A LINEAR SCHEDULING MODEL TO PLAN ROAD WORKS

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ABSTRACT

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.

The Linear Scheduling (LS), which is a road work planning method that is particularly indicated for dealing with linear infrastructure building processes, was highly appreciated in the past solely because its graphic plotting looks very clear. However, unlike reticular techniques such as the Critical Path Method (CPM) and the Project Evaluation and Review Technique (PERT), the LS method has never drawn the same degree of attention because, of its lack of algorithms and calculus codes, which has never allowed its widespread employment.

The key element of scheduling methods based on reticular techniques lies in the possibility of identifying the critical path, i.e. the sequence of those activities according to which any change in a single activity duration brings about a modification of the entire project timing.

Nowadays, the new methods of Linear Scheduling can be used as an alternative instrument to the better established reticular techniques since they make it possible to identify a group of controlling activities. A controlling activity corresponds to a partially or totally critical activity. Thus, the concept of controlling activity path is just an extension of the one of critical path.

My contribution, thus, is aimed at illustrating the linear model, one of the innovative instruments of the current road work planning techniques and the ways one can make use of them when managing the activities to be carried out in road construction sites.

KEY WORDS

PLANNING/ WORKS/ LINEAR/ ACTIVITY/ PATH.

1. INTRODUCTION

The scientific literature is rich of programme techniques, construction of public works that differ in representation, activities analysis systems and logical relations between different operations. The most common methodologies of the planning of the works are the grid or Gantt diagrams, the reticulate techniques, like the Critical Path Method (CPM) and the Project Evaluation and Review Technique (PERT). The principle reasons why these methods are widely used is partly due to the fact that potentiality calculating algorithm for recognising the critical course from the vast usage in other sections, from the ease of use to the limited knowledge of the potential of other methods.

The linear techniques (LS) are less widespread, nevertheless if supported by specific algorithms according to the recognition of the "pseudo critical" path, represent a valid approach to the work programmes in some of the public constructions.
The success rate of each of the methodologies obviously depends on the technological characteristics and of the project of the work to be scheduled. Listed in diagram n.1 are the range of applications of each technique.
The linear scheduling, particularly, provides excellent results in the treatment of the "linear works" (for eg.: roads and highways) in which the construction derives from a constructive process by summing few simple activities repeating without a continuing solution in a long term linear course; the linear techniques, unlike the reticulate ones, are not easy to use for the scheduling process of construction "punctual works" (non linear; for eg.: bridges, public housing, etc.) consisting of a high number of very complexed operations, not of the same kind, that is, not repetitive within time and space.

2. THE LINEAR SCHEDULING

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 (Harmelink, Rowings, 1998).
Shown in table 1 and figure 1, for example, the elementary case (Ioannou, Martinez, 1998) of the realization of the system for the platform a road section 3,5 Km in length, to be completed in about 68 days. The works were subdivided in seven basic activities:

Table 1: List of the activities

	ACTIVITY	DURATION (DAYS)	START	FINISH	PRODUCTIVITY (MT/DAY)
A	clear & grub	15	0	15	233,3
B	move dirt	15,5	9,5	25	225,8
C	place subbase	15,5	20,5	36	225,8
D	Pave	16,7	31,1	47,9	209
E	cure pavement	11	47,9	58,9	318,2
F	place shoulders	5	58,9	63,9	700
G	place guardrail & landscape	4	63,9	67,9	875

Figure 2 shows the extreme simplicity and the immediate legibility of the representation which facilitates the management and revision even during the course of the works.

2.1. Linear constructive procedures

A constructive procedure is linear if the main part of the activities are linear. In general the construction operations of a road can be "linear", "in blocks" and "in bars" (figure 3).
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).

