

PREPLANNING METHOD FOR MULTI-STORY BUILDING CONSTRUCTION USING LINE OF BALANCE

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ABSTRACT

This paper reports one aspect of a research program devoted to the topic of production control in multi-story building construction. Preplanning using the line of balance technique attempts to solve planning problems by making production process clearer and simpler. A preplanning method is presented which needs little detailed information about productivities and work volumes and may be rapidly produced. The plan brings an overall view of the project by grouping the main activities that are highly interdependent. The concept on the best rhythm for each group of activities focus on the sequence of work, continuity of labor team working and completeness rather than on pure schedule goals. Many characteristics of the method support lean construction concepts, such as waste elimination, variances minimization, flexible planning and scheduling sequencing. Using line of balance concepts also suggests some control tools which are being experimented on application cases and are briefly described.

KEY WORDS

Buildings, construction planning, lean construction, line of balance, preplanning.

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INTRODUCTION

Most construction projects are scheduled based on some sort of critical path planning method (CPM). A number of version of this technique have been developed and is used as the basis for many of the popular project management software packages. Many researchers discussed the suitability of CPM for construction projects, mainly those repetitive projects, such as railroads and multi-story buildings, and more recently for the lean construction concepts. As more complex becomes the project more complex it will be this network approach. Usually such master schedules cannot be accurately detailed too far into the future because of lack of information about actual duration and deliveries. Other important disadvantage relies on the main idea of the CPM method which is focused on finding the path which is critical. The schedule is developed based on this premise and the resource capacity and material requirements are input for the project simulation. The emphasis is on project duration shortage and resource leveling. The fact of having a “critical path” implies having non critical ones, which have float time. It means that the planning construction incorporates wastes what significantly diverts from a modern construction philosophy (Melles and Welling 1996).

One production scheduling and control technique which tries to surpass the CPM difficulties for multi-story building scheduling is the Line of Balance (LOB) technique. The LOB technique was developed in the early 40's into the manufacturing environment and adapted by researchers for using on construction industry in the 70's. Since that time several techniques have been developed to schedule activities with a repetitive nature. Each technique includes a multitude of variations, and most incorporated combinations of networks, a graphical technique, and an analytical or simulation tool. These family of techniques is known as linear scheduling. A review on the line of balance was presented by Lutz and Hijazi (1993). However LOB has not found a lasting popularity mainly due to the CPM commercial software widespread availability. The main concept on the line of balance is the work continuity of the labor teams over the construction units. The labor teams work with rhythmic production, and no wastes are willingly planned or introduced into the schedule. This planning method fits much closer to a modern construction philosophy.

The LOB technique is very suitable for repetitive projects like residential buildings, however it may be adapted for non-repetitive projects as well. The main advantages of LOB schedule are its graphical presentation, easy understanding of the schedule and the goals of planning used in it. The research conducted by the authors aims to improve the LOB concepts on building construction and prove its usefulness.

A first stage of this research was developed with the purpose of investigating the use of LOB technique on rapid generation of long term schedules. The first job done analyzed the fundamental information needed for planning with LOB, which include production rates and productivity, construction strategies, labor team allocation, among others. These information was collected from multi-story building projects undertaken in the city of Florianópolis (SC), Brazil. These buildings had from 6 to 16 floors and 380 to 625 m² of floor area in each typical floor. In this stage two computational tools were developed. The first one is a knowledge-based system called GERAPLAN (Mendes Jr. and López 1998) used for pre-planning a construction project. In GERAPLAN the user is able to generate an initial planning for the whole project with a few strategic decisions. The other one is a

spreadsheet model for on site usage (Mendes Jr. 1998), using the planning information generated by GERAPLAN. This model permits to obtain more detailed graphic visualization of the schedule and to introduce new information along the execution in order to make the production control.

