LINE-OF-BALANCE SCHEDULING IN PAVEMENT CONSTRUCTION

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ABSTRACT: Linear Scheduling Methods are best suited to projects that display repetitive characteristics, but their use in the construction industry is limited. Line-of-Balance (LOB) is a Linear Scheduling Method that also makes use of network technology. Its benefits and shortcomings are investigated in a highway surface treatment project where LOB has been used experimentally. It was determined that LOB is extremely sensitive to errors in man hour, crew size, and activity duration estimates. There are also problems of a visual nature with the presentation of the diagram. On the other hand, LOB allows a better grasp of the project than any other scheduling technique because it is possible to adjust activities' rates of production. It provides a smooth and efficient flow of resources and requires less time and effort to produce than network schedules. Research to make Linear Scheduling Methods more attractive is recommended.

INTRODUCTION

Two duplicate questionnaire surveys conducted among the *Engineering News-Record* top 400 contractors in 1979 (9) and in 1983 (3) indicated that planning and scheduling are regarded by the majority of large contractors as having high potential for productivity improvement. In other words, most large contractors believe that there is need for improvement in planning and scheduling.

Methods for planning and controlling highly repetitive projects have been investigated in the last 10–15 years. The techniques that were developed are grouped for the purposes of this paper under the generic term of "Linear Scheduling Methods." Their origins are not clear; there may actually have been multiple origins, possibly in different countries. They have been originally devised to solve industrial production problems and their consideration for use in the construction industry is rather a recent event. They include a multitude of variations that are based on the same resource oriented principles (7,15). They are named differently: Line of Balance Schedules (5,8,13,16,17,26,33), Vertical Production Method (VPM) (22,23,24), Time-Space Scheduling (25), Cascade Networks (34), Velocity Diagrams (35), Fenced Bar-Charts (19,20), Chain Bar-Charts (29,30,32), Construction Management System (1,27), and Combined PERT/LOB (12,36); but they have common features. Some others make use of process interaction simulation techniques (6), stochastic approaches (11), and dynamic (37) or linear (31) programming.

Johnston has summarized the development of Linear Scheduling Methods in the construction industry (14). The literature indicates that those methods could be used in projects such as multiple housing schemes

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(6,8,29,31,35), bridges (37), high rise (18,22,39) and low rise (1,27) buildings, pipelines (11,16), and highway construction (5,14). The general consensus is that Linear Scheduling Methods are well-suited to projects that are composed of activities of repetitive nature. But, their use is believed by some to have faded into obscurity with the advent of network techniques.

An historical evaluation of construction scheduling and control in the past 25 years suggests that after the enthusiastic boom of the early 1960's, the use of network techniques by construction companies has reached a steady level, after a slight decline in the early 1970's (2). There is evidence that contractors do not use networks in highly repetitive jobs because of their belief that high repetition would reduce the chances of successful scheduling and control by networks (4,38). The same concern is noticed in the literature (1,7,28) and is an indication that Linear Scheduling Methods were not, after all, replaced by network techniques but only continued to be seldom used as was the case before the advent of networks. For example, a telephone survey conducted in 1982 in District One of the Illinois Department of Transportation (i.e., in Cook, Lake, McHenry, Kane, DuPage, and Will counties) investigated the extent to which Linear Scheduling Methods are being used by road builders; it was found that of the 203 highway contractors that were located in District One none used these methods (10,21).

This paper describes an experiment with Line-of-Balance (LOB) scheduling in a pavement construction project. After a brief explanation of the method and a brief description of the project, the several phases of the experiment are reported step by step: the initial phase with a preliminary velocity diagram, the next phase combining network technology and basic linear scheduling concepts, and the final phase ending with a refined LOB schedule that was used in conducting the entire project. The benefits obtained and the problems encountered in the preparation and implementation of the LOB schedule are discussed.