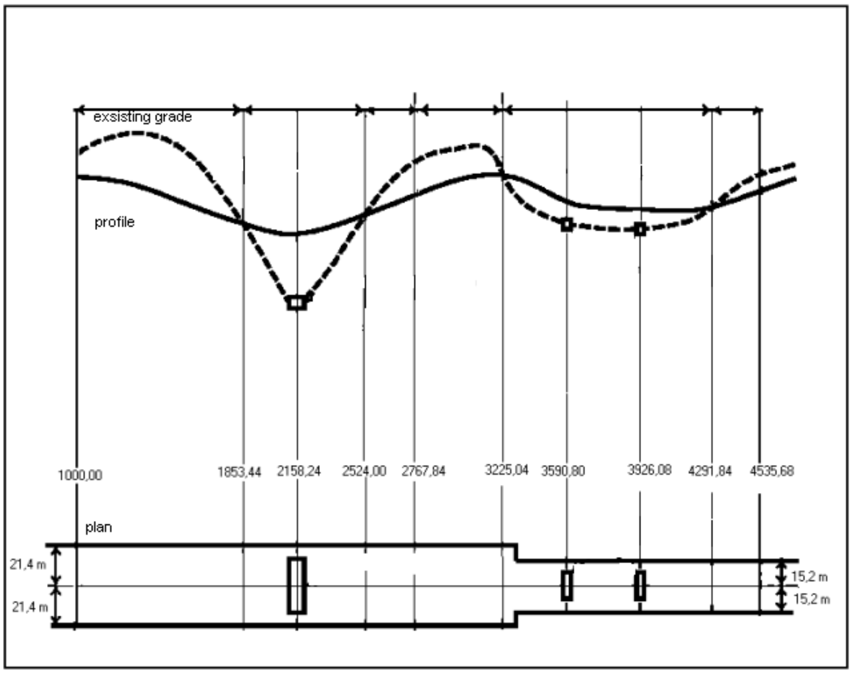

Figure 1 – Plan and profile of the road

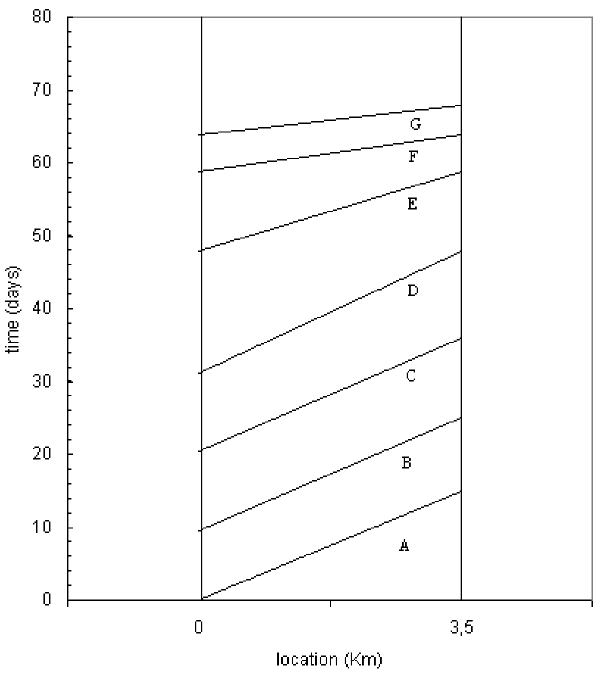

Figure 2 – Work programme

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 limitated period of time of the programme (for eg. the creation of an underground passage).

