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# Application of a Heuristic Algorithm for Efficient Resource Scheduling: A Case Study

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## Abstract
In the scheduling of construction projects, conflicts can arise when activities require resources that are available in limited quantities. Mathematical techniques exist for allocating resources whilst retaining minimum project durations. One such technique is 'LINRES', a heuristic algorithm devised by researchers at Northumbria University in the UK who demonstrated the advantages of LINRES over 32 existing heuristic rules, in trials on a hypothetical project (Abeyasinge *et al.*, 2001). Following this hypothetical test of the algorithm, the present paper reports on the live implementation and empirical testing of LINRES on a real project. The project was an important section of the Shariati Combined-cycle power plant, carried-out by the MAPNA Company in Iran: namely, the Heat Recovery Steam Generator (HRSG). Research was carried out to investigate if the LINRES algorithm could improve the scheduling of the HRSG construction, which took place in 2002. Data from the project were simultaneously subjected to manipulation by LINRES and by Primavera Project Planner, one of the most powerful software planning tools available on the market. Outputs were compared, and the performance of the LINRES scheduling tool was found to be superior in its ability to provide an acceptable trade-off between the resource aggregation profiles and consumption.justified.

## Keywords
Heuristic algorithm, Resource constraints, Scheduling

## 1. Introduction

Many commentators have noted that construction projects are prone to suffer from delays; indeed this is a common conception of the industry (see, for example, Economist, 2005). There are a variety of reasons, most of which have been investigated at one time or another, but fundamentally there is the simple, logical fact that when a project overruns it does so because of: a) an inadequate target; b) inadequate execution; or c) a combination of the two. This paper is concerned with setting adequate targets for completion. Project schedules with their completion targets are set in a number of ways. Simpler projects are 'manually' planned utilizing the Bar (or Gantt) Chart as an accessible scheduling tool; larger and more complex projects tend to employ more detailed scheduling techniques, often computer-based, that are normally based upon a 'family' of techniques variously known as Critical Path, Program Evaluation and Review Technique (PERT) or Precedence Network. For simplicity the distinctions between these techniques will be ignored in the present paper, and they will be referred to simply as ‘critical path network’ or ‘CPN’ techniques.

It has been noted that in the field, site managers are reluctant to follow the formal systematic CPN schedules they inherit from head office, which they often regard as merely 'theoretical' (Johansen, 1996). In fact, it has been argued (for example, by Woodworth and Shanahan, 1998) that they are right in this aversion and that in many cases, network techniques do not work in the field. Perhaps the main reason for this is that when critical path networks are initially formulated, there is the assumption that the resources (labour, materials, equipment) required to perform each activity are readily available (Mawdesley *et al*., 1997) and are only considered once a project duration is established (Nkasu, 1994). Indeed, the conventional starting point of familiar CPN scheduling techniques is an assumption of unlimited resource availability for project activities. In other words, these analyses are time-oriented routines, which disregard (initially at least) the resource needs of each activity. Using an approach which calculates early and late starts and finishes (based upon logical and technological constraints) a critical path is identified which minimizes the overall project duration: the availability of the resources required to complete each activity is either ignored or neglected until later.

To completely ignore the constraints imposed by limited resources would, of course, condemn most network schedules to being useless in the field, and to overcome this, further action is taken to adjust the schedule. The normal approach is a process involving the identification, quantification, aggregation, smoothing and levelling of the resources required for the work. The techniques for doing this have been described in a great number of texts on the subject, and the standard approaches have been summarized by Gordon and Tulip (1997). The problems with this approach are two-fold. First, there is always the possibility that some of the resources required for construction are simply not available in the field in the quantities demanded by the revised resource-constrained schedule. Although serious, and potentially damaging to the schedule, this is a matter of the project management team’s realistic expectations. It is covered elsewhere (e.g. in Johansen, 1996; Mawdesley *et al*., 1997) and the problem is not addressed in the present paper. The other problem is the fact that a resource-constrained schedule, despite its initial objective of smoothing and levelling resource overloads within the initial (time-constrained) timescale by manipulating activities within their float, will tend to produce a completion time outside that set using time-constrained scheduling only. In such circumstances, the objective becomes one of optimizing the project timescale within the accepted resource constraints.

