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LINEAR SCHEDULING ANALYSIS TOOLKIT FOR ROAD AND AIRPORTS CONSTRUCTION PROJECTS

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ABSTRACT

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 toolkit for LSM and this lack of toolkit is one of the reasons for its limited usage. The product of this research is a toolkit comprised of models, procedures and tools that allow for implementation of the linear scheduling method. This toolkit is able to calculate the controlling activity path of such schedules, to level the resources of a project scheduled and to print reports of the status of the schedule. The paper describes the toolkit that was developed by the research, its documentation and example for an Italian case study that was scheduled using this prototype.

Keywords: linear construction project, controlling activity path, resource leveling, budget.

INTRODUCTION

Low-volume roads, as presented in this paper, constitute a significant proportion of the road network in Italy and in many other countries in the world: In fact, roads in low-volume conditions make up around 80% of the total road network in Italy. The situation is very similar throughout Europe, especially in the north. Rural roads are a vital part of the infrastructure of societies: they allow a flow of goods and services throughout rural areas, support rural development, supply access to local markets, help attract teachers to rural schools and encourage rural technical support from government agencies, as well as providing a variety of other uses and benefits. At the same time, however, road construction can make a significant adverse environmental impact, modifying natural terrain, disturbing large areas, and leading to major cultural and land use changes. Thus, roads need to be well planned, well designed, well constructed, and properly maintained for minimal adverse impact and to be cost effective in the long term with acceptable maintenance and repair costs. 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 with 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. 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 Low-Volume Road 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 road projects putting location on the horizontal axis coincides with the dimensional nature of the project [1, 2].

REVIEW OF EXISTING TOOLKIT FOR LINEAR SCHEDULING

Schedulers and planners have come to rely on the concepts of critical and non-critical activities in managing complicated projects. 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 toolkit for LSM and this lack of toolkit is one of the reasons for its limited usage. Since the LSM is best suited for infrastructure projects, it is very essential to develop an easy-to-use and effective toolkit to support its use. The following paragraphs briefly discuss about computer based applications available for linear scheduling, their input requirements, output capabilities, as well as their advantages.

Linear Construction Project Manager (LCPM)

LCPM v1.0 is a prototype of a scheduling toolkit for highways and railways. 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. 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 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 program does not produce a graphical output for resources other than labour. The program does not show cash flow charts and S-Curves [3].

Florida Linear Scheduling Program (FLSP)

FLSP v1.0 is a linear scheduling toolkit which has two functions; the first function is that FLSP schedules a specific linear construction project by using the Linear Scheduling Method and the second is that it performs resource management.

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 [4].

Purdue University Linear Scheduling Software (PULSS)

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. 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. 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 [5].

Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS) Software

The CA4PRS software, a Microsoft Windows application on an Access database, was developed as a scheduling and production analysis tool for highway pavement rehabilitation projects in California, especially high-traffic urban segments. CA4PRS estimates the distance (lane kilometres) and duration of pavement rehabilitation or reconstruction given project constraints by using Monte Carlo simulation, CPM analysis, and linear scheduling [6].

Line of balance program for Windows

The Line of Balance program for Windows is a tool for linear scheduling. The toolkit produce a schedule founded on the production rates of a sequence of activities

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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 time axis of the graph is expressed in workdays. The toolkit 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 [7].

TransCon XPosition (TCXP)

TCXP is a linear scheduling software, developed in 1997 by TransCon Consulting Ltd a Virginia based firm, compatible with any computer that has Windows operating systems. The toolkit 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 main advantage of TCXP toolkit 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.

UNIVERSITY OF NAPLES LINEAR SCHEDULING TOOLKIT

Even if the Linear Schedule can be calculated manually for small construction projects, there is a need of computer toolkit to perform the calculations and prepare the charts, tables and histograms for larger linear constructions projects.

The *University of Naples Linear Scheduling (UNaLS)* software v1.0 was a prototype of a scheduling software for transportation constructions projects [7]. This software was developed as a tool to assist in performing the calculations required in using linear scheduling. The following paragraphs present the concepts, inputs and outputs generated by the new version of the UNaLS v2.0 [8]. The new toolkit has two main 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 toolkit has a user friendly interface and minimal knowledge of computers is needed to use this toolkit. UNaLS v2.0 is a toolkit 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 simple way to visually plan linear schedules of Low-Volume Road 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 coordinate system 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. Activity durations are named by difference in Y coordinates of the start end points of activities. Productivity, measured in 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. 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 toolkit 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 toolkit offering the scheduler help with entering correct data and in the right format. 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 to be activated. This window contains the following fields: Project Title, Project Start Date, Project End Date and Project Length.