The lessons learned from the first jobs helped the efficient use of the developed tools for the planning of new projects and the development of the second stage of the work, which is the LOB application on multi-story building sites as a medium term planning and control tool. The LOB application is imbedded into a new model of planning and control which attempts to solve planning problems by making production control process clearer and simpler. The main idea would be: “let everybody manage his own problems and do not create new problems by managing other people’s problems” (Melles and Welling 1996). The line of balance technique has many concepts close to this new model and the research is investigating them on practical site applications.

PREPLANNING METHOD

Repetitive projects such as multi-story building allow working with rhythmic planning. In this case, in order to find the optimum use of resources, a different type of planning is typically used. Crews and equipment are designed to yield the same production rate, in terms of construction units (i.e., one floor/week, one apartment/week, etc.). If activities are planned to be built in this way, all activities could become critical. Nevertheless, most building projects (even simple building construction projects) are not repetitive ones in all their extent. Thus, an “all activities critical” planning might not be applicable for the whole project. When planning is based in construction units (floors or apartments) and production velocities, fairly repetitive construction subdivisions can be developed. In this case the schedule is developed based on the production velocity, in such a way to generate the same work rhythm for all the involved crews. The number of optimum crews is selected so that all crews will perform the same amount of construction units in the same period of time. This approach is essentially the line of balance concept and was proved successful in the applications described in this paper and by others (Ghio et al. 1997).

Detailed construction procedures were developed for major construction activities. The fact of working with a repetitive apartment building project eased the work and allowed development of a significant level of detail for the majority of activities on site. The construction procedures included:

- Crew composition
- Daily construction volume
- Crew sizes
- Required tools and equipment
- Production rhythms

In order to generate a detailed preplanning of the construction job the methodology looks like:

1. Subdivide the construction project into “construction phases” everyone having interdependent activities which may be executed into a unique production rate.

The use of a unique production rate intends to simplify the planning process but it is not a fixed rule;

2. Determine the construction phase “rhythm”: Based on the overall project strategy a work rhythm was determined for each “construction phase”;
3. List all the activities, along with their crews. Verify possible dependencies between activities on different construction phases. These ones may be grouped together or being changed from one phase to another;
4. Design optimum crews: It is necessary to consider the selected construction technology and methods, as well as site constraints. Considering this as well as the productivity measurements and the detailed methods information obtained during initial case studies;
5. Production velocity for each crew: The optimum crews as well as their production rates were assessed during the initial case studies;
6. Divide all the activities into two groups: the main activities for each “construction phase” and a second group of secondary or complementary activities which usually are very fast with low labor consumption, and hence small duration. The main group had up to 80 activities in the most cases studied;
7. Calculate construction volumes for each construction area and the main activities: Construction volumes were calculated for each area (i.e., basement, floor 1, etc.). This is different than the usual budget all round volume calculations, because this one is directed towards its use for repetitive construction planning;
8. Calculate the time required to built each area: Divide the area volume by the production velocity of each crew. This will yield different time periods for each activity;
9. Adjust the number of optimum crews to generate almost the same production rhythm for every crew working in the same construction phase. In order to adjust the construction time to generate equal rhythms, the number of optimum crews is changed. Crews shall be designed in such way that all of them will be performing productive work continuously. Table 1 presents a simple case.

Table 1: Construction volumes and rhythm for walls

| Activities Walls | Nº Labor | Construction Volume | Production Velocity | Units | Duration with 1 crew (days) | Nº of crews | Duration (days) RHYTHM |
|---------------------|-------------|------------------------|------------------------|---------------------|--------------------------------------|----------------|------------------------------|
| Setting out | 1 | 430 | 44 | m/day | 10 | 1 | 10 |
| Bricklaying | 5 | 855 | 30 | m ² /day | 29 | 3 | 10 |
| Internal Plastering | 8 | 2200 | 120 | m ² /day | 19 | 2 | 10 |

10. Develop the line of balance scheduling by plotting sequentially all the construction activities according to technical interdependencies and balancing the crews in order to avoid conflicts into any floor. Determine the total duration of the

construction phases and the time buffer between consecutive ones, thus calculating their start and finish dates.