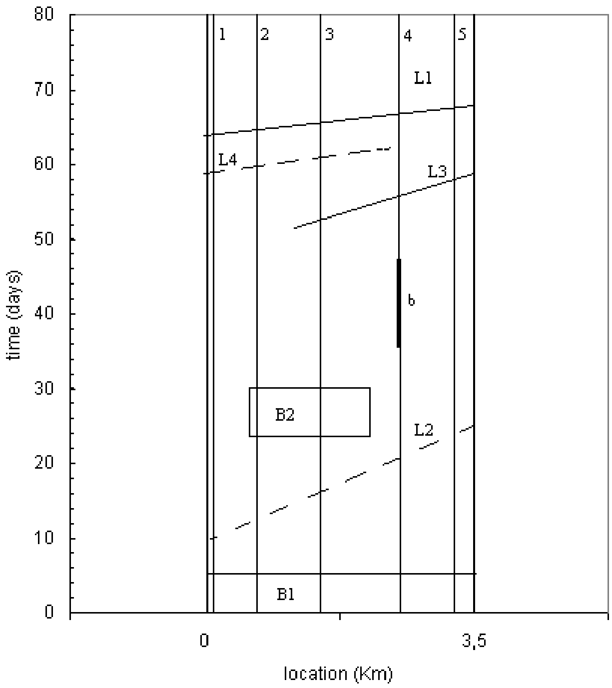

Figure 3 – Activity typology and logical sequence

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 3, 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 (Harris, Ioannou, 1998).
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;

b) Ascending phase
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. 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 4).

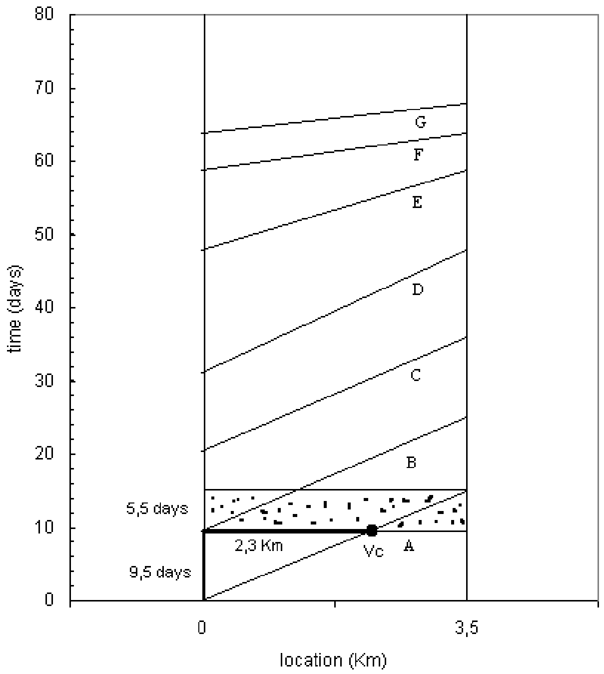

Figure 4 – Ascending phase

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 5) with the recognition of all potential segments and controlled connections.

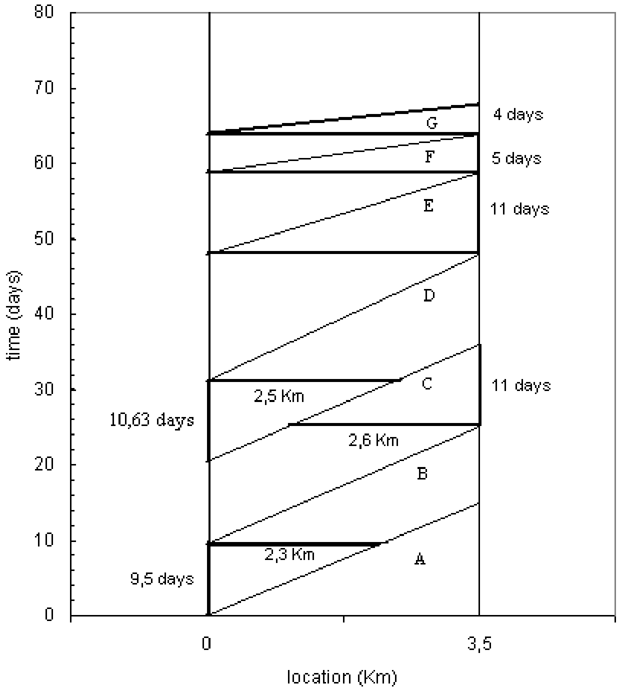

Figure 5 – Ascending phase

c) Descending phase
The aim of the descending course (with origin in correspondence with the final point of the last activity of the project in figure 6) 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. 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 6). The segments portrayed with a continuous route make up the critical portion of each activity and the critical connections between them.

