# Computer Based Linear Scheduling Application for Highway Construction Planning

Dell'Acqua G.
Department of Transportation Engineering, University of Naples "Federico II"

Lamberti R.
Department of Transportation Engineering, University of Naples "Federico II"

Discetti P.
Department of Transportation Engineering, University of Naples "Federico II"

## Synopsis

Since the early 1960s many techniques have been developed to plan and schedule linear construction projects. However the bar charts and the network diagrams overshadowed the others. As a result, these techniques developed into powerful and effective tools that are today. However, those techniques are suitable for many types of projects but they do not fit for linear constructions. Linear projects are typified by activities that must be repeated in different locations such as highways, railways, and airports.

Road construction works can be divided into three main categories: earthworks, pavement laying and structure building.

By earthworks we mean all those works aiming at modifying the ground morphology, whether this is done on the ground surface (diggings or excavations and embankments), underground (trench digging, wells and tunnels) or underwater (structures being built by permanently working under the water level).

Pavement laying consists of using materials whose properties have been normalized using complex techniques. Instead, building protection and completion structures means working at erecting constructions such as supporting walls, bridges, overpasses, side ditches, road drain wells etc.

Recently, there has been renewed interest in linear scheduling. Much of this interest has involved a technique called linear scheduling method. Only recently has there been the ability to calculate the controlling activities of a linear schedule, independent of network analysis.

In this paper the authors propose the results of a computer based linear scheduling application for highway construction project management.

The ultimate product of this research is a Linear Scheduling prototype (UNaLSS – University of Naples Linear Scheduling Software) comprised of models, procedures and software tools that allow for implementation of the linear scheduling method. This software is able to allow planners to visually plan highway construction projects, to calculate the controlling activity path of such schedules and to print reports of the status of the schedule.

The paper describes the software that was developed by the research, its documentation and example for an Italian case study that was scheduled using this prototype.

In addition to the software, the authors propose to road agencies and contractors the utilization of linear scheduling for highway construction management. With this computer tool, road agencies will be able to integrate the software with its current project management tools improving the existing methods.

For complete implementation of UNaLSS additional modules and further research have to be developed. Two of the proposed modules are the cost and resource analysis modules, which would allow project schedulers to calculate the minimum additional cost to reduce project delays and to optimise resource allocation. This additional capability will provide the linear scheduling method with the statistical analysis tools comparable to those of network diagrams.

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A linear project can be defined as a project where the majority of activities on the project are linear activities. Linear activities are those activities that are completed as they progress along a path. A highway construction project can be a linear project, and a paving activity on this project can be considered a linear activity.

A linear schedule is a visual representation for a repetitive project's construction plan. It shows the plan's logic and the relationships between activities. The schedule is displayed as a graph, with time on one axis and location on the other axis. Time and location can be on either axis, depending on which makes more sense. For a highway project, putting location on the horizontal axis coincides with the dimensional nature of the project. The graphical representation in Figure 1 is an example of a linear schedule.

## LINEAR SCHEDULING MODEL

Schedulers and planners have come to rely on the concepts of critical and non-critical activities in managing complicated projects.

After several years of research with the Iowa Department of Transportation on several highway construction projects, Rowings and Harmelink (1993, 1994) developed an algorithm that determines the critical path in a linear schedule. This algorithm, called the linear scheduling model (LSM), identifies the controlling activity path (CAP) through an upward and downward pass through the activities. The determination of the critical path is the fundamental concept that makes all of the analysis provided by reticular techniques possible. The development of the CAP in the linear scheduling model makes reticular-type analysis of linear schedules possible. The CAP identifies which activities are controlling activities and which activities are non-controlling activities.

Figure 1 shows a linear schedule in which the controlling activity path has been determined. The purple segments of activities labelled as controlling indicate the segments of activities that are controlling. The horizontal links are where the controlling activity path moves from one activity to another. These activities, as in reticular scheduling, define the longest path of activities necessary to complete the project. The points at the ends of the controlling segments indicate the time and location that the controlling status of an activity changes.

By definition, activities on the critical path in a reticular schedule do not have float and activities not on the critical path must have float. This concept can be applied to a linear schedule as well. Activities or segments of activities not on the controlling activity path, as indicated by segments of activities that are not purple in Figure 1 must have float. Reticular scheduling techniques use float to measure the amount of time that the duration of a non-critical activity can be extended, or the start of the activity delayed, before it enters the critical path. Linear activities are represented on the linear schedule as a line where the slope of the line is in units of time and distance. Linear schedules can also include non-linear activities described as block and bar type activities. For these activity types, the definition of float is similar to that in CPM.

The CAP is significant in that it provides a basis for analysing linear schedules and allows for the development of functionality at a level commensurate with that found in reticular techniques software today.

## REVIEW OF EXISISTING SOFTWARE FOR LINEAR SCHEDULING

The Linear Scheduling Method (LSM) is the most effective scheduling tool to use in linear projects. Computer programs have been developed for various scheduling techniques such as Bar Chart, PERT and CPM. There are not many commercially available software for LSM, however, this lack of software is one of the reasons for its limited usage. Since the LSM is best suited for highway projects, it is very essential to develop an easy-to-use and effective software to support its use. The following paragraphs briefly discuss about the various software available for linear scheduling, their input requirements, output capabilities, as well as their advantages.

