be alleviated to some extent by using overtime, additional shifts, or subcontracting. Also, schedule logic and activities may be adjusted to accommodate the constraints. For example, activities may be split up to satisfy the constraints. In any case, management must be aware of the constraints before any of these alternatives can be considered, and cost effective decisions made.

In addition to the basic limitations of each resource (labor, material, equipment), the management of resources can become very complicated when the interdependencies between resources are considered as well as the efficiencies of those resources. For example, even if adequate labor is available on a construction project, materials and equipment are required at the appropriate time for the labor to work efficiently. Even if labor is available, optimal crew sizes must be considered to achieve maximum efficiency. For example, if a project is staffed based on early start and finish dates, a labor profile of peaks and valleys may result. It may not be good labor management or cost efficient to lay people off only to rehire a few weeks or months later. This can be avoided with effective resource management.

IMPACT OF RESOURCES ON PROJECT SCHEDULES

A critical activity in a project is traditionally defined as one that, if delayed, will delay project completion. Normally, these activities have zero float and are part of paths through the project network composed solely of other critical activities. If they take longer to perform than their estimated duration, the project completion will be delayed. If they are performed at their estimated duration but start late, the project completion will also be delayed. Float is traditionally defined as the amount of time that an activity can be delayed without impacting succeeding activities (free float) or the project completion (total float). One reason for starting late is that resources are not available in the quantity required. The same principle applies to those activities with float. Float will be used on those activities with insufficient resources until the resources become available. If all the float is used and the resources are still not available in the required quantity, the project will start to experience a critical delay.

In order to demonstrate the effects of resources on project schedules, we have developed a sample network using **Primavera** software. The sample network is a hillside water tank project that has been simplified for the purposes of illustration. The project consists of 17 activities on five paths. Each of the activities has

been resource loaded with labor, generically called "workers," who can perform any task on the project. In all of our examples, the basic network logic and activity durations will remain the same, but resource constraints will change to illustrate their effect on project float, critical path, and project completion.

Figure 1 shows the network schedule as calculated, assuming no resource constraints. The critical path is shown, and the project is completed on day 34. The corresponding labor profile is shown in Figure 2 based on the early start and finish dates and assumes no resource constraints. Note that the labor peak is 23 workers and occurs early in the project. As stated earlier, when resource constraints are ignored, unlimited resources are assumed.

Figure 3 shows the network schedule if labor is limited to 22 workers. The only change between this schedule and Figure 1 is that the early start for the chain link fence activity has been delayed. The project is still completed on day 34. This illustrates how float can be used to satisfy resource constraints. The practice of delaying activities with float is common by project managers, although they may not know that a more realistic schedule can be developed from the beginning with proper schedule management. The labor profile in Figure 4 shows that the resource limit has been satisfied without a change to the project completion date.

Figure 5 shows the same schedule activities and logic except that a limit of 15 workers has been assumed. In this example, even if float is used completely, it is not possible to satisfy the constraints. As a result, the project completion date is extended 13 days and the project now completes on day 47. Figure 6 shows that the resource constraints have been satisfied at the expense of the project completion date. This also shows how the traditional float and critical path concepts can break down. Only two activities are critical in the traditional sense, but other activities that seem to indicate float are resource critical. In other words, if they do not release their resources as scheduled, the completion date will slip further. The critical path as calculated is no longer composed solely of activities with zero float, and some activities with float cannot be delayed at all without impacting project completion. The traditional critical path and float definitions no longer apply and the entire schedule is now resource driven.