To overcome this problem, referred to as ‘the general resource-constrained project scheduling problem (RCPSP)’ a number of theoretical approaches to have been proposed that employ mathematical programming or heuristic techniques (see, for example, Abeyasinge *et al*., 2001). For the practitioner however, the most practicable method of optimization would be either manual (perhaps satisfactory for the least problematic or least complex projects) or involve using routines embedded in commercially available software. In 2001, Abeyasinge *et al*. proposed a new method of scheduling projects within resource constraints but with the shortest project duration, that is, duration as close as possible to that of the initial, *unconstrained* version. Their method, involving a heuristic algorithm which they called LINRES, was originally applied to a hypothetical trial project. Thirty-two previous theoretical approaches were reviewed and applied to the same hypothetical project, with the result that LINRES outperformed most other routines and ‘provided a reasonable trade-off between the resource aggregation profiles and the durations’ (Abeyasinge *et al.*, 2001). Despite these results, LINRES has hitherto not been tested on a real project, and this is the subject of the present paper, as real data from the project featured in this case study has provided the opportunity to test LINRES empirically.

## 2. Research Aim, Objectives and Outline Methodology

The aim of the research described in this paper was to evaluate the LINRES algorithm on a real project. To do this LINRES was used in parallel with a well-known, commercially available software package, PRIMAVERA Project Planner©, one of the most powerful software planning tools available on the market, which allows users to 'reconcile resource demand with available capacity, identify capacity and resource bottlenecks and determine the operational feasibility of a specific scenario' (Primavera, 2009). Results from the two systems were then compared.

The project in question was the construction of the two Heat Recovery Steam Generators (HRSGs) of the 325MW Shariati Combined-cycle Power Plant (Shariati CCPP) by the Iran Power Plant Projects Management Co. (MAPNA) from 2002. MAPNA is a large company, with a turnover of about 4 billion Euros and over one thousand employees (2006 figures). HRSGs can be the most time- and resource-consuming of elements in power plant construction; they are normally on the overall project's critical path, and make particular demands upon the scheduling techniques employed by the contractor.

A common classification of resources on any project is men (i.e. all forms of human resources), machines (non-human resources in the form of construction plant and equipment), materials and money (i.e. financial resources). In scheduling the HRSG construction, financial resources and materials were not considered; light and heavy machinery (e.g. cranes, lorries, lift-trucks cars, cutting and welding machines) were normally fairly accessible, and scheduled in such a manner so as to serve multiple activities; human resources (skilled and non-skilled workers) were the main focus of efforts. In the context of the project, it was reasonably assumed that there would be no shortage (and therefore no limit) of non-skilled workers. Skilled human resources that were to be used commonly in most of activities of the HRSG package were: Shielded Metal Arc Welders (SMAW); Gas Metal Arc Welders (GMAW); Pipe fitters; Surveyors; and Assemblers. Based on experience, the availability limits for these categories of skilled human resources for this particular project were estimated to be those given in Table 1, below.

**Table 1: Acceptable Limits of Skilled Human Resources**

| Resource name | Maximum accessible limit (Person/day) |
|---|---|
| SMAW Welder | 22 |
| GMAW Welder | 6 |
| Pipe fitter | 8 |
| Surveyor | 2 |
| Assembler | 8 |

## 3. Planning with PRIMAVERA Project Planner Software

The project was then scheduled using PRIMAVERA software and the limits on skilled human resources were applied, as described above. The software will automatically level resources to any user-imposed constraints and present the resulting profiles. The following chart is the result of this scheduling with PRIMAVERA software.