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 "Create activity dialog box".

Users can select description, type (linear, block or bar), start and end dates, start and end locations and the graphical characteristics of the activity.

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.

UNaLS v2.0 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 "Create no-activity period dialog box". Users can select description and start dates.

Automatically the toolkit draws the activities and the no-activity periods in the schedule layout shown in Figure 2. After all the activities and no-activities periods are drawn into the schedule layout the activity sequence list is calculated. This process is automatically done using UNaLS v2.0.

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. Once the activity list is calculated the user can click on the "calculate CAP" button and UNaLS v2.0 will draw the CAP for the schedule in colour purple using a different type line. UNaLS v2.0 does not differentiate between intermittent and continuous activities. All activities are considered continuous for the CAP calculation.

The linear schedule can be seen as a graphical plot by using the graph view menu. By using UNaLS v2.0, it is possible to plot the schedule to any printing device supported by Windows operating system. As part of any toolkit 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 I could understand how schedulers plan the work and what are their needs. Some test schedules were elaborated and reviewed.

Controlling activity path algorithm

The linear scheduling is established with graphical representation of the activities on a co-ordinated XY level that shows on the axis the time indication and the location. The linear activities are represented by a straight segment in which the gradient quantifies the marginal productivity of the same activity. Each of the points in the diagram describes the advancement and the duration of the works [1, 2, 9, 10].

A constructive procedure is linear if the main parts of the activities are linear. In general the construction operations of a road can be "linear", "in blocks" and "in bars" (Figure-1).

The linear activities can be characterized alternatively as so:

- continuous (L1), if the carrying out involves the whole and without continuity the development of the site (for eg. the laying of the pavement);
- intermittent (L2) if the carrying out involves only in part the development of the site (for eg. construction of the plumbing system);
- partially continuous (L3), if the carrying out involves, without continuity, only a part of the work (for eg. movement of dirt);
- partially intermittent (L4), if the carrying out involves, only a part of the works (for eg. carrying out plumbing works).

The block and bar activities, can be characterized as so:

- block (B1), if the carrying out involves within the same time interval the entire development of the work (for eg. completion of temporary signs for the site, etc.);
- partial block (B2), if the carrying out of the involves at the same time all the sections of a limited portion of the works (for eg. construction of bridges, viaducts, etc.);
- bar (b), if it deals with an elementary activity arranged in a determined and limited period of time of the programme (for eg. the creation of an underground passage).

An activity is said to be pseudo critical if it is entirely o partially critical. The succession of the critical portions (segments) of the activities that cover the entire constructive process is called the pseudo critical course.

The algorithm used for identifying the pseudo critical course is articulated in three phases: a) identification of the sequences of the activity; b) the ascending phase; c) the descending phase.

a) Sequence of the activity

This phase defines the list of sequences that identify the possible logical relations between the activities that make up the constructive process.

In Figure-1, the programme of the construction of a road section is shown, made up of: four linear type activities (L1, L2, L3 and L4), two block type (B1 and B2) and one bar type (b).

The list of the sequences is the list of all possible complete successions of activity, in a consecutive order according to the execution logic, from the opening to the closing of the works [11].

Note that all the sequences will be connected according to the course of the continued linear activities (opening, A, D, G, closing the works); and taking into consideration the planned obligation in correspondence

with the different placing (graphically shown in Figure-2 by the vertical lines 1-:-5); the successions portrayed are:

1.   beginning of works -B1-L2-L4-L1- end of works;
2.   beginning of works -B1-L2-B2-L4-L1- end of works;
3.   beginning of works -B1-L2-B2-L3-L4-L1- end of works;
4.   beginning of works -B1-L2-b-L3-L1- end of works;
5.   beginning of works -B1-L2-L3-L1- end of works;