### Purdue University Linear Scheduling Software

Purdue University Linear Scheduling Software (PULSS) v 1.0 is a prototype software that serves as a proof of concept for the computerization of the LSM algorithm that determines the controlling activity path in a linear schedule. It was developed within a Computer Aided Design (CAD) environment to take advantage of

the visual capabilities of Linear Schedule and offer the user a friendly and simple way to visually plan linear schedules of highway construction projects.
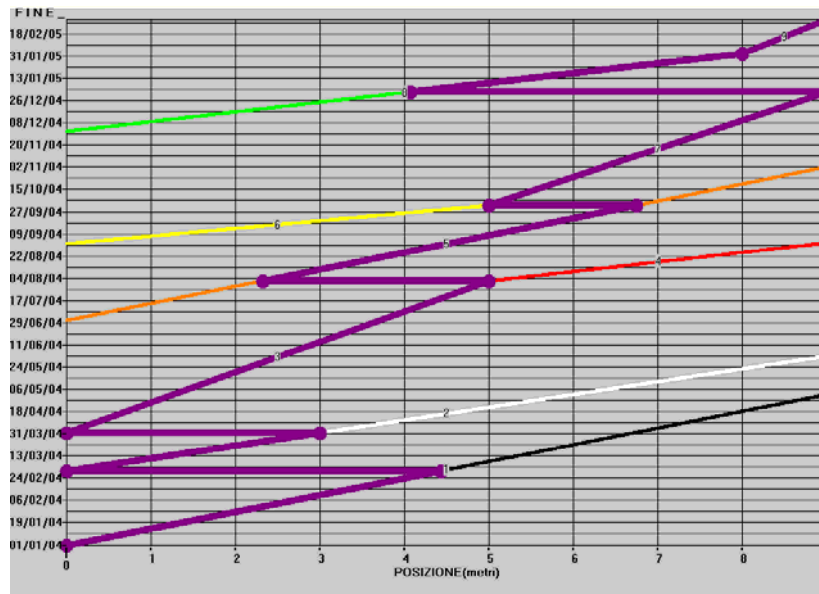


**Figure 1: LSM controlling activity path (UNaLSS output)**

In general, CAD applications provide the graphical environment in which civil engineering models can be created. These models are drawn as graphical entities that are abstractions of real objects. These entities can be drawn in a two-dimensional or a three-dimensional coordinate system space. Looking at dimensions from a broader perspective, any of the XYZ axes can also be used to represent attributes other than distance, such as time.

Linear schedules represent construction activities in a two-dimensional coordinate system of time and space. By converting one the XYZ dimensional axes to time coordinates, CAD can be used to model linear construction activities.

To implement the LSM algorithm in CAD, the Y coordinate is considered as the date and the X coordinate the location. Time and space are only two of the attributes of an activity in a linear schedule. CAD can represent other attributes as well.

Name of activity: a fundamental property of entities in CAD is the layer on which they exist; entities on these layers can be manipulated in various ways such as making them visible or invisible, changing their colour, or a number of other attributes; in LSM, the entities that represent a construction activity exist on a unique layer with the activity name.

Start/End Date: Y coordinates from entities representing activities are equivalent to dates represented by calendar dates.

Duration: activity durations are determined by the difference in Y coordinates of the start and end points of activities.

Productivity: measured in units of space per units of time (feet/day) is represented by the slope of linear activities.

Resources: metadata, also called entity extensions, are attributes that can be associated with particular entities in a drawing; in the proposed framework, this metadata field can be used to include the number and type of resources that the activity consumes for its completion.

Modelling construction activities in the manner described above provides the basis for the implementation of the LSM algorithm that calculates the Controlling Activity Path in a linear schedule. CAD environments provide comprehensive sets of functions to manipulate entities. These functions along with the development environment included in CAD packages can be exploited to implement the LSM algorithm. Depending on the particular CAD package, routines can be written in a variety of programming languages, such as Visual C, Visual Basic and different flavours of LISP. These development tools and functions allow the manipulation of graphical entities, selection of objects according to different layers or positions in the drawing space and distance calculations between different objects to name a few.

## Florida Linear Scheduling Program

Florida Linear Scheduling Program (FLSP) v1.0 is a linear scheduling software developed by the University of Florida in 1999. The tool has two functions; the first function is scheduling a specific linear construction project by using the Linear Scheduling Method and the second function is to perform resource management. It is a very user friendly software offering the scheduler help with entering correct data and in the right

format. Each screen has a "Next" button that allows the user to advance to the next screen, and a "Back" button to go back to the previous screen. Help on each screen is available by using the "Help" button provided. Also, there is a print option on each screen that allows the user to print information available on each window.

The software helps in avoiding the crossing of adjacent operations by giving a warning to the user while entering data for the operations.

FLSP is developed to offer the user a simple tool by using linear schedules and also for resource management and cost control by using histograms and S-curves.

The schedule graph shows the sequence of operations developed in time and space, offering the scheduler a visual representation of the project. Three minor labels are added to the time axis, which are the work days, calendar days and the month and year label. The vertical axis refers to the station number. Grids can be provided in order to view the graph more clearly and the user has the option to remove the grids if he wants to. The horizontal grid line for the end station is denoted by a bold line in order for it to be distinguished from the other grid lines.

Identification of the project is facilitated by entering the details of the project on the Project Description screen, which can be viewed on the Linear Schedule Graph. The date and time the project was last updated appears on the top left corner of the graph.

Viewing and interpreting the FLSP graph is made easier by the elimination of unnecessary drawing accessories, which otherwise create confusion to the scheduler. Only lines are used in order to represent different operations.

The Linear Schedule Graph is bound on the 'Time Axis' by the end date of the project as initially assigned in the "Time Calculations" Screen.

The Resource Histogram is a very useful tool for the planner in determining the efficiency of the project by the correct schedule and allocation of available resources. The histogram shows the daily consumption of a certain resource which is determined by adding number of uses of that resource on a certain day for all the operations performed on that particular day. A maximum of five resource histograms can be drawn for each operation, thereby offering the possibility of managing the most important resources for the project.

In addition to the resource histogram, the user is also provided with a graph which shows the dynamic movement of the financial resources. The S-Curve was selected for the purpose of enabling the manager to have a clear view on the expenditure of funds on the project in order to exercise close financial surveillance.