Line of Balance Scheduling

The object of scheduling a repetitive process may be summarized as being to ensure that (17):

1. A programmed rate of completed units is met.
2. A constant rate of repetitive work is maintained.
3. Labor and plant move through the project in a continuous manner such that a balanced labor force is maintained and kept fully employed.
4. The cost benefits of repetitive working are achieved.

In order to meet these objectives, a network diagram for one of the many units to be produced is prepared as a first step. Then, the manhours necessary, as well as the optimum crew sizes are estimated for each activity. This information yields a natural rhythm for each activity (e.g., number of units/day) defined as the optimum rate of output that a crew of optimum size will be able to produce. Any rate of output that differs from a multiple of the natural rhythm is bound to yield some idle time for labor and equipment. That is why the number of crews nec-

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essary for the entire project is so arranged that the rate of output, a multiple of the natural rhythm, is as close to the target rate as possible.

Once the number of crews, and the actual rate of output have been computed for each activity, the LOB diagram can be drawn. The number of units to be produced is plotted against time. Two oblique and parallel lines, whose slope is equal to the actual rate of output, will denote the start and finish times respectively of each activity in all the units, from the first to the last. An example of an activity that has a duration of 0.5 days and a natural rhythm of 2 units of production per day is given in Fig. 1. In the first case only one crew of optimum size is used and an actual rate of production of 2 units per day is achieved. In the second case, two crews of optimum size are employed and an actual rate of production of 4 units per day is achieved. The vertical arrows show the movement of the crews from one unit to the next. There is no idle time for any of the crews in either of the cases. The actual rate of production is the slope of the line of balance joining the start times of the repetitive activity in each unit, and is calculated as

$$m = \frac{Q_j - Q_i}{t_j - t_i}; \quad i < j \quad \text{(1)}$$

where m = rate of production (units of production per units of time); Q_i, Q_j = number of units started (i and j); and t_i, t_j = time elapsed between the start of the project and the start of the ith and jth units, respectively.

The slope of the line of balance joining the finish times of the repetitive activity in each unit is also equal to m. If the duration of the activity is known and if the actual rate of output is limited to a multiple of the natural rhythm, then the foregoing equation is effectively reduced to

$$m = \frac{p}{d} \quad \text{(2)}$$

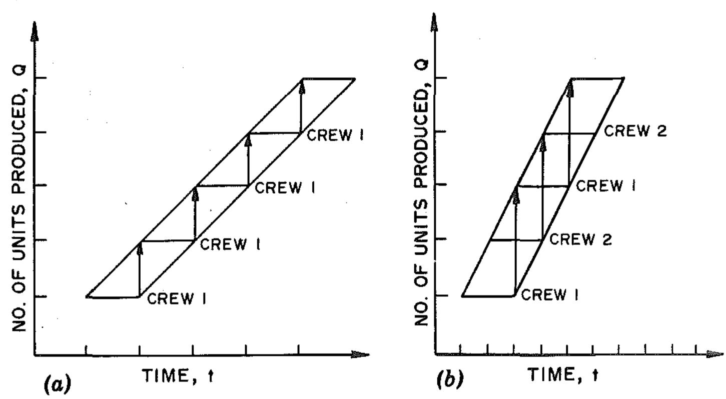

FIG. 1.—Line-Of-Balance Diagram for Activity (Activity Duration = 0.5 Days; Natural Rhythm = 2 Units/Day): (*a*) Number of Crews Used = 1; Actual Rate of Production = 2 Units/Day; (*b*) Number of Crews Used = 2; Actual Rate of Production = 4 Units/Day

where p = number of crews used in the activity; and d = duration of the activity in one unit.

The time ordinate t of the start of an activity is calculated by the following relationship:

$$t_i = t_1 + \frac{1}{m}(Q_i - 1) \quad \text{(3)}$$

where t_i = time ordinate of start of activity in ith unit; t_1 = time ordinate of start of activity in first unit; m = rate of production; and Q_i = number of units produced, i. The value of t_1, the start time of the activity in the first unit can be obtained from the time calculation performed for the unit network. The finish time of the activity in the ith unit can be calculated by adding the duration of the activity (d) to its start time on unit i (t_i).