The procedure must be repeated until the entire pseudo critical path can be recognised. 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 recognised; 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.

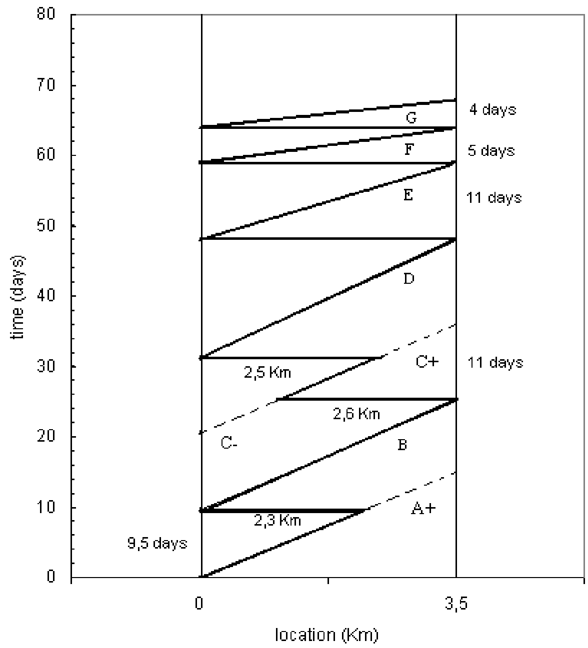

Figure 6 – Descending phase

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.

2.2. Work control

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 recognising 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 6).
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 (Harmelink, 2000).

For example, if we consider the segment C'+ in figure 7, 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.

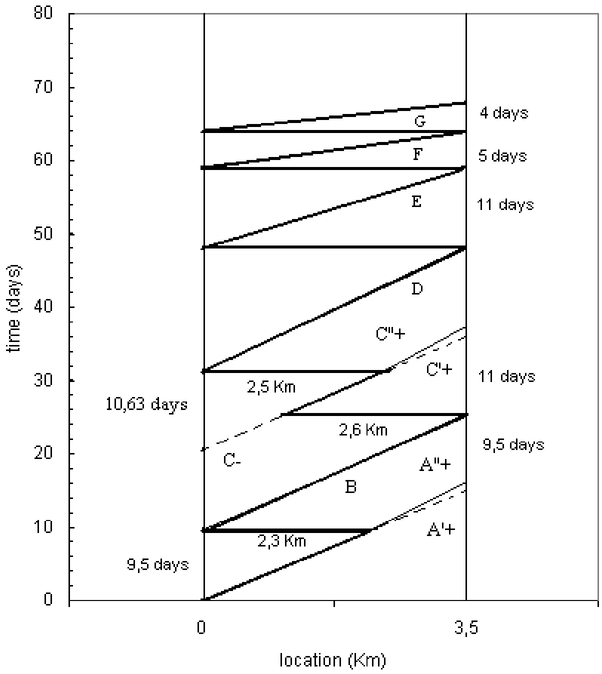

Figure 7 – Descending phase

3. LINEAR OR RETICULATE TECHNIQUES?

The difference between linear and reticulate techniques derives from the choice of a group of useful attributes to define the basic properties that the techniques must satisfy. These properties can be of a general and/or relative validity to the specific typology of the work to be created. The more evident differences derive from the examination of the potential and the simplicity of the use of both the techniques in different constructive processes.
In Table 2 the synthesis of the compared results of the application is delivered, of a reticulate method (CPM) and a linear (LS), to two actual cases: the construction of the road superstructure, previously analyzed (in figure 1), and the creation of a reinforced cement bridge (Yamín, Harmelink, 2001). The chosen works are represented by two different constructive typologies, the former is a linear type and continuous, the latter is moderate and discontinuous.