The analysis of the work plan is developed towards the rising times; the phase is finalized to the identification of the particular succession made up of linear activities which are joined and separated by the minimum time interval [11, 12, 13].
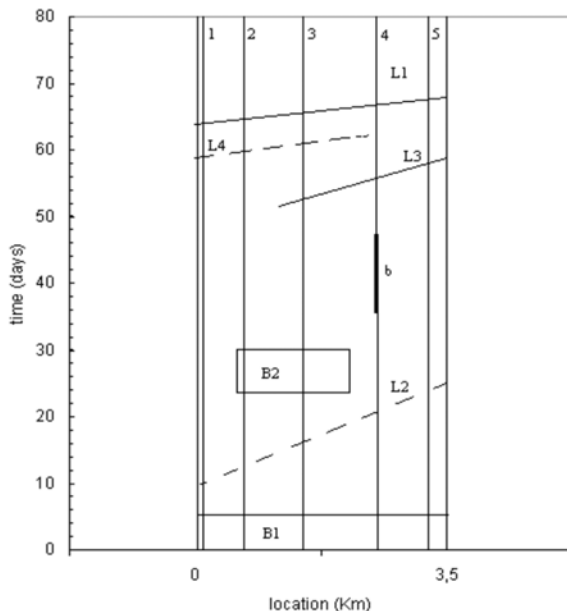
Figure-1. Activity typology and logical sequence (5).

The former activity is the one that starts according to the origin of the axis and is called "origin" activity whilst the latter is called the "target" (Figure-2).
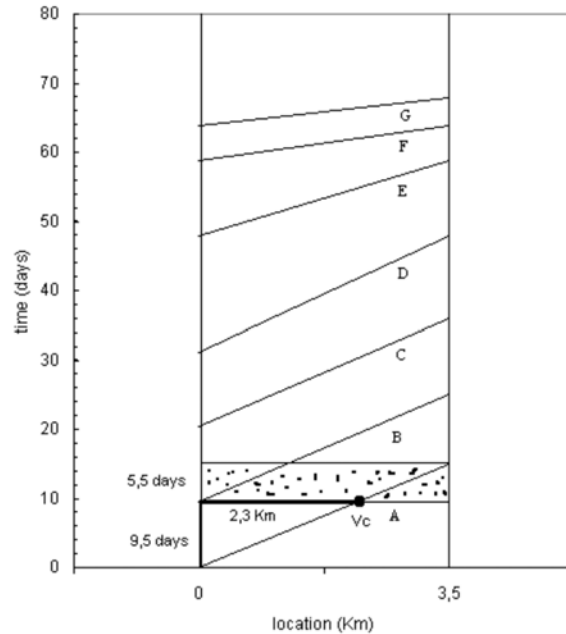

Figure-2. Ascending phase (5).

In order to describe the relation between the two we must determine the three following elements:

▪ the minimum amount of time interval between two activities that are functionally connected (defining them so with a vertical line, in the space/time plan, that don't intersect others); the minimum time interval is always located according to the points of discontinued angles of one of the two activities; in the case of partial blocks the connection is placed in correspondence to the summit of one of the blocks;
▪ the temporary overlapping that is the time interval in which two connected activities are at the same time being carried out;
▪ the minimum distance between two activities functionally connected (that is separated by a specific minimum time interval), carried out at the same time in a limited time range.

Figure-3 shows the segments represented by the minimum interval (for eg. in Table-1 equal to 9, 5 days) and the minimum distance (for eg. in Table-1 equal to 2, 3 Km) as well as the time overlapping area (for eg. in Table-1 equal to 5, 5 days). The segment that links the former activity "origin" in the ascending course to the "target" is said to be a potential connection between pseudo critical segments.

The intersection point between the supporting straight line of the minimum distance and the origin activity is called the "critical summit" (Figure-4). The segment represented in the first origin activity that connects the origin of the axis with the critical summit, is a potential controlling segment: as a consequence the minimum distance is a potential controlling connection.

The confirmation of the effective controlling function of the segment must be set off from the following descending phase. The procedure must be repeated obtaining the first target activity as a new origin and valuating overlapping time and minimum space of time between the following activities.

The ascending course is concluded (Figure-3) with the recognition of all potential segments and controlled connections.
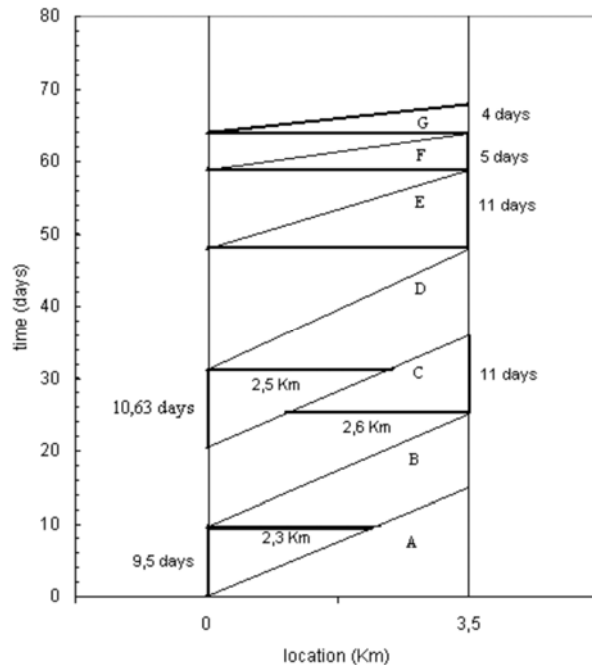

Figure-3. Ascending phase (5).