An elaborate description of the LOB method is given in Refs. 17 and 33. The procedure is illustrated by means of an experiment conducted on a highway pavement construction project presented in the following sections.

Single Layered Highway Surface Treatment

When great amounts of settlement are expected from a base course, a pavement type that can accommodate these settlements is desired. Surface treatment is among the most economical examples for this kind of condition. The project where LOB was used consisted of the surface treatment of a 100 km stretch of rural highway. The sequence of activities was as follows: (1) Compaction of the base course; (2) application of the prime coat; (3) drying of the prime coat; (4) application of the surface coat; and (5) compacting.

The bituminous materials that were used for the prime coat and for the surface coat were MC30 and AC 150/200, respectively. These were brought to site from a nearby refinery and stored in separate tanks equipped with heating systems. Clean, single graded aggregates of 1 in. size of rough texture and angular shape were transported from crushers to suitable storage points along the road under construction.

The flow of work in the pavement construction illustrates its linear, continuous, and repetitive character. While the surface of the base course was swept by machines to form a clean and dustfree surface on which the prime coat could be applied, MC30, the cutback asphalt used in the prime coat, was transported from storage tanks to the distributor by relay trucks. The distributor heated the material to an application temperature of 40–50° C, then sprayed it on the surface at a discharge rate of 1.75–2.50 kg/m^2. The drying of this layer, (i.e., the evaporation of the volatile part in MC30, namely kerosene), took usually 24 hr. Meanwhile, AC 150/200, the bituminous material to be used in the surface coat, was transported by relay trucks from the storage tanks to the distributor which heated it to an application temperature of 168° C. The surface of the prime coat was swept, the distributor sprayed the material with a discharge rate of 1.50–2.00 kg/m^2 on the dry and clean prime coat; and special trucks with a mechanism in their back to ensure a uni-

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form distribution of aggregates on the hot surface coat, followed closely the distributor. Once aggregates were placed, compaction began, initially by tandem rollers and then by pneumatic tired rollers. After the cooling of the surface coat, the highway was opened to traffic.

Line of Balance Implementation

The first attempt to build a schedule consisted of dividing the project into four main activities: (1) Aggregate transportation; (2) prime coating; (3) surface coating preliminaries; and (4) surface coating.

The rates of production for these four activities were determined by considering the following factors:

1. The contract duration: This was 48 working days.
2. Estimated subcontractor performance: Subcontractors in charge of "Transportation of Aggregates" and of "Transportation of Bituminous Materials" were asked to estimate the time for the completion of their deliveries. Negotiations ended with 47.5 and 24 working days, respectively.