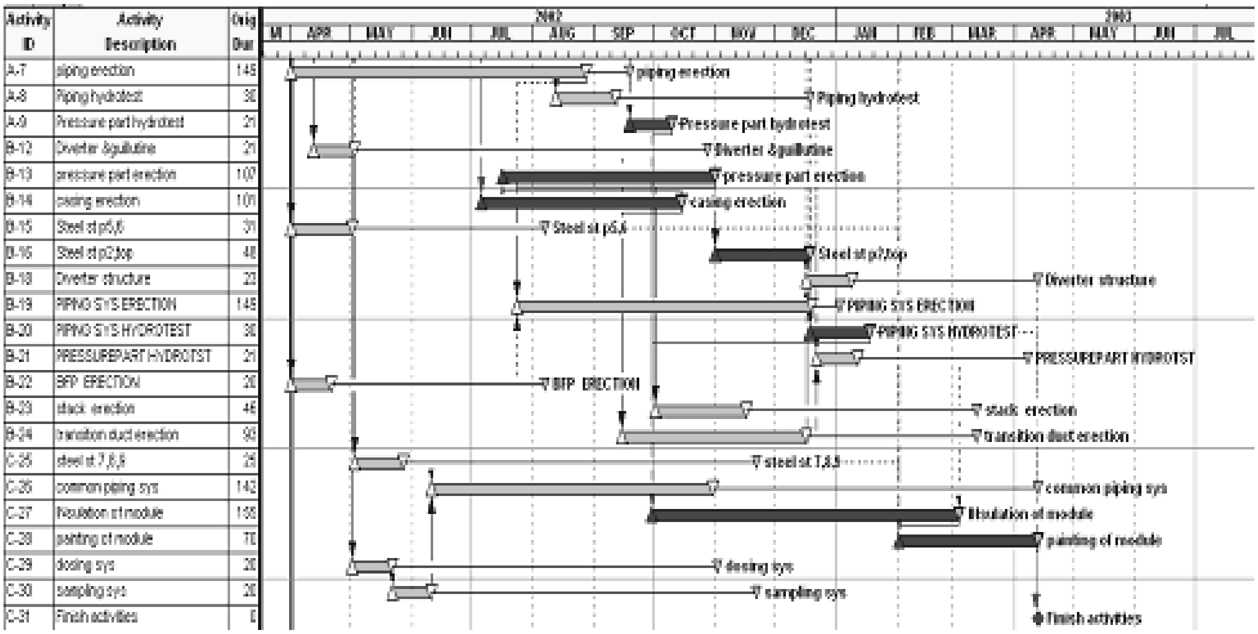


**Figure 1: Scheduling of HRSG Package Activities (PRIMAVERA)**

In addition to this chart, the following resource consumption tables were produced for the previously defined critical resources (SMAW welder, GTAW welder, Pipe Fitter, Assembler and Surveyor).