The aim of the descending course (with origin in correspondence with the final point of the last activity of the project in Figure-4) is the determination of the segments which are actually controlling. The linear scheduling in this phase allows the identification of the segments (portions of activity) in which the percentage of productivity cannot be varied without modifying the duration of the entire construction process [14, 15, 16, 17]. The activities that do not belong to the pseudo critical path can also be executed at a lower percentage instead of the one that has been programmed without influencing (within determined limits however quantifiable) regarding the date of the closure of the works. The descending procedure of the controlling activities, in the example we are looking at, continues along the operation F until the intersection with the connection with activity E (in Figure-4). The segments portrayed with a continuous route make up the critical portion of each activity and the critical connections between them.
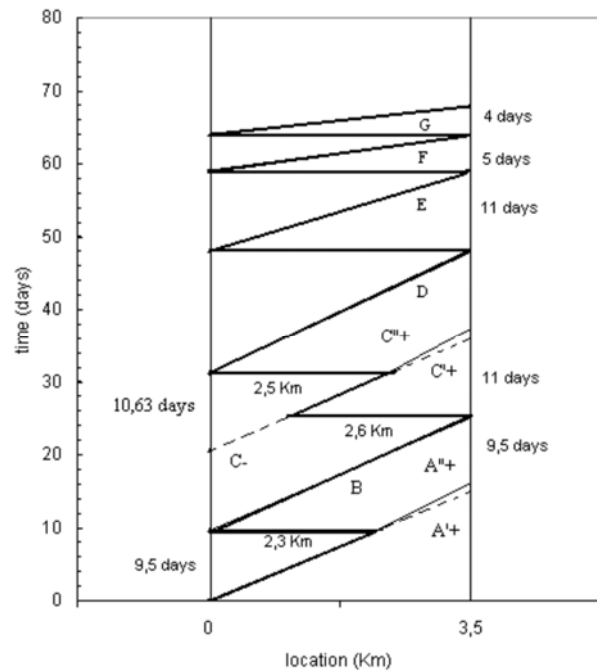

Figure-4. Descending phase (5).

The procedure must be repeated until the entire pseudo critical path can be recognized. In the case of the beginning of an activity followed by a potential connection between itself and a preceding activity, the critical connection will be made from a horizontal segment including both the initial point of that activity as well as the axis activity.

The descending phase is completed when the entire pseudo critical process has been recognized; which is made either of a whole activity or only in critical parts; regarding these last points, the critical summits include the space and time location and the transition from none controlling to controlling.

The presence of non linear continuous activities (partial and/or intermittent linear, block, bar) modifies the pseudo critical process. For example a block type activity can be inserted in the pseudo critical process with all of its length: the corresponding connections are the segments that unite the top of the rectangular block on the main axis with the closest two continuing linear activities.

The inclination of each segment in the co-ordinated plan referring to space and time represents the productivity of the linear activity; the constance of the said dimension during the entire development of the activity is only in theory that does not find any comparison in real cases. Similar theory is the eventuality portrayed by an execution of the different operations without any space and time continuity. In reality it is always necessary to introduce various "margins" between linked activities for multiple reasons regarding organization of the work site and/or for safety.

The algorithm used for recognizing the pseudo critical process allows the identification of the portions (limited in time and space) critical and non of the activity

(different to the CPM, that only foresees entirely critical and non critical activities); as agreed the single non critical portions of activities are branded with the name of the activity to which they belong and with the symbol "-" (negative) if it's not initially critical, but becomes so, and vice versa with the symbol "+" (positive) even if critical to begin with but loses it during the course of the (respectively C -, C + and A +, in Figure-4). The average productivity of the activities (or portions) non critical can be reduced, within certain limits, without postponing the closure date of the work. The analysis, in the beginning and within construction, of the programme allows quantifying the exact limits of advancement, constantly during the whole project. The identification of the segments of the non critical activities quantifies the possible reduction of the productivity of each of them. The minimum distance in time between two consecutive activities is the smallest interval of time that separates, in the absence of conflicts and conditional constructive process, the activities, the minimum distance constitutes the bond to reduce the production of each non critical segment [12].