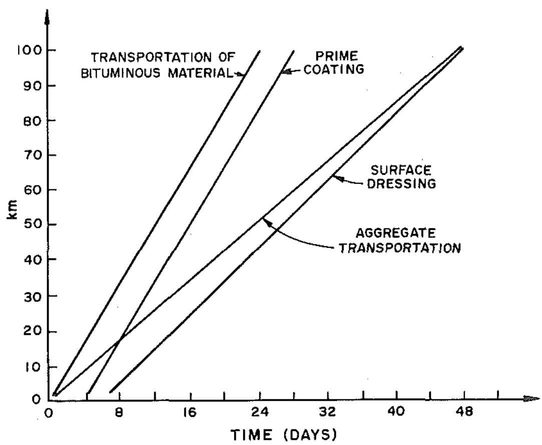

FIG. 2.—Velocity Diagram for 100 km

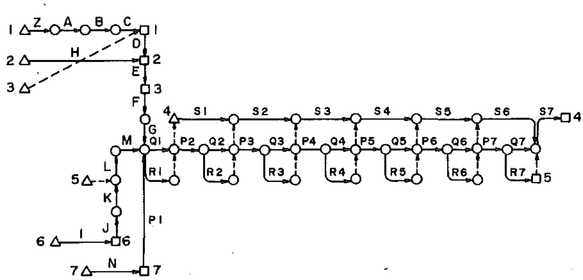

FIG. 3.—Unit Network for 1 km

TABLE 1.—Description of Activities

Notation (1)	Description of activities (2)
A	Pumping of cutback asphalt from main tanks to relaytruck
B	Transportation of cutback asphalt to construction site by relaytruck
C	Pumping of cutback asphalt from relaytruck to distributor
D	Heating of cutback asphalt to application temperature
E	Prime coating by distributor using cutback asphalt
F	Drying of prime coated surface
G	Sweeping of prime coated surface
H	Sweeping of compacted base course
I	Heating of asphalt cement to pumping temperature at main tanks
J	Pumping of asphalt cement from main tanks to relaytrucks
K	Transportation of asphalt cement to construction site by relaytrucks
L	Pumping of asphalt cement from relaytrucks to distributor
M	Heating of asphalt cement to application temperature
N	Transportation of aggregates from crusher to storage points along highway
P_i	Travelling back to storage points, loading aggregates travelling to construction site
Q_i	Surface dressing by distributor using asphalt cement
R_i	Laying of aggregates by trucks on hot asphalt cement
S_i	Compaction of pavement
Z	Travelling of cutback asphalt relaytruck back to main tanks

TABLE 2.—Coordinates for Initial LOB Diagram

Activities (1)	Duration (d) (2)	Rate of production (m) (3)	Start time for first kilometer, t_1 (4)	First kilometer finish time, $t_1 + d$ (5)	Start time for tenth kilometer, $t_{10} = t_1 + 9/m$ (6)	Tenth kilometer finish time, $t_{10} + d$ (7)	Start time for 100th kilometer, $t_{100} = t_1 + 99/m$ (8)	100th kilometer finish time, $t_{100} + d$ (9)
A	0.5	0.500	0.0	0.5	18.0	18.5	198.0	198.5
B	0.5	0.500	0.5	1.0	18.5	19.0	198.5	199.0
C	0.5	0.500	1.0	1.5	19.0	19.5	199.0	199.5
H	0.5	0.500	1.0	1.5	19.0	19.5	199.0	199.5
D	0.5	0.500	1.5	2.0	19.5	20.0	199.5	200.0
E	0.4	0.500	2.0	2.4	20.0	20.4	200.0	200.4
F	24.0	0.500	2.4	26.4	20.4	44.4	200.4	224.4
G	0.5	0.500	26.4	26.9	44.4	44.9	224.4	224.9
N	10.0	0.100	0.0	10.0	90.0	100.0	990.0	1,000.0
I	2.0	0.500	0.0	2.0	18.0	20.0	198.0	200.0
J	0.5	0.500	2.0	2.5	20.0	20.5	200.0	200.5
K	0.5	0.500	2.5	3.0	20.5	21.0	200.5	201.0
L	0.5	0.278	25.9	26.4	58.3	58.8	382.0	382.5
M	0.5	0.278	26.4	26.9	58.8	59.3	382.5	383.0
P_i	2.6	0.278	26.7	29.3	59.1	61.7	382.8	385.4
O_i	2.6	0.278	26.9	29.5	59.3	61.9	383.0	385.6
R_i	2.6	0.278	26.9	29.5	59.3	61.9	383.0	385.6
S_i	2.6	0.278	27.1	29.7	59.5	62.1	383.2	385.8

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3. Logical limitations: For instance, surface coating could not start before at least 1 day had passed after the application of the prime coat.

4. Strategic limitations: One example is a 4 day buffer between transporting bituminous materials and applying the prime coat.

This information was used to prepare a velocity diagram presented in Fig. 2, where an activity is shown by an oblique line, the slope of which gives the rate of production for the 100 km stretch: $M_{\text{bit. mat. transp.}} = 100/24 = 4.167$ km/day; $M_{\text{prime coating}} = 100/(28 - 4) = 4.167$ km/day; $M_{\text{aggregate transp.}} = 100/47.5 = 2.105$ km/day; and $M_{\text{surface dressing}} = 100/(48 - 6) = 2.380$ km/day.