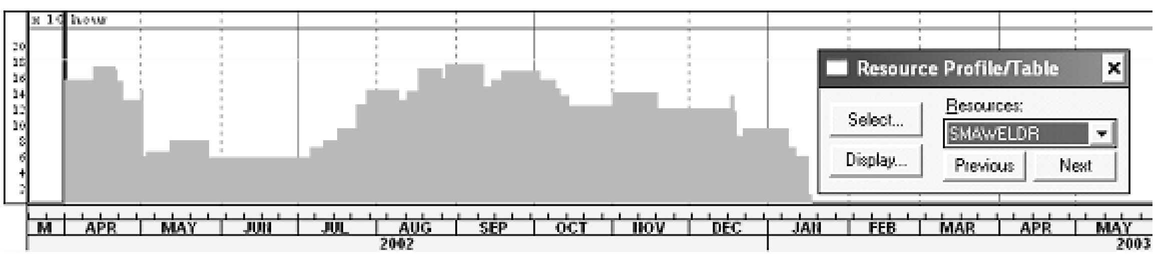


**Figure 2: Resource Consumption Table for SMAW Welder**

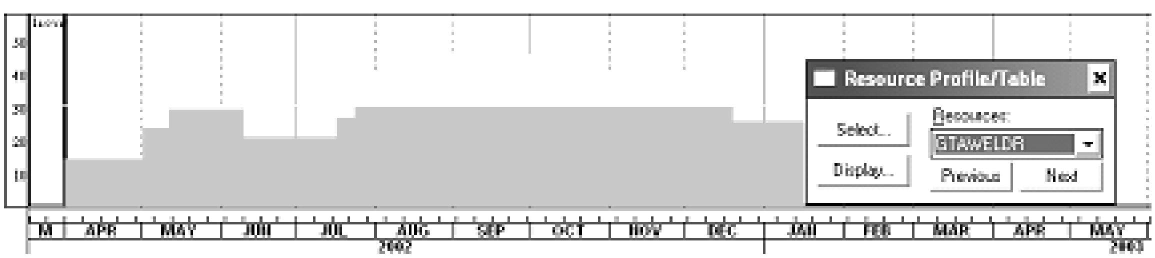


**Figure 3: Resource Consumption Table for GTAW Welder**

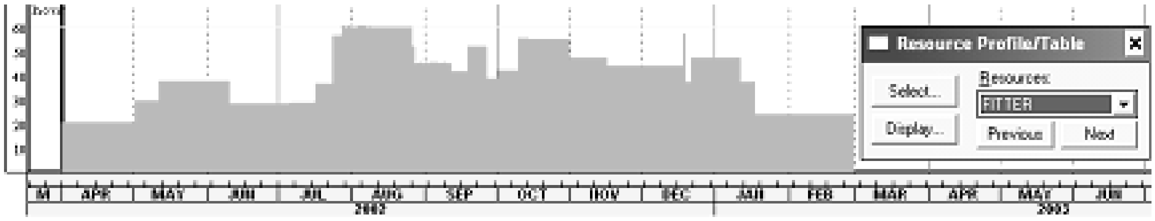


**Figure 4: Resource Consumption Table for Pipe Fitter**

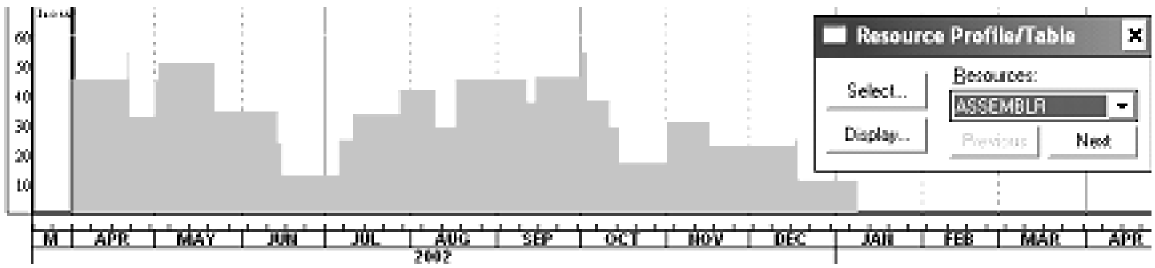


**Figure 5: Resource Consumption Table for Assembler**

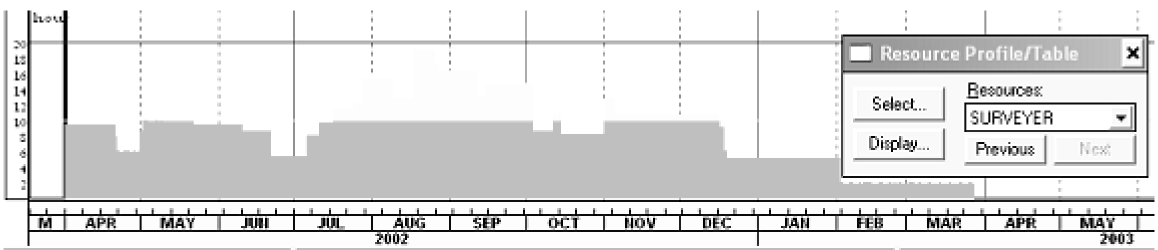


**Figure 6: Resource Consumption Table for Surveyor**

## 4. Introduction to the LINRES Algorithm

The LINRES heuristic algorithm was developed using a Precedence Network (activity-on-node) and Gantt chart approach, but can equally be used with CP networks that are developed in an activity-on-arrow format. The aim of LINRES is to produce a schedule that operates to set resource constraints within the shortest possible project duration (as close as possible, that is, to the duration of a schedule that is resource-unconstrained). The algorithm begins with conventional CP networks and bar charts, but then develops an original type of 'ancillary network' to optimize the schedule within any resource constraints that have been set. Starting with a conventional critical path analysis, a link-structure is created. The link-structure is a device peculiar to LINRES that can then be manipulated to attempt to circumvent problematic resource constraints. A further concept, companion