For example, if we consider the segment C'+ in Figure-4, its productivity, equal to the average productivity of the activity C that is 225,8 m/per day, can be reduced within the limit of 163,4 m/per day portrayed in the graph by the inclination of the segment C''+; a further reduction of the productivity is in fact not compatible with the bond imposed by the minimum time distance of 10, 6 days between the consecutive activities C and D.

Also the productivity of the segment A+ can be reduced from 233, 3 m/per day (A'+) to 200 m/per day (A''+). The difference between the programmed productivity and the minimum admissible productivity is said to be the flowing of the activity.

The closing date of an activity can be postponed, within certain limits, and without any consequences on the completion times of the work reducing the productivity of the single non critical portion of the activity itself; however the delay of an activity reduces the time between the activities and limits the variation range of the activities productivity.

The recognition of the variation range of productivity is fundamental for the management of the work site and the allocation of the resources during the works.

Resource leveling formulation

This section describes the mathematical formulation, using integer linear programming, for levelling the resources of a project scheduled using the UNaLS toolkit. The formulation minimizes the sum of the absolute deviation of resources used on any day from an average daily resource use or desired resource use [18, 19, 20, 21].

$$z = \sum_{1}^{T} (devp_i + devm_i)$$

Where $devp_i$ and $devm_i$ are the absolute deviations above and below, respectively, a day's desired resource rate. This formulation levels the resources to a desired resource rate determined by the following equation.

$$d_{rr} = \sum_{1}^{T} y_i / T$$

Let y_i be the sum of the resource required for any day, i. The variable y_i will consist of the resources required for all activities.

Example

The new version of the toolkit was tested several times by scheduling a particular phase of the Road rehabilitation project (Figure 5, 6). The phase consists in construction of a new viaduct which has a total length of 265 meters. The resource histogram (Figure-7) 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).

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Table-1. Activities tabular report.

Activity	Start station	End station	Duration (days)	Symbol
Mobilization	22	251	40	Block
Pier foundations	251	22	75	Line
Piers erection	251	22	120	Line
Span Caps	251	22	80	Line
Provisional works SS18	0	22	20	Block
Abutment foundations SS18 side	17	22	30	Block
Viaduct abutment SS18 side	17	22	30	Block
Railway provisional works	251	265	20	Block
Abutment foundation railway side	251	254	30	Block
Viaduct abutment railway side	251	254	30	Block
Viaduct Completion	254	17	40	Line
Railway underpass	254	265	80	Block
Underpass SS18	0	17	80	Block
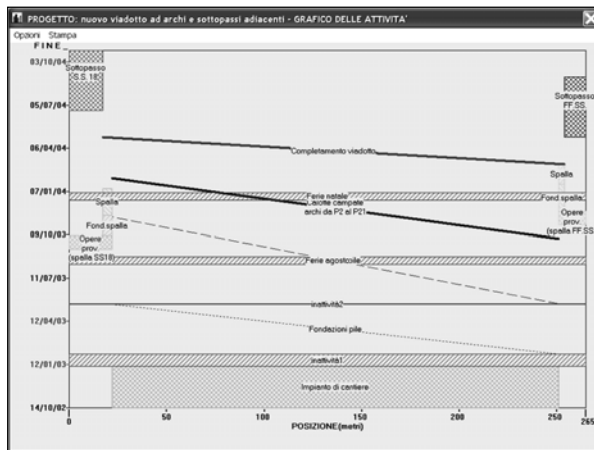
Figure-5. Linear schedule layout frame.
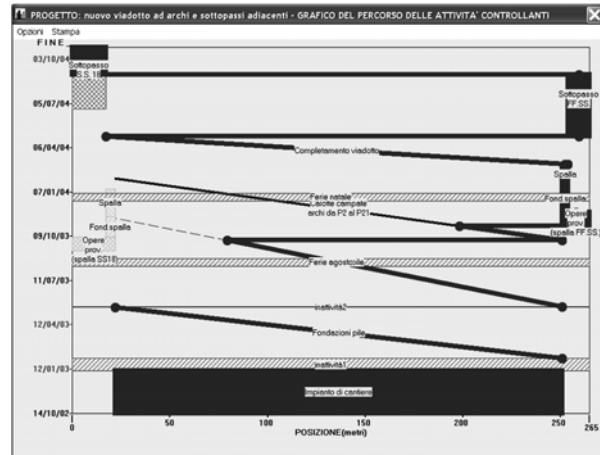
Figure-6. Controlling activity path calculation.