## TransCon XPosition

TransCon XPosition (TCXP) is a linear scheduling software developed in 1997 by TransCon Consulting Ltd a Virginia based firm. This software is compatible with any computer that has Windows operating systems. The software makes use of all the drawing components in order to facilitate plotting of the linear schedule. These components are: axes, access constraints, bars, lines, and blocks. The TCXP is essentially a drawing software. The user has to know for each activity, the start and the finish dates together with the start and finish locations.

Project information containing the description of the project, names or titles of the contractor and the owner, project start and finish dates and also the project start and end stations are to be inputted first. Activity data is to be input next, as: Activity ID, description, symbol (block, line, bar), start and finish dates and start and end stations. Also, there is an option of entering the percentage completion for each activity.

The project information can be directly input into the software. It can also be imported from other spreadsheets or from other scheduling software.

Related to the graph capabilities, the scheduler has an option to set up the grid lines by defining their colour, style and interval of the horizontal and vertical sight lines. These sight lines on the time axis can be set at monthly, weekly or daily intervals.

The linear schedule can be seen as a graphical plot by using the Graph View menu. Different styles, patterns, fillings and also a large pallet of colours are available so as to distinguish each activity from the other. Special graphical symbols like arrows and flags are used to represent earth movement operations.

By using TCXP, it is possible to print or plot the schedule to any printing device supported by Windows 95. The user can also print the tabular activity data to be included with the schedule.

The main advantage of TCXP software is that it allows visualization of the plan of construction operations by using the basic components and graphical symbols of linear scheduling, thus providing time/space portrayals that are easier to communicate and understand, in comparison to other scheduling tools.

The software also has some disadvantages; the main disadvantage being that the program is more a graphical tool than a planning and scheduling tool. The program does not calculate the finish date of an activity; the user has to input both the start and the finish dates. TCXP does not help the user to calculate the buffer spaces between the adjacent activities. Also, it does not consider one of the most important elements in scheduling, which is the productivity rate of an activity. All the above elements have to be calculated in advance by the scheduler, who will introduce them as input data in the software. This involves repetition of work by the user, thus increasing the total time taken to schedule the project.

## Line of Balance Planning By Spreadsheet

Spreadsheets like LOTUS, Excel, Quattro Pro, can be used as general-purpose packages in applications that would have required a specific program a few years ago. The spreadsheet can help the planner in interpreting the data in order to plan linear construction projects.

In the first three columns of the spreadsheet activity data such as the activity ID, activity description and the duration of the activity (y) are inputted. The start date of the project is also an input data on which the start and the end dates of the following activities will depend.

The scheduler has to input relation to calculate the time distance between the adjacent activities and the start days for units 1 and N of each activity, for example units being piers in case of viaducts.

Between activity i and i+ 1:
- if $y_j < y_{i+1}$ then start buffer will be considered, and
- if $y_j > y_{j+1}$ then end buffer will be considered.

Final and initial dates of each activity are calculated by the computer depending on the type and the value of the buffer.

For each activity, the calculation of start dates of units 1 and N is done by using the following formulae:
- In case of start type buffer:

start day unit 1 ($sdu_1$)= start day of previous activity + activity duration + buffer

start day unit N ($sdu_N$) = start day of unit 1 + total time for (N-1) units
- In case of end type buffer:

$sdu_1$ = start day of unit N of previous activity - previous activity duration + buffer

$sdu_N$ = start day of unit 1 + total time for (N-1) units

In many cases, it is much easier to use standard packages to produce a more limited solution with less effort. It is more beneficial for users to learn how to use packages of general application than to have to learn how to use a special program for each application.

An other advantage of this software is the flexibility. The data which is available in a large variety of standards can be easily manipulated and used in the evaluation of the line of balance schedule by using the spreadsheet. By using the spreadsheet, buffers between activities can be calculated automatically, because they are related to the activity durations.

The principal disadvantage of using this software, is that it considers that the activity production rate is the same for the whole space; it does not consider division of locations in stations and sections, which is very common for linear projects. This program is useful for projects of a successive nature, i.e one activity starts only after the end of the previous activity and that no two activities run simultaneously. Therefore, it is not suitable for projects which are not successive in nature also because constraints are also not considered. The software calculates the buffer between two consecutive activities, which is one of the most important problems, but only if the location is one section.


## Line of Balance Scheduling Program for Windows

The Line of Balance program for Windows is a tool for linear scheduling. The software produce a schedule founded on the production rates of a sequence of activities developed along a linear track through the work.

To use the basic functions of the software, the scheduler needs to have a construction with a limited number of sections, a sequence of activities, and the production for every operation in days/section.

The first input describes the project by identifying characteristics such as contractor's name, project's title, the start of the project and the number of sections in the construction. Four options are available for modifying some features of the plan, which are: as-plan and as-built schedule, resources and holidays. Each of these options have their own screen heading.

The as-plan scheduling screen is used for entering activities and production (days/section) for new projects or modifying activities and/or production for existing projects. All changes to existing activities or input on new activities are done by using the "Active Operation" screen. On this window, the illustrations and the production are records that can be modified by the scheduler when required.

The holiday window is used to add or delete holidays to/from the six holidays the program was pre-loaded with.

The scheduler has to use the "Active Operation" window to input the resource requirements for every activity. The user also has the possibility to input or delete resources according to requirements. The software calculates calendar start and finish dates based on a standard five-day work week.

The work days of the activities are determined by the program using linear construction scheduling formulation.

The main result of the tool is a graphical line of balance schedule, which can be viewed prior to printing. The time axis of the graph is expressed in workdays. The software can print as an output, the resource histogram, and a standard bar chart which has the time scale in calendar days.