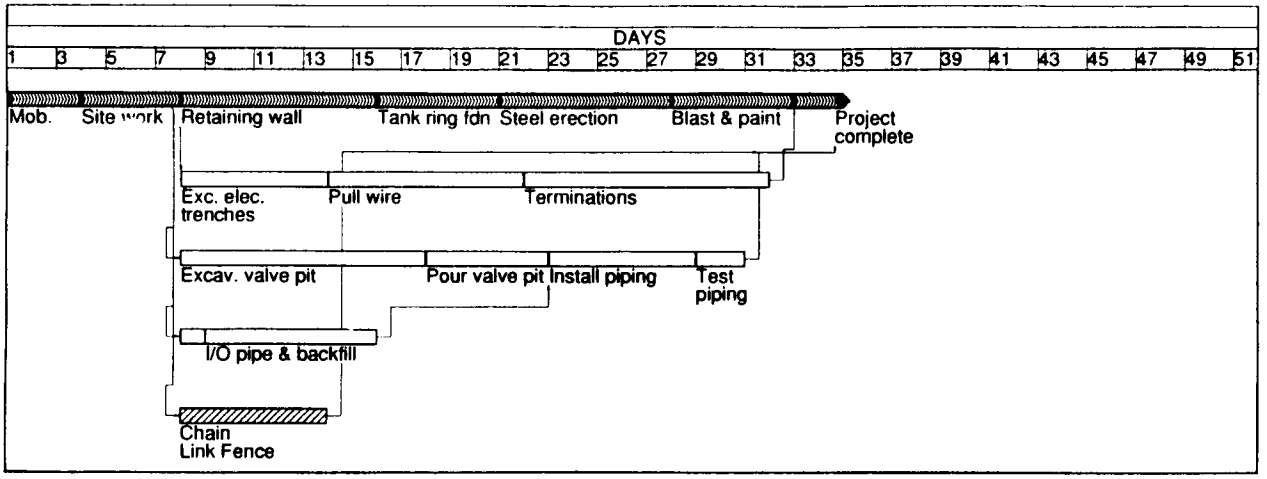

Figure 1—Network Schedule (Unlimited Workers)

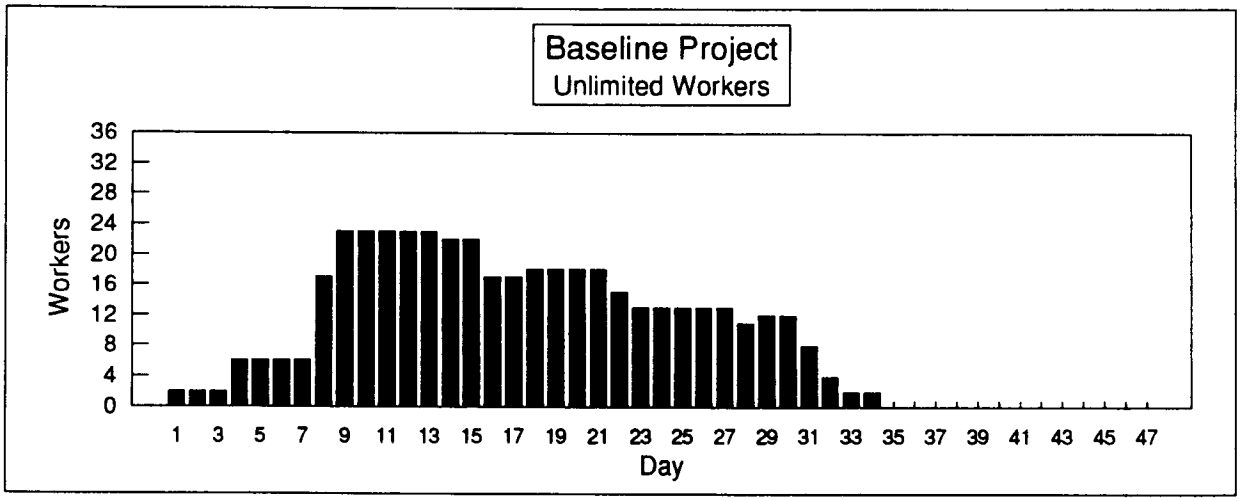

Figure 2—Labor Profile (Unlimited Workers)