APPLICATION CASE

This preplanning method was applied for two multi-story residential buildings. The project 1 having 10 floors with 679,00 m² of floor area and four apartments on each floor. The project total time was assigned to 22 months. The project 2 having 11 floors with 469.00 m² of floor area and four apartments on each floor. The project total time was assigned to 37 months. Table 2 shows the initial scheduling for the project 2 showing the scheduled dates for all the construction phases dealing with activities on the main tower building.

The use of the line of balance for repetitive or non-repetitive projects, allows a much more accurate planning and budget. During the development of the preplanning effort, an accurate and detailed planning of daily activities was conducted from start to finish of the job. Although it was clear that internal and external problems will affect the actual accomplishment of the schedule, a construction budget was calculated from the detailed preplanning. Materials costs did not vary from those in the original budget, since the materials are independent of the planning effort. Every crew had a specific task, and therefore, it was defined for how long they would work on the job. The total man hours were calculated based on the crew optimal composition, multiplied by the time they will work on the job, multiplied by the hourly rates of every crew component. A similar approach was followed for the construction equipment costing. The budget calculated in this way is shown to be much more accurate. On the other hand, the preplanning allowed to find the potential reductions in costs due to a better manpower utilization.

PURPOSES OF INITIAL PLANNING

This initial planning is simple to be elaborated and brings an overall view of the project which is not well done by CPM methods. This plan may be used as a medium term planning and control tool since it is also easy of being update and verified. The authors are testing it as a three months action plan. Another relevant feature is the grouping of the main activities. During the execution these groups may be exploded into what a level of detail needed giving information for other production control tools (short term and lookahead plans).

The following purposes for initial planning were identified:

1. Shape work flow in the best rhythm for achieving project objectives;
2. Match labor teams and related resources;
3. Group together activities that are highly interdependent, so any work method can be planned for the whole operation;
4. Produce assignments for each group of activities (construction phases) without the need of a great amount of information and detailed level;
5. Identify operations to be planned jointly by multiple trades or by multi-skilled workers;

6. Propitiate conditions for the continuity of the labor teams over the construction units
7. Provide information about the construction progress for the sub-contractors and suppliers.

Table 2: Line of balance scheduling for the project 2

| Project subdivision "Construction Phase" | Duration (weeks/floor) | Rhythm (weeks/floor) | Total Duration (weeks) | Start (week) | Finish (week) |
|---|---------------------------|-------------------------|------------------------------|-----------------|------------------|
| Concrete Structure | 3 | 3 | 33 | 9 | 41 |
| Bricklaying | 4,5 | 3 | 34,5 | 26 | 60,5 |
| Pipes and Ducts | 4 | 3 | 34 | 50 | 83 |
| Internal Plastering | 7 | 3,5 | 42 | 78 | 119 |
| External Plastering | 11 | 1 | 21 | 90 | 110 |
| Openings | 12 | 3 | 42 | 90 | 131 |
| Floors | 24 | 2 | 44 | 90 | 133 |
| Sanitary and Electrical | 15 | 1 | 25 | 112 | 136 |
| Painting | 5 | 1,5 | 20 | 108 | 127 |

Many of these purposes are very closed the ones remarked by Ballard (1997) for lookahead plans. It seems that this initial planning may be successfully applied on building construction on supporting this kind of medium term plans.

CHARACTERISTICS OF THE GENERATED PLAN

Some characteristics of the initial planning support lean construction principles. These principles includes:

1. Eliminate waste: the work is scheduled for the continuity of the labor teams, thus it has no waste embedded and maximum performance may be achieved. Since the work may be planned for the whole operations flow aspects may be best driven;
2. Minimize variances: grouping activities related with each other the work will be performed as a "cell production layout". As labor teams work closed to each other they may pay attention on the quality assignments and problem solving right the time it is needed.
3. Use visual management: the essence of the line of balance method is its visual capability of transmitting the goals. This may lead to a better learning process of the planning and control tools and the development of a individual form of understanding.
4. Produce flexible plans: the initial plan is flexible in the way it permits changes in two levels: within a group any schedule may be changed without affecting the

overall plan and final date; between any group buffers may be introduced in order to give some slack to any group. This slack will reduce the impact on the next work and may no produce changes on the project end date (Ballard 1995). This use of LOB in this planning method gives a global view over the slacks giving answers more rapidly than CPM method when any change may be done;