The velocity diagram presented in Fig. 2 lacked the expected detail for efficient control and therefore was expected to be of little use on site. Another attempt was therefore made to develop an LOB schedule with sufficient detail, and a unit network (Fig. 3) incorporating all activities for a 1 km stretch was prepared. The interface events are shown by squares and triangles and are marked with matching numbers. The activities used in the network are described in Table 1. An LOB diagram was prepared by using the network data, and manhour and crew estimates. Only the first 10 km portion rather than the entire 100 km is presented in Fig. 4 to avoid scale problems and enhance visual interpretation. Activity durations in this diagram are free of safety factors, and no safety buffers were used between any of the phases; activities were scheduled to start at their earliest start time. Eqs. 1–3 were used to calculate the coordinates of the start and finish times of the activities at the first, the tenth, and the hundredth kilometers (Table 2).

The LOB schedule presented in Fig. 4 was satisfactory as far as the mechanics of the technique are concerned but was soon found to be unworkable on site. It became apparent that it needed further refinement for more efficient use of resources and more appropriate flow of work (5). For example, an economic analysis indicated that the benefits obtained by performing prime coating activities at an accelerated rate of 0.714 km/h, rather than the 0.500 km/h rate calculated in Table 2, largely offset the cost of using extra resources for the accelerated operation. The

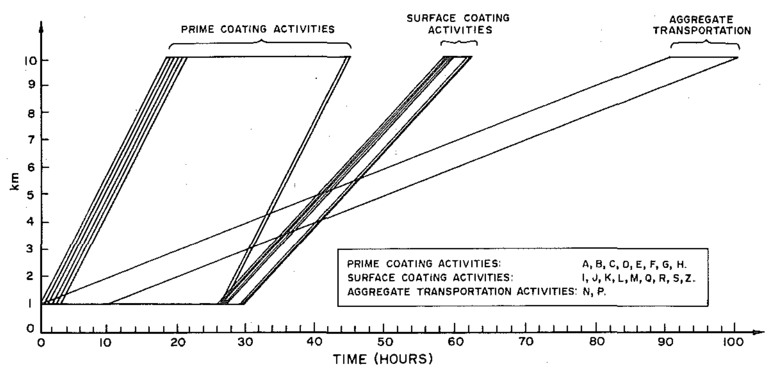

FIG. 4.—Initial LOB Diagram for First 10 km

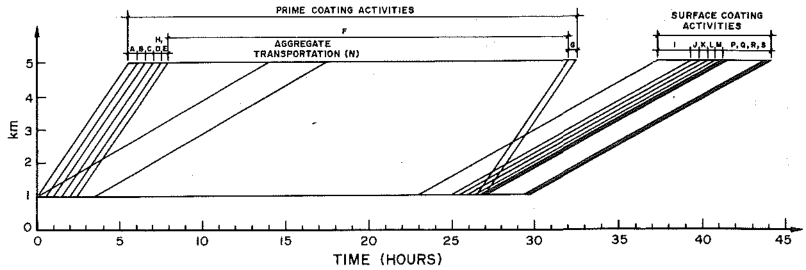

FIG. 5.—Final LOB Diagram for First 5 km

unworkable situation, clearly apparent in Fig. 4 and Table 2, whereby "Transportation of Aggregates" crosses surface coating activities on the third kilometer, had to be corrected by increasing the transportation rate of aggregates from 0.100 km/h given in Table 2, to 0.286 km/hr, always keeping the most efficient operation sequence with no idle time for any of the resources. Finally, the practice of using early start times had to be abandoned to allow for more workable sequences; for example, the sweeping of the base course had to be pushed to its late start time to make sure that prime coating activities followed immediately afterward.