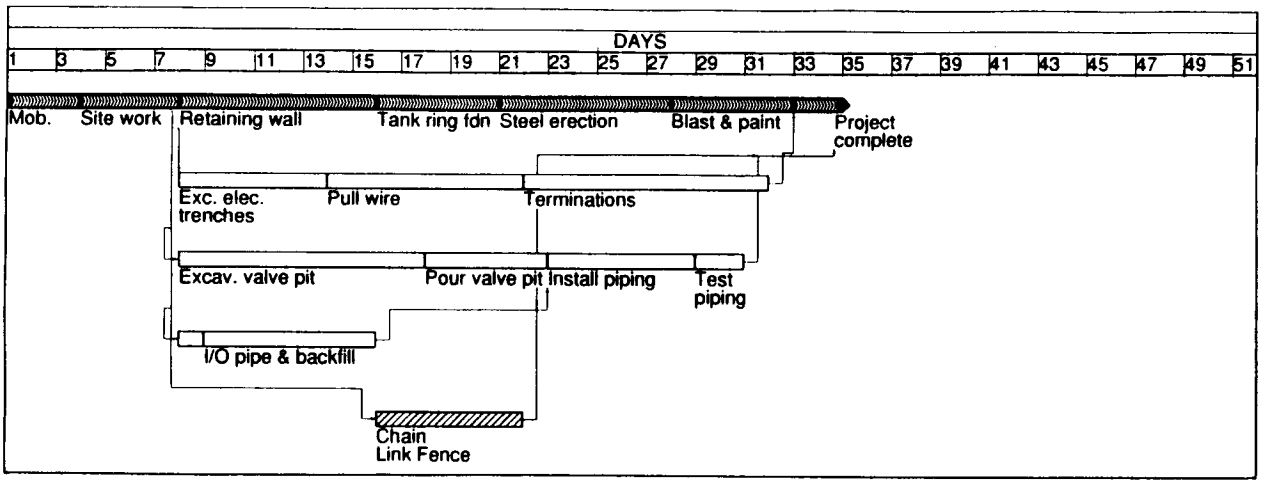

Figure 3—Network Schedule (Labor Limited to 22 Workers)

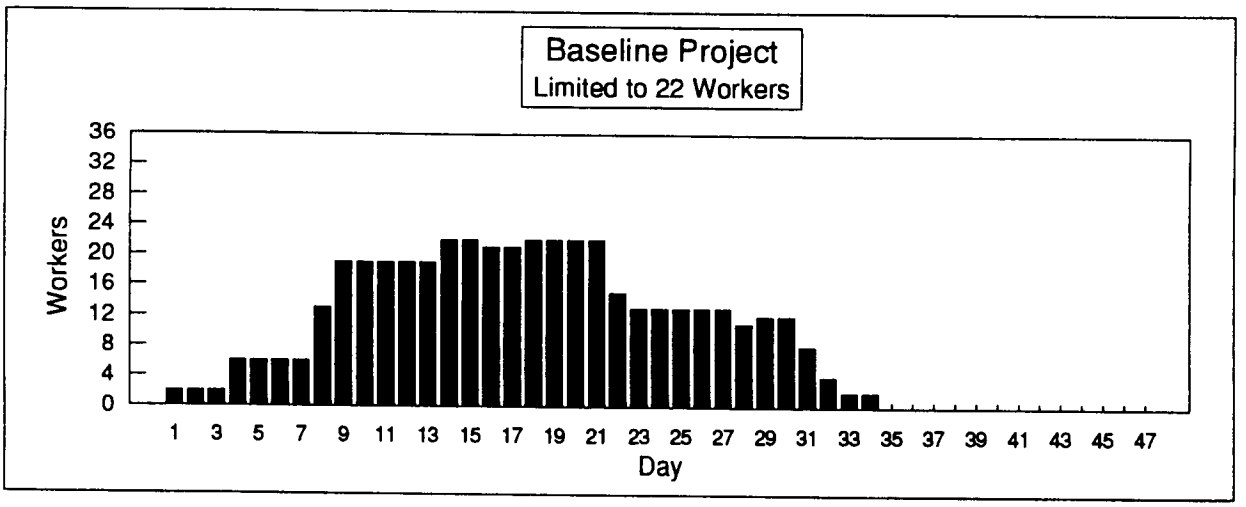

Figure 4—Labor Profile (Limited to 22 Workers)