5. Sequence the schedule: the line of balance concepts produces a schedule which focus on sequencing operations aiming higher productivity on a whole group of activities. The plan does not give much importance to intermediate dates. It focus on the work continuity and a higher level of completeness. All the work related to the main activity must be concluded in the right sequence. Importance on the schedule rather than productivity make worse for the work flow uncertainty (Ballard and Howell 1998).

CONTROL TOOLS

The initial planning may be updated during the project execution serving as a medium term planning and control tool. In this situation this initial planning may be renamed to action planning. On the actual research step the authors are implementing this features. One observation that may be done right now is that the medium term planning must be done into two different levels. The highest level comes from the action planning and it works well for the most repetitive, time and resource consuming activities. The lowest level will be produced by looking for other activities which should be done in the lookahead time (some weeks).

The control of the activities showed in the line of balance schedule may be done in terms of units completed within the period. The line of balance chart may show this actual information against the planned one. Otherwise a line of balance progress chart may be developed for a desired date. Figure 1 shows a line of balance chart from an application case under development.

This line of balance chart shows the number of completed floors in the vertical axis against the time to completion. The duration for this activity is estimated on 6 days. Three teams will execute this work which results on a rhythm of 2 days per floor completed. Though the emphasis into this control seems to be the labor productivity since it forces a rhythm to be achieved, the manager must view it in other way. The scheduled activity actually is one of several tasks executed by these same teams. What must be forced in this chart is the end date for all these activities. The productivity for the main task itself may be higher than that showed in the line of balance chart, and really is. In this case the main task “Cerâmica de piso” is executed on one floor in 3 days, if there were not any other related task to be done. Considering the whole “service” the final completion time was 25 days, when the estimated time was 30 days.

In this way , the action plan needs for a complementary tool in order to control all the task that are really done by these teams. As it was suggested above the Lookahead planning (Ballard 1997) do this role.

The line of balance chart has the ability to show how the production is situated related to the key rhythm for a group of activities. It also shows the changes that may occur on the end date and may aid the manager to decide on a crew reduction or increasing in order to keep the desired rhythm.

The progress chart in counter part is built for a given date and shows what is the level of completed units (floors, apartments, or rooms) for some activities. Figure 2 shows the progress chart for some activities of the same application case for the date 20/Fev which corresponds to the time 20 in Figure 1.