activities, is introduced and, in a series of iterations using certain rules, the link-structure is compressed as much as possible. The resulting solution is then returned to conventional network and/or bar chart format. It is not the authors' intention to explain the working of the LINRES algorithm in this paper. For a detailed account, readers are referred to the original work by Abeyasinghe *et al.*, (2001). However, the following diagram, taken from that paper, illustrates the main steps described by the originators of LINRES.

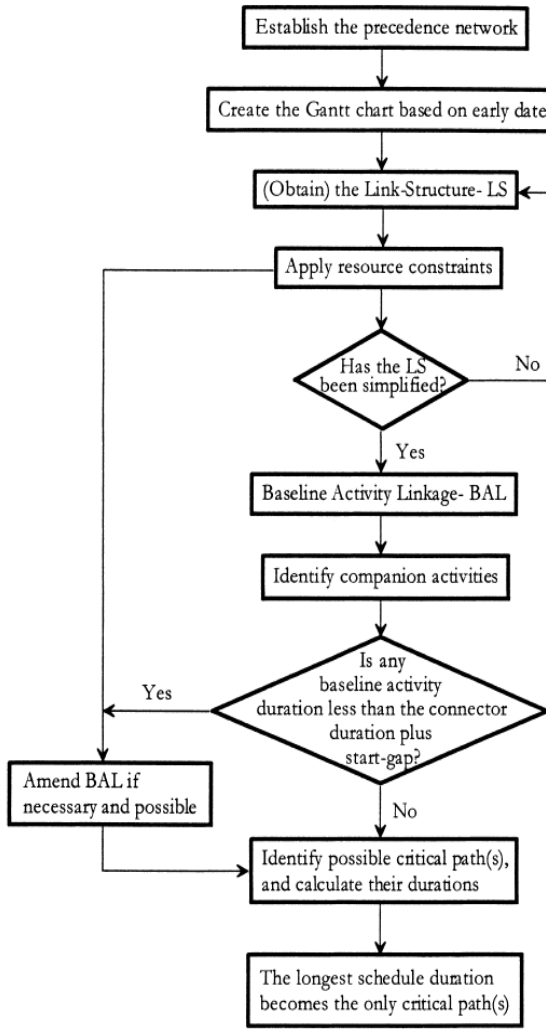


**Figure 7: Main Steps in the LINRES Algorithm**

## 5. Implementation of LINRES to the Project

There are two HRSGs on Shariati CCPP with two identical activities sets, and a Common Systems and Accessories (CSA) package activities. From the project documents, 668 individual activities were identified. These were grouped into 30 higher-level activities: 12 relating to each HRSG package (hereafter identified as A and B) and 6 to the CSA package. Critical Path networks were calculated for each HRSG and for the CSA package. The resource requirements for each activity were determined and the average daily requirements for each of the key resources (identified in Table 1 above) were calculated. A traditional Gantt chart (with earliest start-and-finish dates) was produced, which also showed the requirements for each of the key resources.