The main disadvantage of the program is that it uses days/section as the production rate, whereas, the actual definition of this parameter is output unit/working days, representing the production output of a given crew during a unit of time. What the software designer calls as the production is actually the duration of the

operation. By confusing the actual production rate with the activity duration, the software designer isn't considering the quantity, the crew size, and the real production rate and their influence on linear scheduling.
The software considers the division of the space into sections but it doesn't solve the problem of buffers between adjacent operations at each section.
The resource histogram doesn't have a graphical presentation and resources are given in the form of numbers.

## Linear Construction Project Manager

Linear Construction Project Manager (LCPM) v1.0 is a prototype of a scheduling software for highways and railways. The program was developed as a tool to assist in performing the calculations required in using the LCPM proposed by El-Sayegh (1998).
A function performed by LCPM is scheduling construction works. The scheduler can enter information about the work, and once the design data are input, the schedule is calculated based on which, graphs and tables can be generated. LCPM has an interface and minimal knowledge of computers is needed to use it.
The program requires the scheduler to input the data into the dictionaries and also data for the scheduling. The data stored in dictionaries is used to calculate work item duration, costs and some reports. The dictionaries include equipment, labour, materials, crew mix and crew types. For the first three resources, i.e. equipment, labour and materials, the scheduler will input data using three main fields, which are, code, description and cost. The crew mixes are formed by using the "Crew Mix" form which contains the crew mix code, description, equipment, quantity, labour and quantity of labour. The crew types are to be inputted in a "Crew Type" table, which consists of five fields; these fields are, the crew type code, the crew description, crew mix code, daily linear production, and unit of distance measurement. The crew mix table and crew type table are linked such that a crew mix can be assigned to more than one crew type, while crew type can have only one crew mix.
In order to do the scheduling, the user will input the data in a step by step manner. The scheduler will input all project information and calculate the schedule before viewing the tables and graphics or starting the probabilistic scheduling algorithm. The user has the option of either using the deterministic or probabilistic schedule, depending on the degree of uncertainty in the production rate estimates.
In the deterministic schedule, a first input is to define the Work Breakdown Structure (WBS) for the linear operations in the project. The WBS form is divided into two parts, the top part contains data about the work packages, and the bottom part contains data about the operations that belong to the specified wok package.
A work package can have more than one activity. For one activity, the user has to assign relationships and lags to the successor activities; lag is the amount of buffer time that the scheduler desires between consecutive activities. All this is done by using the Activity Logic Network (ALN) form.
The next step is to divide the project into work areas. In each work area, the user has to enter the work area number, starting station, ending station, and the rank which determines which work area has priority over shared resources.
The input data for the probabilistic scheduling is done by using the Probabilistic Scheduling command button, which will activate the "Crew Types" form. This form allows the scheduler to edit different production rate observations for every crew type.
In the probabilistic scheduling, once the observations for each crew are entered, the mean linear production rate and standard deviation for each crew are calculated by clicking the "Calculate" button.
Each graphical report contains a pie chart that shows the idle and active time percentages for the specified crew.
The LCPM has the specific advantage that the project is divided into work areas, thus considering the different production rates for each activity on the different sections. Project control is made easier by this dividing of location.
Unfortunately the problem of the buffer time between two consecutive activities remains with the scheduler. The prototype has no algorithm to solve this problem. The software does not consider the calendar days, holidays and other constraints that might appear during construction. The program does not produce a graphical output for resources other than labour. The program does not show cash flow charts and S-Curves.

## UNIVERSITY OF NAPLES LINEAR SCHEDULING SOFTWARE

Even if the Linear Schedule can be calculated manually for small construction projects, there is a need of computer software to perform the calculations and prepare the charts, tables and histograms for larger linear constructions projects. University of Naples Linear Scheduling Software (UNaLSS) is a prototype of a scheduling software for transportation constructions projects such highway and railway. This software was developed as a tool to assist in performing the calculations required in using linear scheduling. This paragraph presents the concepts, inputs and outputs generated by UNaLSS.

The UNaLSS has two functions; the first function is scheduling a specific linear construction project by using Linear Scheduling Method and the second function is calculating the Controlling Activity Path by using the Linear Scheduling Model. The software has a user friendly interface. Minimal knowledge of computers is needed to use this software. Figure 2 presents a hierarchy of screens available in the software.
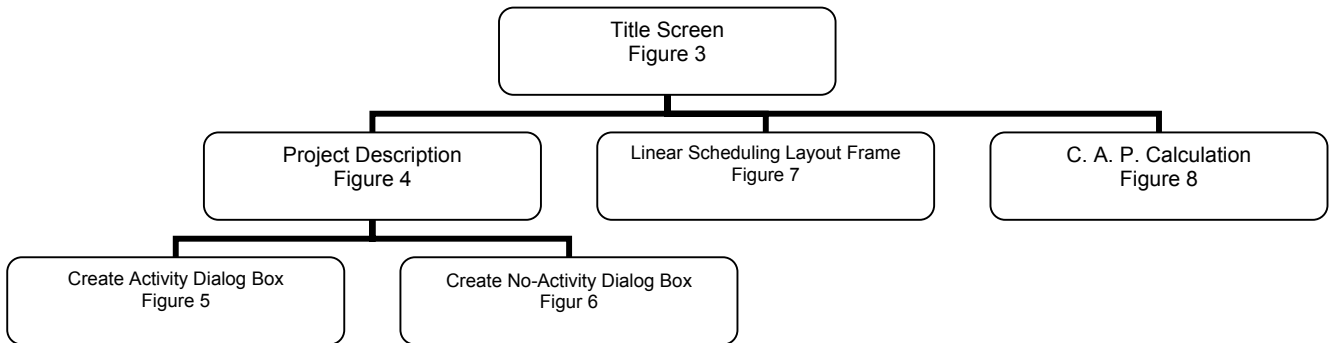


**Figure 2: Hierarchy of screens in the software**

**Program Description**

UNaLSS (v1.0) is a prototype software that serves as a proof of concept for the computerization of the LSM algorithm that determines the controlling activity path in a linear schedule. It was developed in Visual Basic programming language to take advantage of the visual capabilities of Linear Schedule and offer the user a friendly and simple way to visually plan linear schedules of highway construction projects.