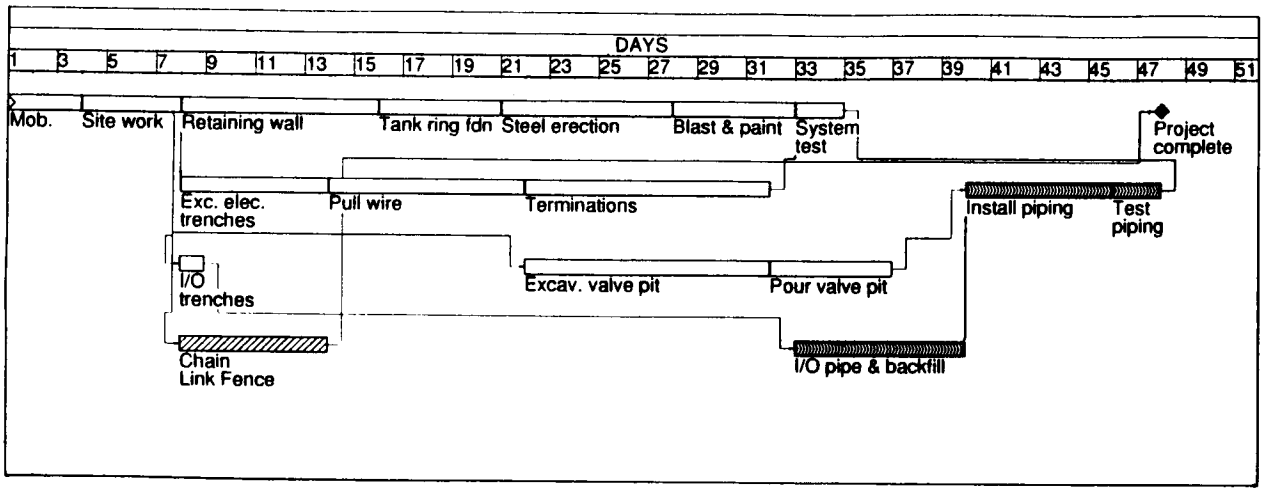

Figure 5—Network Schedule (Limited to 15 Workers)

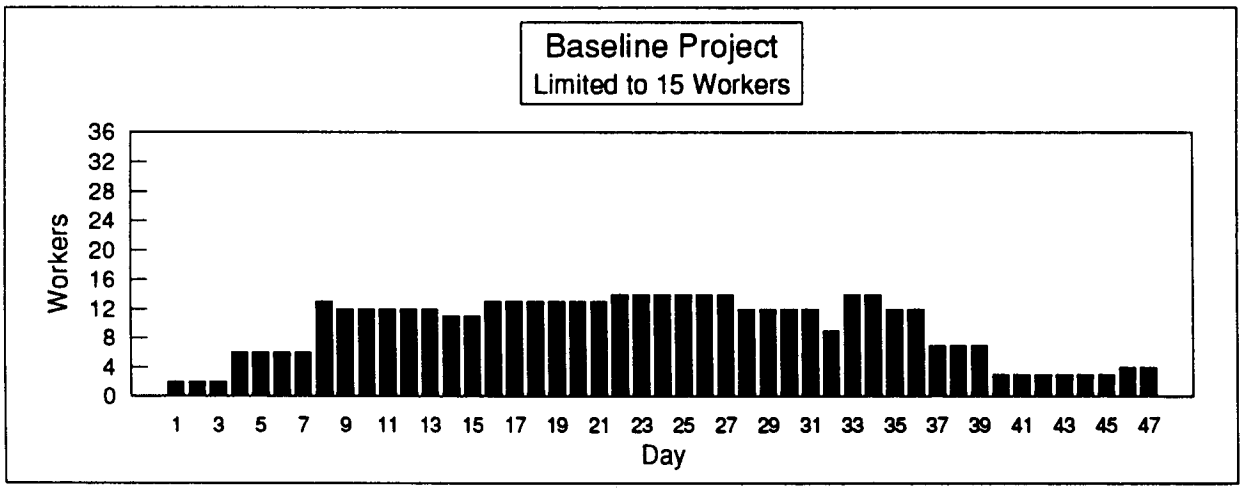

Figure 6—Labor Profile (Limited to 15 Workers)