The final LOB diagram, of which a 5-km portion is presented in Fig. 5, was prepared after the preceding modifications were made. A stage buffer was not introduced between prime coating and surface coating activities since this would only increase the already existing and ample natural buffer between these two stages of production. Calculations based

TABLE 3.—Coordinates for Final LOB Diagram

Activities (1)	Duration (d) (2)	Rate (m) (3)	Start time for first kilometer, t_1 (4)	First kilometer finish time, $t_1 + d$ (5)	Start time for fifth kilometer, $t_5 = t_1 + 4/m$ (6)	Fifth kilometer finish time, $t_5 + d$ (7)	Start time for 100th kilometer, $t_{100} = t_1 + 99/m$ (8)	100th kilometer finish time, $t_{100} + d$ (9)
A	0.5	0.714	0	0.5	5.6	6.1	138.6	139.1
B	0.5	0.714	0.5	1.0	5.1	6.6	139.1	139.6
C	0.5	0.714	1.0	1.5	6.6	7.1	139.6	140.1
H	0.5	0.714	1.0	1.5	6.6	7.1	139.6	140.1
D	0.5	0.714	1.5	2.0	7.1	7.6	140.1	140.6
E	0.4	0.714	2.0	2.4	7.6	8.0	140.6	141.0
F	24.0	0.714	2.4	26.4	8.0	32.0	141.0	165.0
G	0.5	0.714	26.4	26.9	32.0	32.5	165.0	165.5
N	3.5	0.286	0	3.5	14.0	17.5	346.5	350.0
I	2.0	0.278	22.9	24.9	37.3	39.3	379.3	381.3
J	0.5	0.278	24.9	25.4	39.3	39.8	381.3	381.8
K	0.5	0.278	25.4	25.9	39.8	40.3	381.8	382.3
L	0.5	0.278	25.9	26.4	40.3	40.8	382.3	382.8
M	0.5	0.278	26.4	26.9	40.8	41.3	382.8	383.3
P_i	2.5	0.278	26.7	29.3	41.1	43.7	383.1	385.7
Q_i	2.6	0.278	26.9	29.5	41.3	43.9	383.3	385.9
R_i	2.0	0.278	26.9	29.5	41.3	43.9	383.3	385.9
S_i	2.6	0.278	27.1	29.7	41.5	44.1	383.5	386.1

on Eqs.1–3 for the start and finish times of the first, the fifth and the hundredth kilometers are presented in Table 3.

Evaluation of Line-of-Balance Implementation

The total duration of the project for the 100 km of surface treatment was calculated as 386.1 hr in the final LOB schedule presented in Fig. 5 and Table 3. This is approximately equal to the target duration of 48 working days of 8 hrs each, specified in the contract. The actual duration at the end of the project was recorded as 408 hrs, a delay of slightly over 5%. An identical surface treatment project of the same length, specification and contract duration, was scheduled by CPM and was completed the year before in 450 hr, a delay of slightly over 16% (5). One however must be extremely cautious in interpreting the difference in performance because there are too many variables that cannot be accounted for, and that make it difficult to compare the two projects. For example, the delays in the CPM scheduled project were basically due to two fatal accidents that halted all activities on site for some time, whereas, the delays in the LOB scheduled project were due mainly to equipment breakdowns. The observations made during the planning and the implementation phases are presented below:

1. Manhour estimates and optimum crew sizes were obtained from field personnel who had many years of site experience, from technical specifications and previous records. The activity durations thus obtained diverged sometimes from the performance actually achieved on site, and had to be corrected to better reflect actual conditions. It was observed that the error introduced by such divergences, even if minimal, compounded to result in large deviations in the project duration, especially as repetition increased. For example, if the duration of an activity is overestimated by $r\%$, the correction of the error will reduce the duration by $r\%$ and increase the rate of production (m) given in Eq. 2 by the same percentage. If the time ordinate (t) of the start of an activity is calculated by means of Eq. 3, then it will be clear that the $r\%$ error in the rate of production (m) will be magnified by ($Q_i - 1$) times into significantly large deviations as repetition increases (Fig. 6). This extreme sensitivity of the LOB method to errors in manhour and subsequent duration estimates for each activity must be well-recognized at the outset.