Table 2 – Comparison between linear and reticulate techniques

ATTRIBUTED DIMENSION	RETICULATE TECHNIQUES	LINEAR TECHNIQUES
Utility for reducing uncertainty/risk	Even though the CPM schedule foresees fixed duration of the activities, it can easily be supported by the PERT with probabilistic techniques. This characteristic enables the planners to have a better idea regarding the time and risks of the programme.	There is no formalized method to date that can allow the method LS to determine the uncertainties connected to the completion times.
Utility for increasing economic production and operation	With the extension of the resource levelling/allocating techniques, the CPM schedule can improve the completion times of the project and the costs by intervening on the production (adding and removing resources). Certain limitations were identified in the schedule of the finalized activity to the creation of continuing works due to difficulty in guaranteeing continuity in using the team of workers.	Limited possibilities to improve the production through the changing of the resources. Simplicity in scheduling the linear construction, improvement of co-ordination and productivity.
Utility for reaching a better understanding of the objectives	In the complicated constructive procedures the grid of the CPM can be very complex. This complexity can render the projects difficult to understand and to pass on.	LS is very easy to understand, and can be used at every level of the creation of a project.
Accuracy in calculations	The CPM supports the direction of the works for calculating the times needed to complete the project, linking with the PERT statistic evaluation of the procedure. It is difficult to determine and represent the space limitations (if they exist).	The computation of the space/time dimensions can be easily developed. This is the great advantage of the LS method, as compared with the CPM in the schedule of the linear constructions. This potential permits the direction of the works to plan accurately the activities in relation to time and space.
Critical procedure	It is the principle characteristic of the CPM, that can be returned very easily.	The algorithm of the LS model identifies analytically the way of the controlling activities that is equivalent to the critical way, with the additional properties of the localising of the critical point.
Ease of use	The widespread information has made the CPM method very easy to use. However, the user needs a notable quantity of exercises to produce valid information for the goals of the control activities	Very easy to understand. It can be used at all levels of enterprise (directors, team leaders and workers). The lack of computerization makes it difficult to use in great complex constructions.
Ease of up-dating	The method cannot easily be up-dated. Once some up-dating has been done it becomes difficult to read. The up-dated programmes usually have greater work duration times than before the up-dating.	It is easy to up-date the LS method. The linear programmes can be used as documents of the construction for the request of indemnity or for historical data banks of the productivity.

In the construction of the bridge, in order to simplify management, only the principle activities that make up the process of construction of the bridge supposing a distribution of the stationary resources in the course of the works, were considered.

Following is a list of the activities:

A. Construction of the north foundation :excavation, creation of the crate and casting of the concrete;
B. Construction of the south foundation :excavation, creation of the crate and casting of the concrete;
C. Construction of the north retaining wall: preparation and assembly of the scaffolding, creation of the crate and casting of the concrete;
D. Construction of the south retaining wall: preparation and assembly of the scaffolding, creation of the crate and casting of the concrete;
E. The launch of the east beam in C.A.P. (length 20 m) covers the entire light from the north retaining wall;
F. The launch of the west beam in C.A.P.
G. Mounting of the slab in C.A.P. (each panel of the slab is positioned between the two beams mentioned in the previous phases);
H. Laying of the pavement.

The reticulate and linear techniques provide, generally, a good presentation of the work plan and of the inter-relations between the different operations.
Nevertheless, for the activities which are in function at the same time on the same site, the LS type is generally presented in a confusionary manner. In fact as we have demonstrated in the example in figure 8, the mounting of the slab overlaps the launch of the west beam.