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 [22-30].

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, P1 and C1, 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 (see Figure-8). 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 Figure 8, 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 (see Figure-9). If reduction of C's productivity is allowed (C1→ C2), the minimum productivity of P would be 0.60 m/day (P3).

DISCUSSIONS AND RESULTS

Using the original schedule as a baseline, project control and update can be performed by plotting progress on top of the baseline schedule [31-43]. 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 three advantages of UNaLS v2.0 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;
- the implementation of a resource levelling algorithm in a linear schedule.

Some disadvantages that can be easily rectified by improving the toolkit 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 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.
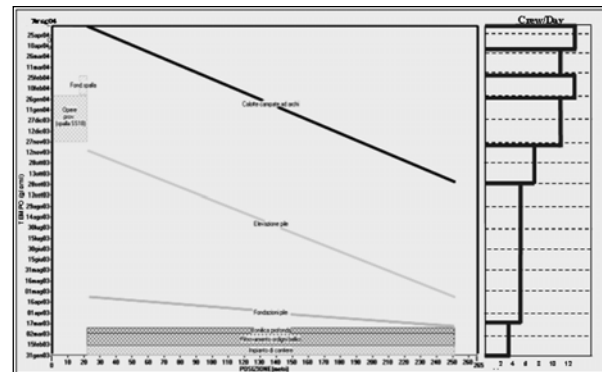
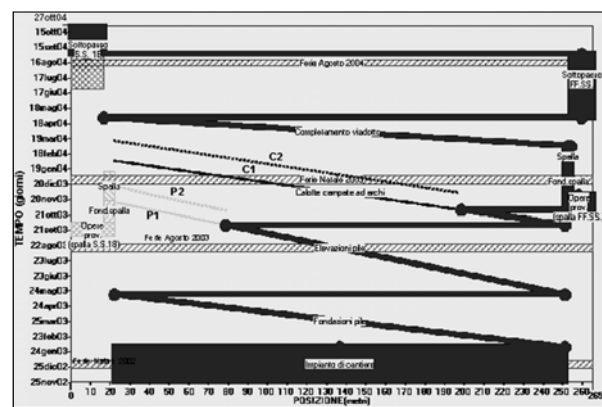

Figure-7. Crew/Day utilization.

Figure-8. Moving linear activities.

CONCLUSIONS

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 toolkit 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 toolkit that is 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 toolkit 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 toolkit analysed. The UNaLS v2.0 is a new original tool for highway construction management which 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.

For complete implementation of UNaLS v2.0

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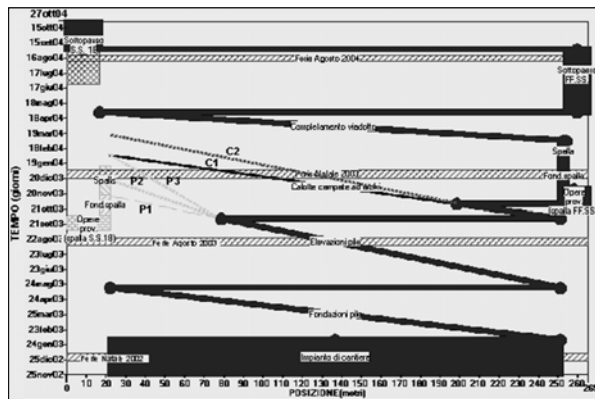

Figure-9. Resource management effects and possibilities.

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REFERENCES

[1] Vorster M. C., T. Beliveau Y. J. and T. Bafna. 1992. Linear Scheduling and Visualization. In Transportation Research Record: Journal of the Transportation Research Board, No. 1351, Transportation Research Board of the National Academies, Washington, D.C., USA.

[2] Yamín R. A. and D. J. Harmelink. 2001. Comparison of Linear scheduling model (LSM) and Critical Path Method (CPM). Journal of Construction Engineering and Management, ASCE. 128(5): 374-381.

[3] El-Sayeg S. M. 1998. Linear Construction Planning Model (LCPM): A New Model for Planning and Scheduling Linear Construction Projects, Texas A and M University.

[4] Herbsman Z. J. 1999. The Application of Linear Scheduling in the FDOT Construction Operation. State of Florida Department of Transportation and University of Florida.

[5] Harmelink D. J. and R. A. Yamín. 2000. Development and application of linear scheduling techniques to highway construction projects. Final Report. Division of Construction Engineering and Management, School of Civil Engineering Purdue University, Indiana Department of Transportation and U.S. Department of Transportation Federal Highway Administration.