2. Except for the drying of the prime coat that took 24 hr, activity durations ranged between 0.2 and 0.5 hr in the experiment reported in this paper. Delays, on the other hand, were due mainly to equipment breakdowns. Repairs generally took several hours. Because of the large magnitude of delays when compared with activity durations, it was not possible to incorporate safety contingencies into activity time estimates, as these tended to increase total project duration considerably and provide no short term measures to compensate for the delay. The best way to overcome this difficulty was found to be the use of stage buffers in between various phases of the project, this way protecting the optimum use of resources in every unit and yet allowing for deviations in case of unforeseen delays in one unit. Fig. 7 shows the use of stage buffers between two activities: A delay that occurs in Activity A on the 4th unit

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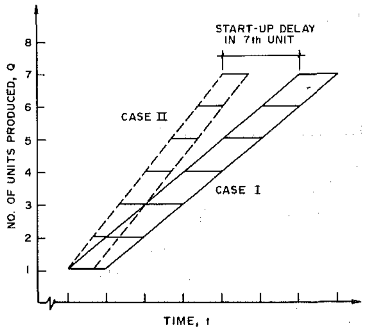

FIG. 6.—Effects on Activity Completion Times of Error in Estimated Activity Durations under Repetitive Conditions: For Case I, Activity Duration, d = 3 Days; Number of Crews Used, p = 1; and Rate of Production, m = 1/3 = 0.33; For Case II, Activity Duration, d = 2 Days; Number of Crews Used, p = 1; and Rate of Production, m = 1/2 = 0.50

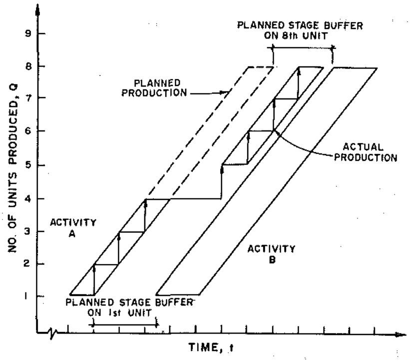

FIG. 7.—Use of Stage Buffer in LOB Diagram

is absorbed by the stage buffer and does not affect the performance of the following Activity B in any of the units. Also, except for unit 4, the crew used in Activity A performs optimally in all other units. A stage buffer can also be seen in the final LOB diagram (Fig. 5) between the prime coating and surface coating activities.

3. The "learning" phenomenon whereby the actual duration of an activity is reduced as repetition increases, is not part of the LOB method used in this experiment. The learning phenomenon does exist; it occurs however at the very beginning of repetitive cycles. In case the rate of repetition is large, the effect of "learning" on the average activity duration may be assumed to be negligible. Whatever little effect there may be at the very beginning could be absorbed by strategically positioned stage buffers. The possibility of incorporating "learning" data into LOB calculations requires further research.

4. The preparation of an LOB schedule is generally easier than the preparation of a network and its related calculations, especially as repetition increases. In the project reported in this paper, the unit network for a kilometer of surface treatment consisted of 58 activities (including dummy activities). A network schedule for 100 km would therefore have consisted of 5,800 activities: this would have been costly and extremely time and space consuming. The LOB diagram for 10 km, part of which is presented in Fig. 5 required much less time and effort. Activity start and finish times in each unit did not have to be calculated separately as would have been done in a network schedule, but could be obtained graphically from the LOB diagram.

5. The degree of detail of the LOB diagram must be carefully evaluated. If too many activities are plotted, the diagram becomes a jungle

of oblique lines that also sometimes cross each other. On the other hand, a velocity diagram with only 4 activities as the one in Fig. 2, is of little practical use. An optimum level of detail can be selected by an experienced scheduler. For example, in the final LOB schedule presented in Fig. 5, it was found suitable to plot one activity P instead of 7 activities P_1–P_7 used in the unit network. The same reasoning had to be followed for activities Q, R, and S in order to simplify the diagram.