MANAGEMENT OF CHANGES

Effective resource planning is also important when considering the impact of changes on the project schedule. Figure 7 shows the original schedule with one change incorporated in the network, assuming no resource constraints. The fence has been changed from chain link to masonry. This changed activity requires additional resources and takes 12 days rather than six. As may be expected, when this changed activity is inserted in the original schedule, six days of float is used since the activity has grown from six to 12 days. The resource profile based on early dates and no constraints is shown in Figure 8. Again, with no leveling and no constraints, manpower peaks early in the project, but the work is completed in 34 days as in the original schedule. When the schedule in Figure 7 is resource constrained at 22 workers, the schedule and manpower profiles are completely different as shown in Figures 9 and 10. The network shown in Figure 9 shows that project completion is delayed eight days to day 42. In addition, the only activity shown as critical is the masonry wall, while in Figure 7, without resources, this activity shows considerable float. Again, the traditional concept of float and critical path breaks down, and many activities are resource critical. Different leveling techniques would yield different results, but the differences between leveled schedules and schedules that are not leveled would still be significant.

IMPACT ON EFFICIENCY

In addition to the effect of resources on completion dates and the general sequence of work, trying to achieve the dates on a schedule generated without consideration of resources limits and requirements can lead to lost productivity and cost overruns. For example, in Figure 8, the resulting profile based on early dates shows a significant staffing increase to meet the peak demand of 34 workers, followed by dramatic reduction in labor. If management actually tried to meet these requirements, overtime may be one of the alternatives considered. Overtime and disruptions to the labor levels may result in lost productivity [4]. In order to avoid these inefficiencies, leveling and smoothing techniques are available. As shown in Figure 10, when labor is constrained at 22 workers, a more level profile results. Even if this project were not labor constrained, the labor in Figure 7 could be leveled, and staff increases and decreases smoothed, by moving activities with float to later time periods. Many algorithms have been developed to facilitate this leveling and smoothing process, which may lead to increased efficiencies of the labor force. Conversely, if manpower levels are ignored, unnecessary inefficiencies may result.

FORENSIC ANALYSIS OF SCHEDULE OVERRUNS (CLAIMS)

When trying to explain cost and schedule overruns at the completion of a project, the fact that resource considerations were ignored during the planning stage is often central to explaining the overruns.

Even if resources and resource constraints were ignored during initial plan development, the actual schedule will progress in accordance with the actual resource limits. For example, it may be observed during the course of a project that activities with float move from the early dates to the late dates. This reduction of float may not be due to impact on activities, but may reflect a more efficient use of resources. The contractor's desire to keep crew sizes relatively constant may have the effect of moving activities from their early dates to their late dates, or may even cause a delay to project completion if resources were not considered in their planned schedules.

On public construction projects the contractor may prepare an "early" schedule that indicates a completion date earlier than required by the contract. This is sometimes done in order lay the foundation for the contractor to claim delay damages if the work is done on time or even early [8].