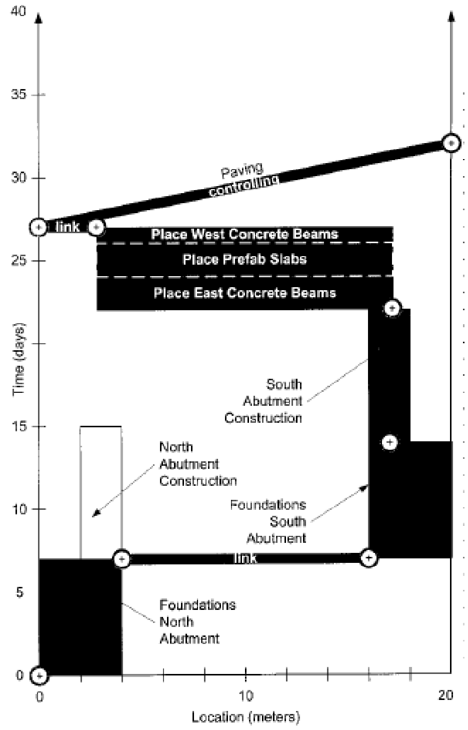

Figure 8 – Concrete bridge schedule

The algorithm for the critical procedure doesn’t allow overlapping between different activities and considers this possibility as a conflict to the work programme. Regarding the construction of the bridge in all activities, excluding the laying of the pavement, are developed according to the same time interval the entire work o part of it. These operations have to be schematized as an activity type “block” that reduce, if higher in number than the linear ones, the advantages come from the linear programme.
The linear and reticulate techniques can be supported by the algorithms that acknowledge the critical activities, controlling the entire duration of the work and of the non critical activities which instead can be delayed, within the limits well defined, without however the

influencing the duration of the entire construction process. As shown in the example, the date at the end of the non critical work for the “construction of the north retaining wall” can be delayed until the “completion of the south retaining wall”, without any delays to the completion of the entire work.
The productivity of the non critical activities can be modified allocating the available resources different to the preliminary planning phase of the works. The allocation of the resources has to be managed through the use of proper algorithms whose results can be conveniently represented with the support of diagrams. The diagram supports the direction of the site so that it can re distributed the resources, during the works, formality and execution times of the different works to be done, by anticipating or delaying the closure date for each singular activity. However, for the LS type techniques, different to the reticulate ones, according to international scientific literature, specific algorithms to optimize sufficient evolved resources to be used in the practical techniques, don’t exist.
The up-dating phases of the work plan, in reticulate or linear approaches, are substantially alike even though supported by the graphic comparison between the original programmes and those modified in the course of the works.

4. CONCLUSIONS

The current methods available and used for the objectives (PERT and CPM techniques), on one hand demanding the minute breakdown of the activity, and on the other hand they allow an easy revision of the planning process of organising the site, as well as (if needed) during the works.
Structurally they lend themselves to an efficient use for different multiple activities of any work, while they are full of imperfections when programming sites with very little macro-activities (those for road and highway construction)
The linear techniques do not guarantee satisfactory results because the potential of the LS type techniques cannot be taken advantage of consisting in the possibility to control the state of space and time advancement of the works.
In this note we refer to some opinions on the applicability of the programming of the road constructions and of the linear techniques to enhance their principle operating merits.
The linear techniques present the following advantages:

- They are particularly efficient for planning, programming and control of the “linear” works that is the activities that repeat along a certain course;
- They adapt to sites that have few productive sections and that follow in the same order without the possibility of overlapping;
- They can be graduated on a different grid (initially of wide links), measured approximately and in detail, without judgement for successive refinements;
- They lend to a continuous revision of the plan in order to adapt it to the needs of the company, in preliminary programming phases (without unattending to all of the time objectives preset), as much as attending to the actual functioning of the work (scientifically supporting the determination of the person in charge on site, in order of the allocation space/time of the resources).

The approach, decisively promising, requires the successive development of calculating codes and specific algorithms for allocating resources that allow the management of real cases, of any type or dimension, supplying elements to optimize 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.

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