The LINRES routine was then performed. A resource-constrained schedule was produced and resource consumption tables (similar to those produced in PRIMAVERA) were derived. The general outline of this routine is shown above in Figure 1, but for reasons of available space the individual steps cannot be replicated here. For a more detailed description of the steps involved, readers are referred to the original work by Abeyasinghe *et al.*, (2001).

## 6. Comparison of Resource Consumption between LINRES and PRIMAVERA

In order to assess the relative performance of LINRES and PRIMAVERA, the total areas under the resource consumption curves (for each method) were compared. The results are summarized in the following table (the area under each curve representing the total man-hours used in each method).

**Table 2: Comparison of Resource Consumption after Leveling (Two Methods)**

| | Surveyor | GTAW | SMAW | Fitter | Assembler |
|---|---|---|---|---|---|
| **LINRES** | **25450** | **107679** | **306676** | **122258** | **98359** |
| **Primavera** | **32530** | **95620** | **342100** | **129780** | **98770** |

The results can also be expressed as a resource histogram as in the following figure.

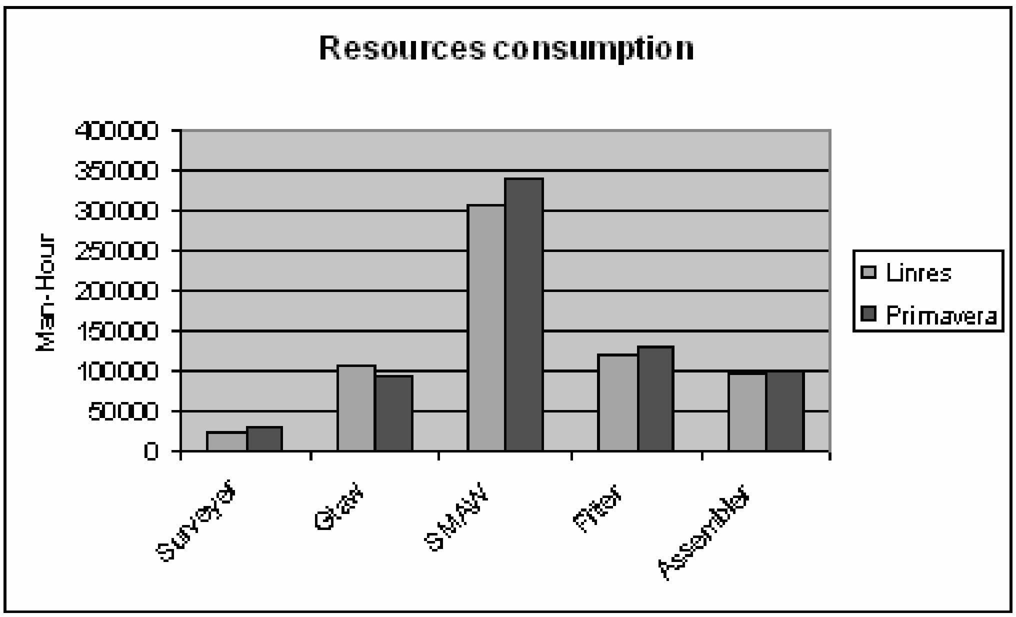


**Figure 8: Resource Consumption after Leveling (Two Methods)**

## 7. Conclusions

Application of the LINRES method resulted in a total of planned 660,422 man hours, as compared with 698,800 planned man hours when the PRIMAVERA resource levelling routines were used. Both routines maintained the time-criticality of the schedule, but the LINRES approach resulted in a reduction of 38,378 planned man hours. This represents a 5% saving on the PRIMAVERA method. This is the first time (to the authors' knowledge) that the LINRES algorithm has been tested on a real project. The result – showing a significant improvement on industry-standard, computerized methods - should encourage further examination. In this case study, the LINRES routines were computed manually, the development of a computer program would reduce the execution time considerably, allowing the possible expansion of sample size to better insight into the model's capabilities, as well as facilitating its use in the field.

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