In general Visual Basic applications provide the environment in which engineering models can be created. These models are drawn as entities that are abstractions of physical elements. These entities can be drawn in a two-dimensional (X,Y) coordinate system space. Looking at dimensions from a broader perspective, any of the XY axes can also be used to represent attributes other than distance, such as time.

Linear schedules represent construction activities in a two-dimensional coordinate system of time and space. To implement the LSM algorithm in visual Basic, the Y coordinate is considered as the time dimension and X coordinate the spatial dimension. Time and space are only two attributes of an activity in a linear schedule. Visual Basic can represent other attributes as well.

In LSM, the entities that represent a construction activity exist in a unique layer with the activity name.

Start/End location: X coordinates from entities representing activities are equivalent to location of the activity in the project.

Start/End date: Y coordinates from entities representing activities are equivalent to dates.

Duration: activity durations are named by difference in Y coordinates of the start end points of activities.

Productivity: measured in units of space per units of time (meter/day) is represented by slope of linear activities.

Modelling construction activities provides the basis for the implementation of the LSM algorithm that calculates the Controlling Activity Path in a linear schedule. Visual Basic environment provide comprehensive sets of functions to manipulate entities.

The routines allow the manipulation of graphical entities, selection of objects according to different positions in the drawing space and distance calculations between different objects.

**General Comments**

Each screens has button that allows the user to advance to the next screen and to go back to the previous screen. Help on each screen is available by using the "?" button provided. Also, there is a print option on each screen that allows the user to print information available on each window. The software helps in avoiding the crossing of adjacent operations by giving a warning to the user while entering data for the operations. It is a very user friendly software offering the scheduler help with entering correct data and in the right format.

**Input Requirements**

Application starts with the title screen, Figure 3. This screen contains the software title and the University of Naples logo.

**Figure 3: Title screen**

Identification of the project is facilitated by entering the details of the project on the Project Description screen, which can be viewed on the Linear Schedule Graph.

For entering new projects the user has to click *New Project* in the File menu and for opening old projects, the user has to click *Open Project* in the File menu and select the name of the project already saved for the "Project Description" window (Figure 4) to be activated.

This window contains the following fields: Project Title, Project Start Date, Project End Date and Project Length.
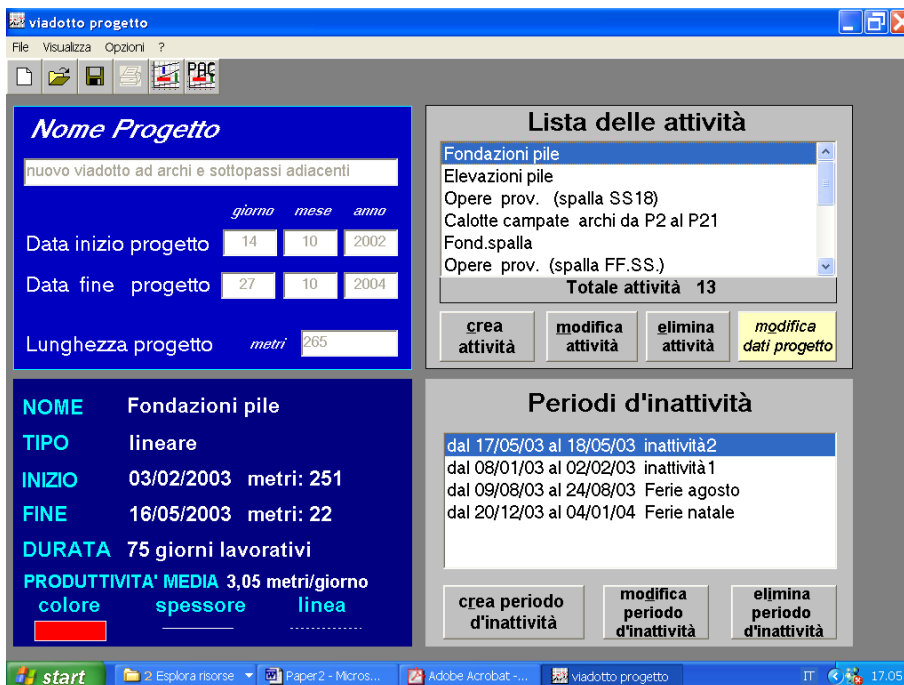


**Figure 4: Project description window**

The purpose of this window is to offer a description on the project to be scheduled. It is possible to skip to the next window by clicking the "Create Activity" button. In this step the user introduces information for each activity to be scheduled. The create activity screen is shown and information about the activity can be introduced through the dialog box shown in Figure 5. Users can select description, the type (linear, block or bar), start and end dates, start and end locations, graphical characteristics of the activity.

**Figure 5: Create activity dialog box**

The linear schedule can be seen as a graphical plot by using the graph view menu. Different styles, patterns, fillings and also a large pallet of colours are available so as to distinguish each activity from the other.

UNaLSS can calculate the Controlling Activity Path if there is a time period where there is no activity being executed in the project. The project description window also contains a dialog box for no-activity periods (holidays and cold weather shutdown). The create no-activity period screen is shown and information about the no-activity period can be introduced through the dialog box shown in Figure 6. Users can select description and start/ dates.