6. A major difficulty in preparing the LOB diagram lies in plotting overlapping activities that have the same rate of production. For example, the last few activities in Fig. 5 are overlapping activities, but unless they are indicated by colored lines, it is difficult to differentiate among them. The choice of the appropriate scale is also critical for better understanding and communicating the information contained in an LOB schedule.

7. Producing and using only a unit network instead of developing an overall network or an LOB schedule for the entire project is not a reliable solution in repetitive jobs. If, for example, only the unit network given in Fig. 3 were used for scheduling and control purposes, the scheduler could not have realized that "Transportation of Aggregates" becomes critical after the third kilometer and disrupts the rate at which surface coating activities are performed. This situation is clearly observed in the LOB diagram of Fig. 4 and was corrected before construction started, as seen in Fig. 5.

8. The LOB method of scheduling gives a good insight into the project at an early stage of the scheduling process because it is based on rates of production that in turn depend on resource usage. For example, the economic analysis that was performed to evaluate the relationship between prime coating and surface coating activities, could not have been initiated if only networks were used since there is no indication of production rates in networks. As a result, considerable economy was achieved by speeding up the production rate of prime coating activities.

9. When using the time data generated by the unit network, the use of early starts (or late starts) for all activities without exception, creates work flow problems. Care must be taken to make sure that floats are not used arbitrarily or indiscriminately in the preparation of the LOB schedule. For example, as discussed previously, float had to be dispensed in such a way as to allow the prime coat to be applied immediately after the base course had been swept into a dustfree surface, whereas, on the other hand, many activities were started at their early start time. Floats must therefore be used intelligently in LOB scheduling, as they would be in network scheduling.

10. It was found that foremen and subcontractors were more receptive to LOB diagrams than to arrow diagrams, but not receptive enough to use them in lieu of bar charts. The LOB schedule had to be converted into weekly bar charts.

11. Finally, it is possible to show progress on an LOB diagram whereas it is not possible to do so on a network that is not time-scaled. Especially when used in association with cost data, progress control by LOB becomes quite efficient.

Conclusions

The LOB method of scheduling is one of the variations of Linear Scheduling Methods that have been developed in the last 20 yrs to manage projects that consist of activities of repetitive nature. Although Linear Scheduling Methods are accepted to be most suitable for scheduling and controlling repetitive projects, there are indications that their use is not widespread. LOB was experimentally used in a pavement construction project to identify the benefits and shortcomings of such a technique.

It was observed that LOB scheduling, as described in this paper, allows a better grasp of the project than any other scheduling technique basically because the scheduler has access to activities' rates of production. Rates of production can be modified to assure a smooth flow of the resources in the most efficient way, all the time making sure that the logical sequence set in the unit network is not altered. It takes less time and effort to produce and maintain an LOB schedule than it does a network. It is possible to use stage buffers between major phases of the project to take care of unforeseen events, a much more realistic and convenient method than adding safety contingencies to the duration estimates of each and every activity in a network. Progress can be illustrated graphically on the LOB diagram; this is one of the reasons why field personnel seem to be more receptive to LOB diagrams than to arrow networks.

It was also observed that LOB scheduling had some shortcomings. For example, there are major problems in the presentation of the LOB information: unless colored graphics are used, it is difficult to differentiate between overlapping activities that have equal rates of production. This shortcoming is more acute if the scheduler fails to select the appropriate scale for the diagram. Finally, the success of an LOB schedule depends a great deal on the setting of the rates of production of the many activities, which in turn depend on estimates of activity manhour requirements and crew sizes. The LOB schedule is extremely sensitive to errors in these estimates that are magnified with increasing repetition.

There is little doubt that Linear Scheduling Methods in general, and LOB in particular, are well suited to repetitive projects. They are superior to bar charts and networks in many respects although they also have some shortcomings. Research must be conducted to identify the shortcomings, eliminate implementation problems, and make these methods more attractive to constructors of repetitive projects.

Appendix.—References

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