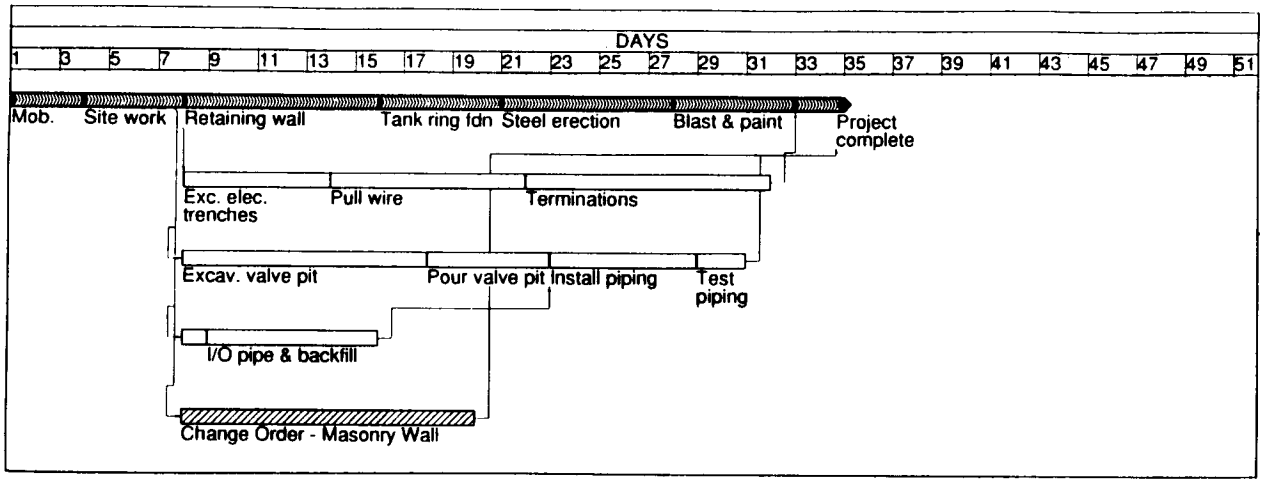

Figure 7—Network Schedule with One Change Incorporated

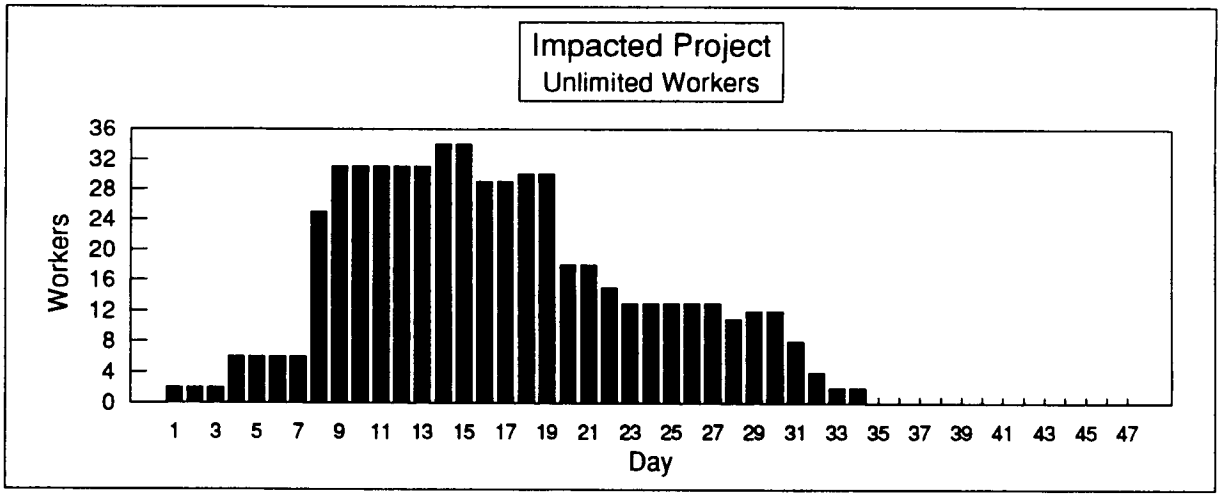

Figure 8—Resource Profile (Unlimited Workers)