**Figure 6: Create no-activity period dialog box**

Automatically the software draws the activities and the no-activity periods in the schedule layout shown in Figure 7. After all the activities and no-activities periods are drawn into the schedule layout the activity sequence list is calculated. For UNaLSS v1.0 this process is automatically done.
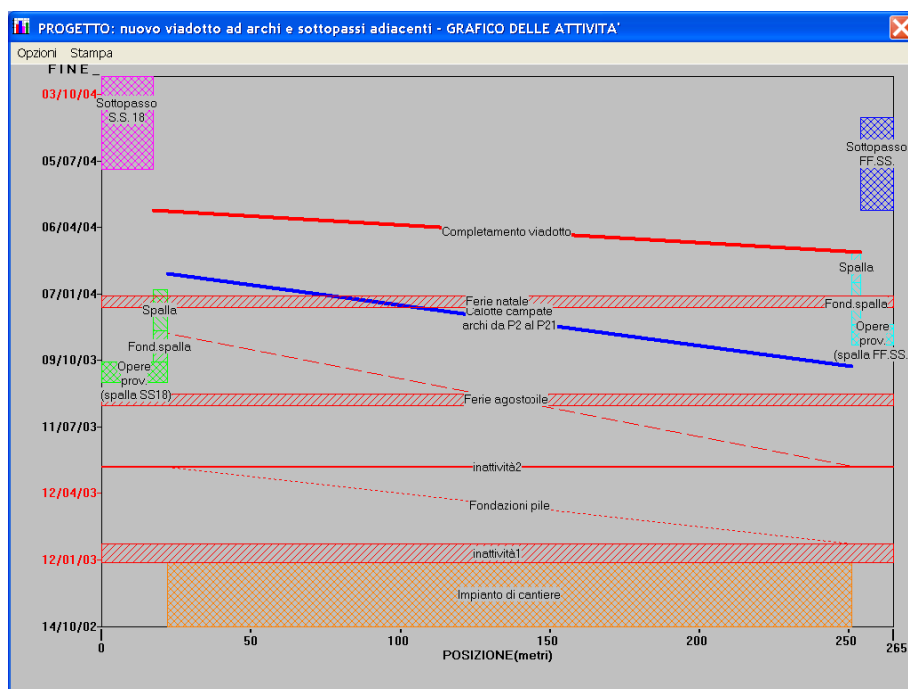

**Figure 7: Linear Schedule Layout Frame**

Grids can be provided in order to view the graph more clearly and the user has the option to remove the grids if he wants to.

## Controlling Activity Path Calculation

Once the activity list is calculated the user can click on the "calculate CAP" button and UNaLSS will draw the CAP for the schedule in colour purple using a different type line (Figure 8).

UNaLSS does not differentiate between intermittent and continuous activities. All activities are considered continuous for the CAP calculation.
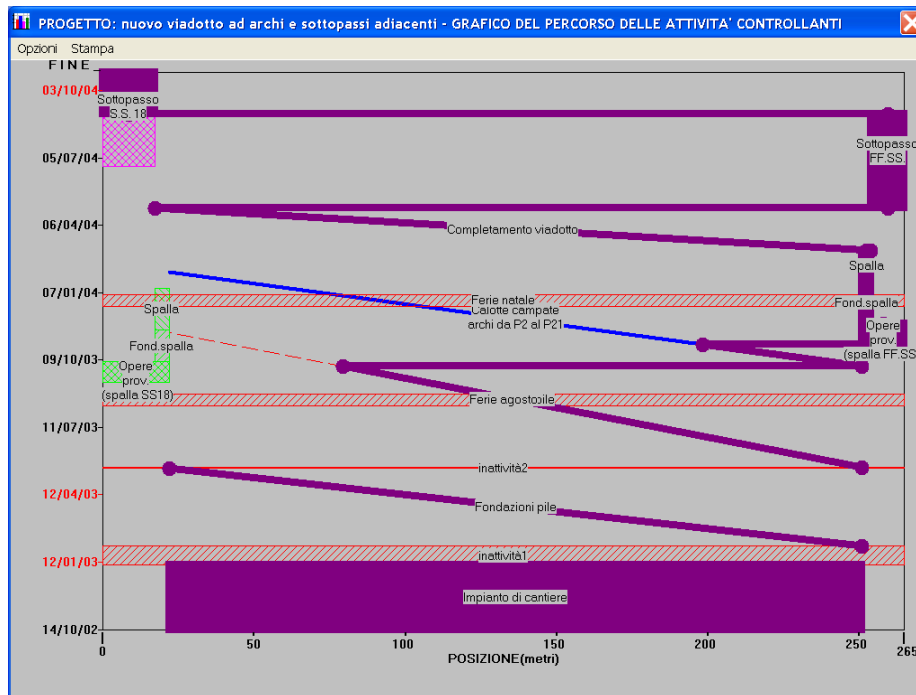


**Figure 8: Controlling activity path calculation**

The linear schedule can be seen as a graphical plot by using the graph view menu. By using UNaLSS, it is possible to plot the schedule to any printing device supported by Windows operating system.

## Tests of UNaLSS

As part of any software development project, prototypes of the program have be used by user that could be considered "typical users" of the future application. For this project several contractors were contacted but finally only three accepted to dedicate some time to provide us with information about its projects. The results of one of this test is shown as follows. Several sites visits and scheduling meetings were held both at the offices and on job-site. From these meetings we could understand how schedulers plan the work and what are their needs. Some test schedules were elaborated and reviewed.

The prototype was tested several times by scheduling a particular phase of the A3 Naples-Salerno highway rehabilitation project. The phase consist in construction of a new viaduct which has a total length of 265 meters. The project started on 25 November 2002 and was competed on 27 October 2004.

The resource histogram (Figure 9) shows the daily consumption of a certain resource which is determined by adding number of uses of that resource on a certain day for all the operations performed on that particular day. The histogram is very useful for the manager in determining the efficiency of the project by the correct schedule and allocation of available resources. Resources are also fixed throughout the duration of the project. For purpose of this example, only thirteen activities will be scheduled (Table 1). In general, activity durations are directly impacted by the amount of resources required to complete any activity. Change in productivity impacts duration. In a LSM, changes in productivity are represented by changes in slopes of the lines that represent activities. This change in slope can affect the controlling path and ultimately change the total duration of the project. Because of the layout of space-time, LSM represents the relationship of activities that cannot be easily determined with the reticular techniques. Furthermore, LSM allows changes in start and end times of activities and productivity in ways that will guarantee the continuity of the activity.