[6] Hegazy T. Critical Path Method-Line of Balance Model for Efficient Scheduling of Repetitive Construction Projects. In Transportation Research Record: Journal of the Transportation Research Board, No.1761, Transportation Research Board of the National Academies.

[7] Lee E.-B., J.T. Harvey and M. M. Samadian. 2005. Knowledge-Based Scheduling Analysis Software for Highway Rehabilitation and Reconstruction Projects. In Transportation Research Record No. 1907, Transportation Research Board of the National Academies, Washington, D.C. pp. 15-24.

[8] Dell'Acqua G., R. Lamberti and P. Discetti. 2005. Computer Based Linear Scheduling Application for Highway Construction Planning. In Proceedings of the III° SIIV Congress, Bari, Italy. CD-ROM.

[9] De Luca, M., Dell'Acqua G. 2014. Runway surface friction characteristics assessment for Lamezia Terme airfield pavement management system. Journal of Air Transport Management. ISSN: 0969-6997, doi: 10.1016/j.jairtraman.2013.06.015. 34: 1-5.

[10] Harmelink D. J. and J. E. Rowings. 1998. Linear scheduling model: Development of controlling activity path. Journal of Construction Engineering and Management, ASCE. 124(4): 260-270.

[11] Harris R. B. and P. G. Ioannou. 1998. Scheduling projects with repeating activities. Journal of Construction Engineering and Management, ASCE. 124(4): 269-278.

[12] Harmelink D. J. 2000. Linear scheduling model: Float Characteristics. Journal of Construction Engineering and Management, ASCE. 127(4): 263-268.

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[13] Dell'Acqua G. and R. Lamberti. 2003. A Linear Scheduling Model to Plan Road Works. In Proceedings of the XXII° World Road Congress, Durban, South Africa. CD-ROM.World Road Association.

[14] Dell'Acqua G.; M. De Luca; R. Lamberti. 2011. Indirect Skid Resistance Measurement for Porous Asphalt Pavement Management. Transportation Research Record 2205: 147-154.

[15] Dell'Acqua G.; M. De Luca; F. Russo; R. Lamberti. 2012. Mix Design with Low Bearing Capacity Materials. The Baltic Journal of Road and Bridge Engineering 7(3): 204-211. DOI: 10.3846/bjrbe.2012.28.

[16] Dell'Acqua, G.; M. De Luca; F. Russo. 2012. Procedure for Making Paving Decisions with Cluster and Multicriteria Analysis. Transportation Research Record 2282: 57-66.

[17] Hassanein A., O. Moselhi. 2004. Planning and Scheduling Highway Construction. Journal of Construction Engineering and Management, ASCE. 130(5): 638-646.

[18] Mattila K. G. and D. M. Abraham. 1998. Resource levelling of linear schedules using integer linear programming. Journal of construction Engineering and Management, ASCE. 124(3): 232-244.

[19] Zilioniene D., M. De Luca M., G. Dell'Acqua. 2013. Evaluation of Climatic Factors Based on the Mechanistic-Empirical Pavement Design Guide. The Baltic Journal of Road and Bridge Engineering. 8(3): 158-165.

[20] Čokorilo O., De Luca, M., Dell'Acqua G. 2014. Aircraft safety analysis using clustering algorithms. Journal of Risk Research. 17(10). DOI: 10.1080/13669877.2013.879493.

[21] Dell'Acqua G.; F. Russo. 2010. Speed factors on low-volume roads for horizontal curves and tangents, The Baltic Journal of Road and Bridge Engineering. 5(2): 89-97. DOI: 10.3846/bjrbe.2010.13.

[22] Lamberti R.; Russo F.; Dell'Acqua G. 2010. Visual impact assessment for infrastructure design. Large Structures and Infrastructures for Environmentally Constrained and Urbanised Areas, ISBN: 978-385748122-2; pages 668-669, code 111904.

[23] Dell'Acqua G. 2011. Reducing Traffic Injuries Resulting from Excess Speed Low-Cost Gateway Treatments in Italy, Transportation Research Record 2203: 94-99. DOI: 10.3141/2203-12.

[24] Dell'Acqua G.; M. De Luca; R. Mauro; R. Lamberti. 2011. Motorway speed management in southern Italy, Procedia Social and Behavioral Sciences, Volume 20, Pages 49-58. DOI: 10.1016/j.sbspro.2011.08.010.

[25] Esposito T.; Mauro R.; Russo F.; Dell'Acqua, G. 2011. Speed prediction models for sustainable road safety management, Procedia Social and Behavioral Sciences. 20: 568-576. DOI: 10.1016/j.sbspro.2011.08.063.