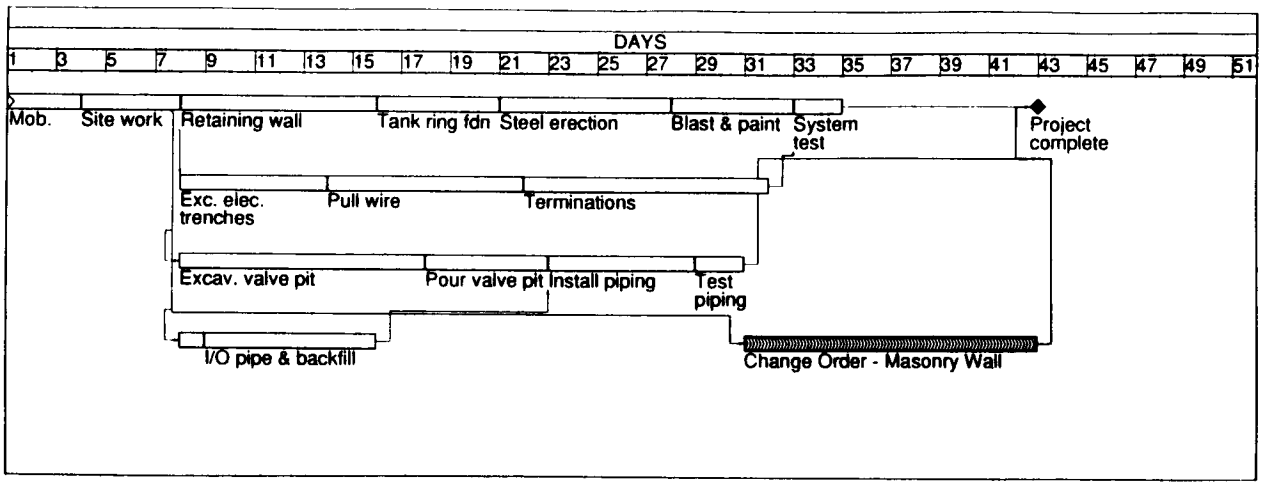

Figure 9—Network Schedule (Limited to 22 Workers)

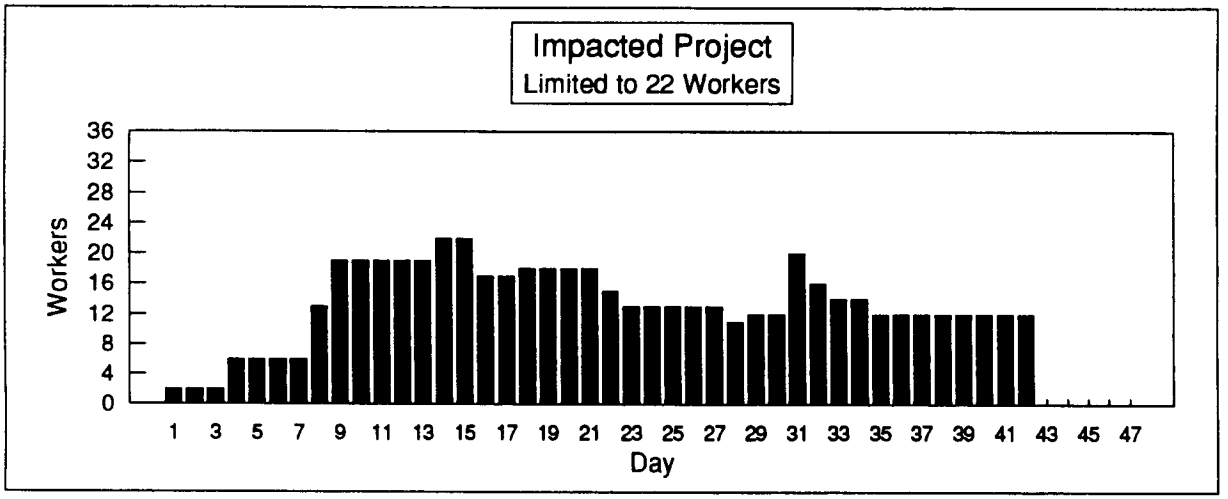

Figure 10—Resource Profile (Limited to 22 Workers)

Therefore, it is important to the project owner to determine if the early schedule is realistic. When these early schedules are analyzed, it is important to see if resources and resource constraints were considered before approving the schedule and establishing it as the baseline plan. If not, the completion date may not be realistic. When actual duration exceeds planned duration, the delay may be attributable to the contractor due to poor project planning if resources were ignored.

Poor resource planning can also lead to unexpected overtime. Without leveling or consideration of resource limits, the contractor may find that planned activities cannot be completed with the current labor. If the activities with float have already slipped as far as they can without impacting timely project completion, the contractor may start to work overtime to mitigate possible delays. Again, a retrospective resource analysis may show that the overtime and possible loss of productivity could have been avoided with better resource planning.

CONCLUSIONS

As demonstrated, the difference between resource constrained schedules and schedules that are not resource constrained can be significant. Unanticipated overtime, schedule delays, and the resulting cost overruns can all be symptomatic of planning and scheduling done without proper consideration for resources and their limits. If resource considerations are ignored during the project, they should always be considered after project completion when explaining poor schedule performance.

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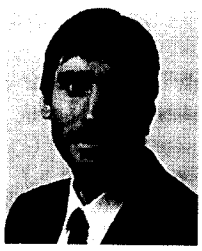

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