By analysing the viaduct construction example, two different cases can be identified for explaining resource management scenarios.

Case 1 assumes that activities cannot change their productivity (fixed by technical requirements) but can be split (Figure 10). P1 (Figure 11) and C1 (Figures 13 and 14), segments that are not in the CAP, can start at later times as long as the least distance (LT) from any of these activities to change and the following activity is less than the actual LT.

**Tab 1: Activities tabular report**

| ACTIVITY | TYPE | START STATION | END STATION | START DAY | END DAY | DURATION (DAYS) | SYMBOL |
|---|---|---|---|---|---|---|---|
| 1 | Mobilization | 22 | 251 | 09/12/02 | 31/01/03 | 40 | Block |
| 2 | Pier foundations | 251 | 22 | 03/02/03 | 16/05/03 | 75 | Line |
| 3 | Piers erection | 251 | 22 | 19/05/03 | 14/11/03 | 120 | Line |
| 4 | Span Caps | 251 | 22 | 01/10/03 | 03/02/04 | 80 | Line |
| 5 | Provvisional works SS18 | 0 | 22 | 09/09/03 | 06/10/03 | 20 | Block |
| 6 | Abutment foundations SS18 side | 17 | 22 | 07/10/03 | 17/11/03 | 30 | Block |
| 7 | Viaduct abutment SS18 side | 17 | 22 | 18/11/03 | 12/01/04 | 30 | Block |
| 8 | Provvisional works railway | 251 | 265 | 30/10/03 | 26/11/03 | 20 | Block |
| 9 | Abutment foundation railway side | 251 | 254 | 27/11/03 | 21/01/04 | 30 | Block |
| 10 | Viaduct abutment railway side | 251 | 254 | 22/01/04 | 03/03/04 | 30 | Block |
| 11 | Viaduct Completion | 254 | 17 | 04/03/04 | 28/04/04 | 40 | Line |
| 12 | Railway underpass | 254 | 265 | 29/04/04 | 01/09/04 | 80 | Block |
| 13 | Underpass SS18 | 0 | 17 | 24/06/04 | 27/10/04 | 80 | Block |

Case 2 assumes that productivity can change, because resources in each activity can be added/removed. Total resources are not interchangeable between activities. Therefore, removing resources will change durations of float activities and reduce costs but will not change the total duration of the project. In this case, LSM demonstrates how easy it is to determine the minimum productivity required, when in time, and the location where productivity can be reduced. For example in Fig. 12, activity P had allocated resources to achieve productivity of 1,90 m/day (P1). Assuming linear correspondence between resources and productivity, the minimum productivity that activity P should have is of 0,90 m/day (P2) if no changes in activity C's productivity is done. If reduction of C's productivity is allowed (C1→C2), the minimum productivity of P would be 0,60 m/day (P3).

Using the original schedule as a baseline, project control and update can be performed by plotting progress on top of the baseline schedule. Discrepancies between planned and executed activities are easily observed. In addition, the only information needed for updating is the location at which the activity is being executed at the updating time. These are easily taken from the field, and no extra calculations are needed.

The main two advantages of UNaLSS are:
- the visualization of the plan of construction operations by using the basic components and graphical symbols of linear scheduling, thus providing time/space portrayals that are easier to communicate and understand, in comparison to other scheduling tools;
- the implementation of the LSM algorithm that calculates the Controlling Activity Path in a linear schedule.

Some disadvantages that can be easily rectified by improving the software are:
- the time axis shows only the calendar days, and not working days;
- the program does not calculate the finish date of an activity - the user has to input both the start and the finish dates;
- the blocks makes the graph very complicated and difficult to read;
- the program does not consider resources and costs;
- the resource histogram does not have a graphical presentation; thereby not facilitating resource management by the scheduler;
- the program does not graphically represent the cash flow (S-curve), thus, not assisting the planner to monitor the expenditure of funds on the project for financial control.
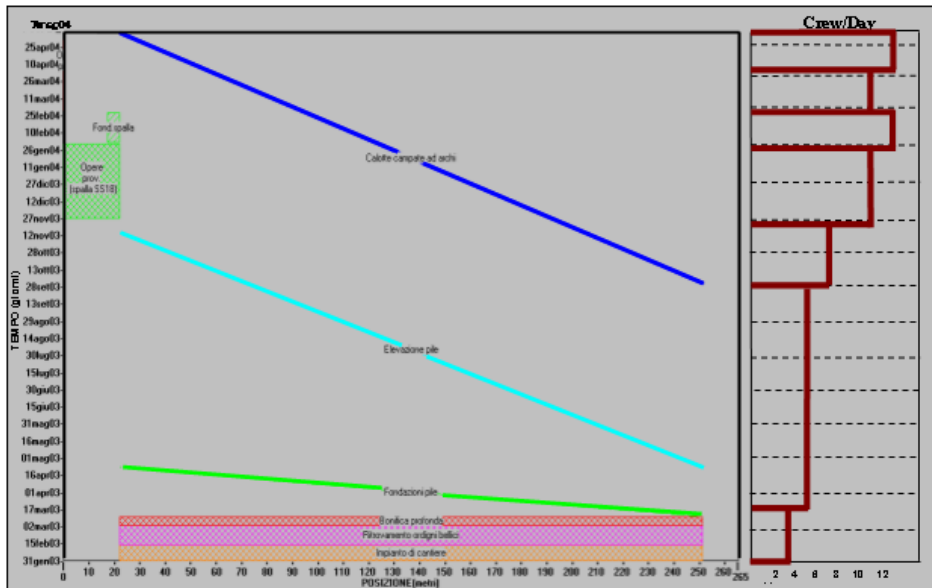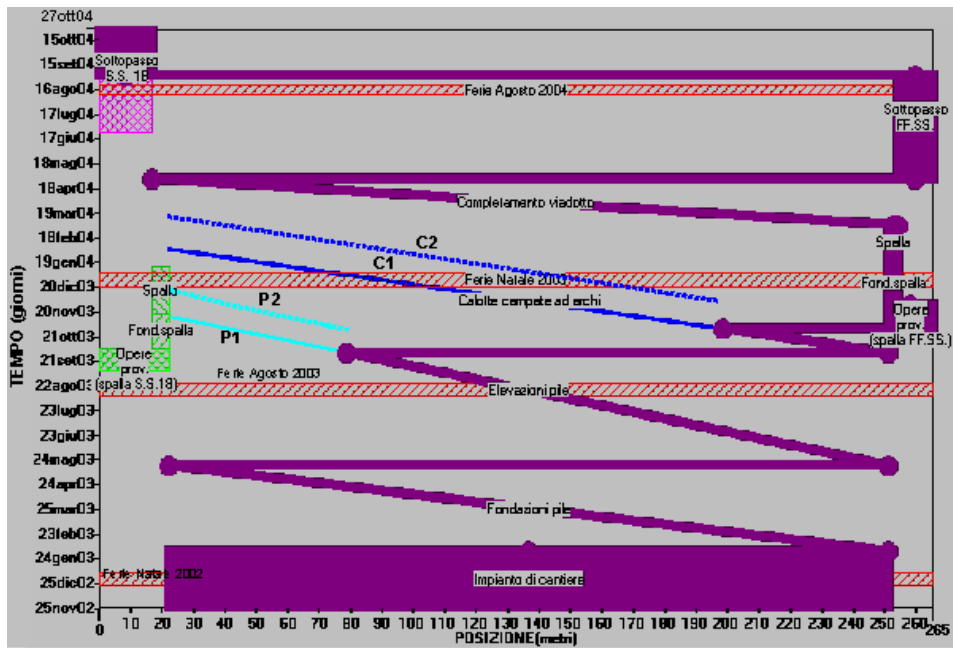
**Figure 9: Crew/Day utilization**