Atividade: Cerâmica de piso

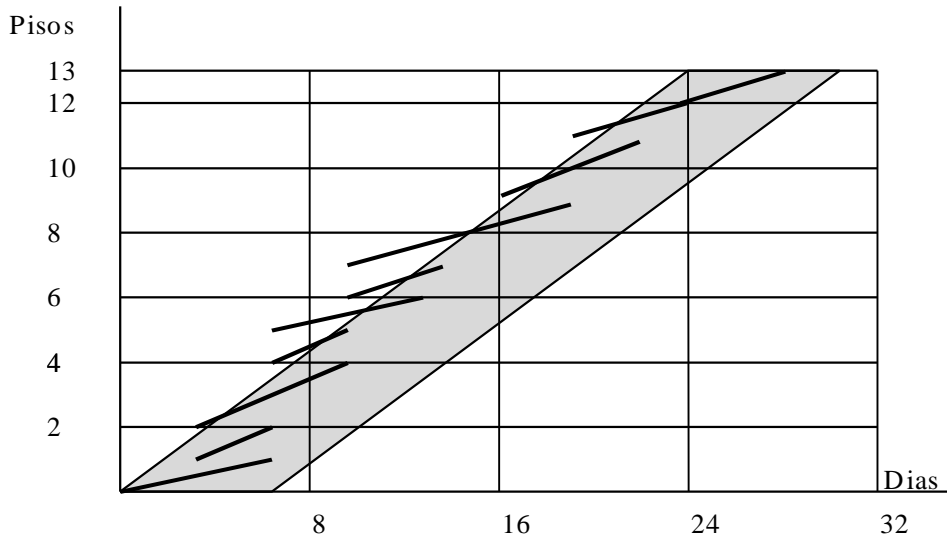


Figure 1: Line of balance chart

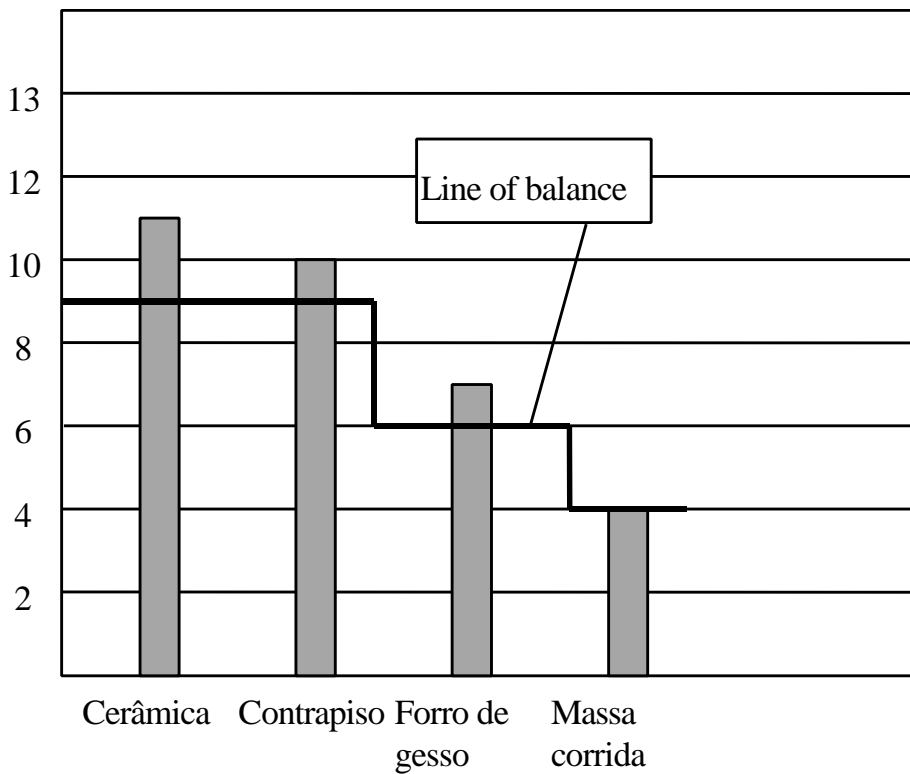


Figure 2: Line of Balance progress chart for the date 02/10/98

CONCLUSION

Work flow uncertainty is made worse by flexibility strategies that sacrifices productivity for the sake of schedule. An initial planning strategy which focus on the sequence of work and the rhythm of labor teams work is provided by the use of line of balance concepts. This initial planning was applied on several residential multi-story buildings. The advantages obtained are related with that the planning is done by grouping together activities that are highly interdependent. In this way any work method permits planning for the whole operations, get advantage of the “cell production”, and matches labor teams and related resources. This approach also makes it possible to get advantage of multiple trades working jointly or of multi-skilled workers.

The concept on the best rhythm for each group of activities focus on the sequence of work, continuity of labor team working and completeness rather than on pure schedule goals.

The proposed planning method also support some lean construction concepts as eliminate waste embedded on the schedule, minimize variances, visual management, flexible plans and sequence of schedule.

The initial planning method is being used as a medium term planning tool together with other tools for short term and lookahead planning. This planning called action plan may be updated on a frequency of three months. Its usefulness for this purpose have to be demonstrated. Two control line of balance control tools are available to measure productivity and progress. These are the line of balance chart and the progress chart.

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