[26] Dell'Acqua G.; F. Russo. 2011. Safety Performance Functions for Low-Volume Roads. The Baltic Journal of Road and Bridge Engineering. 6(4): 225-234. DOI: 10.3846/bjrbe.2011.29.

[27] Discetti P.; Dell'Acqua, G.; Lamberti R. 2011. Models of operating speeds for low-volume roads. Transportation Research Record. 2203: 219-225. DOI: 10.3141/2203-27.

[28] De Luca M.; Mauro R.; Russo F.; Dell'Acqua G. 2011. Before-after freeway accident analysis using Cluster algorithms. Procedia Social and Behavioral Sciences. 20: 723-731. DOI:10.1016/j.sbspro.2011.08.080.

[29] Dell'Acqua G.; De Luca M.; Mauro R. 2011. Road safety knowledge-based decision support system. Procedia Social and Behavioral Sciences. 20: 973-983. DOI: 10.1016/j.sbspro.2011.08.106.

[30] Esposito T.; Mauro R.; Russo F.; Dell'Acqua G. 2012. Operating speed prediction models for sustainable road safety management. ICSDC 2011. 20: 712-721. DOI: 10.1061/41204(426)87.

[31] Dell'Acqua G. 2011. European speed environment model for highway design-consistency. Modern Applied Science. 6(9): September 2012, Pages 1-10. DOI: 10.5539/mas.v6n9p1.

[32] De Luca M.; Dell'Acqua G. 2012. Freeway safety management: Case studies in Italy, Transport. 27(3): 320-326. DOI:10.3846/16484142.2012.724447.

[33] Dell'Acqua G.; F. Russo, S.A. Biancardo. 2013. Risk-type density diagrams by crash type on two-lane rural

roads. Journal of Risk Research. 16(10): 1297-1314 DOI: 10.1080/13669877.2013.788547.

[34] Dell'Acqua G.; Busiello M.; Russo F. 2013. Safety Data Analysis to Evaluate Highway Alignment Consistency. Transportation Research Record 2349: 121-128. DOI: 10.3141/2349-14.

[35] Mauro R.; De Luca M.; Dell'Acqua G. 2013. Using a k-means clustering algorithm to examine patterns of vehicle crashes in before-after analysis. Modern Applied Science. 7(10): 11-19. DOI: 10.5539/mas.v7n10p11.

[36] Dell'Acqua G.; F. Russo; R. Mauro. 2013. Validation procedure for predictive functions of driver behaviour on two-lane rural roads. European Transport, ISSN 1825-3997, Issue 53, paper 10.

[37] Russo F.; Biancardo S.A.; Busiello M.; De Luca M.; Dell'Acqua G. 2013. A statistical look at gender and age differences as related to the injury crash type on low-volume roads. WIT Transactions on the Built Environment. 134: 213-224. DOI: 10.2495/SAFE130201.

[38] Russo F.; S.A. Biancardo S.A.; Dell'Acqua G. 2014. Road Safety from the Perspective of Driver Gender and Age as Related to the Injury Crash Frequency and Road Scenario. Traffic Injury Prevention. 15(1): 25-33 DOI: 10.1080/15389588.2013.794943.

[39] De Luca, M.; Dell'Acqua G. 2014. Calibrating the passenger car equivalent on Italian two line highways: A case study, Transport. 29(4): 449-456. DOI: 10.3846/16484142.2013.845854.

[40] Russo F.; Biancardo S.A.; Dell'Acqua, G. 2014. Consistent approach to predictive modeling and countermeasure determination by crash type for low-volume roads. The Baltic Journal of Road and Bridge Engineering. 9(2): 77-87. DOI: 10.3846/bjrbe.2014.10.

[41] Dell'Acqua G. 2015. Modeling Driver Behavior by using the Speed Environment for Two-Lane Rural Roads. Transportation Research Record 2472: 83-90. DOI: 10.3141/2472-10.

[42] Russo, F.; Busiello, M.; Dell'Acqua, G. 2016. Safety performance functions for crash severity on undivided rural roads. Accident Analysis and Prevention, 93: 75-91. DOI: 10.1016/j.aap.2016.04.016.

[43] Pedarla A.; Puppala A. J; Savigamin C.; Yu X. 2015. Performance of Sand-Treated Clay Subgrade Supporting a Low-Volume Flexible Pavement. Transportation Research Record 2473: 91-97. DOI: 10.3141/2473-11.