**Figure 10: Moving Linear Activities with Float - Resources Constant**

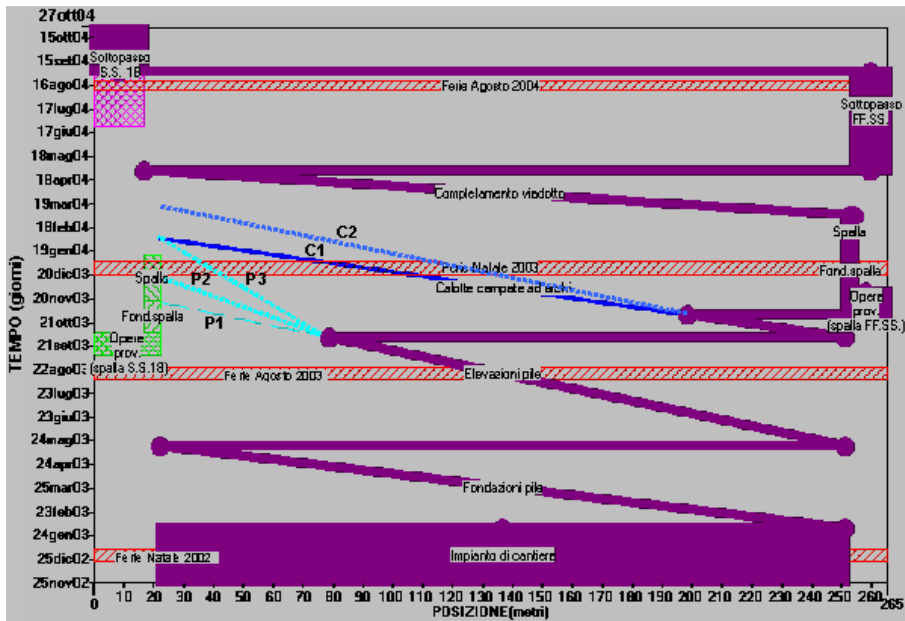

**Figure 11: View of piers**

Figure 12: Resource Management Effects and Possibilities in UNaLSS


Figure 13: View of caps


Figure 14: View of spans

## CONCLUSION

The process of drawing bars, lines and blocks on a linear schedule places the primary focus on planning and returns a measure of credibility to scheduling.

Not many software are commercially available to do planning of construction projects using the Linear Scheduling Method. In addition, even the programs that are available are more a graphical tool than a

planning tool, thus, not meeting the user's requirements. Therefore, the planners in linear construction projects are mostly using the software that are available on the CPM and Bar Charts, even though these are not as suitable for linear projects as LSM is.

The researchers have only lately started developing software for linear scheduling; however, there are some major flaws in the programs developed, which if solved will offer a powerful tool for scheduling linear projects.

Not taking into consideration the site constraints, improper design of time and location axes, not considering the productivity rate of activities, lack of resource scheduling options, etc. are some of the major flaws observed on the software analysed.

In this note we refer on the applicability of the University of Naples Linear Scheduling Software (UNaLSS) v1.0 an original tool for highway construction management; we also demonstrate that the algorithm for controlling activity identification can be implemented in software.

The prototype requires the successive implementation of specific algorithms for resource levelling and cost control that allow the management of real cases, of any type or dimension, supplying elements to optimise the construction process. Nevertheless, the developments of the research must be finalized in order to resolve dysfunctions that emerge in the treating of the non linear activities and in particular in the block activities.

The final objective is to produce a tool which incorporates the rigor of operative research analysis in a clear and the intuitive visual display of the planning intent.

Further applications and development of the software presented in this paper is progressing; the results obtained to date have been of benefit to both owners and contractors.

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