NEW APPLICATIONS OF LINE OF BALANCE ON SCHEDULING OF MULTI-STOREY BUILDINGS

Ricardo Mendes Jr[1]., Luiz Fernando, M. Heineck and Oscar L. Vaca

Dep. de Engenharia de Produção e Sistemas, Laboratório de Gerenciamento da Construção (GECON), Universidade Federal de Santa Catarina, Cx. P. 476. CTC, Campus Universitário, CEP 88010-970, Florianópolis, Brasil.

New practical applications of the Line of Balance technique are presented, introducing simple and transparent tools for initial planning, short term scheduling and production control on multi-storey building construction sites. These developments were being conducted along an investigation on some construction sites on Brazil. The planning methodology is discussed including preplanning details and the control. Two new computational models are briefly presented, the first one a knowledge-based system used for initial planning and the other one a spreadsheet model used for on site short term scheduling and control. This research aimed to develop simple scheduling and control techniques as well the use of simple computational tools. The practical applications carried out on building sites demonstrates that this goal is being achieved. The use of this methodology also permits the learning process of a construction company to grown quite fast due to the use of information from previous projects and a detailed formal preplanning.

Keywords: Buildings, expert systems, line of balance, scheduling, software..

INTRODUCTION

Most construction projects are scheduled based on some sort of critical path planning method (CPM). A number of versions of this technique have been developed and are used as the basis for many of the popular project management software packages. Many researchers discuss the suitability of CPM for construction projects, mainly repetitive projects, such as railroads and multi-storey buildings, and more recently for the lean construction concepts. The main idea of CPM is to find the critical path. 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. As more complex becomes the project more complex it will be this network approach. Other important disadvantage is the complexity for users to deck the information. 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 1997).

One production scheduling and control technique which tries to surpass the CPM difficulties for multi-storey building scheduling is the Line of Balance (LOB) technique. The LOB technique was developed in the early 40s into the manufacturing environment and adapted by researchers for using on construction industry in the 70s. However it has not found a lasting popularity mainly due to the CPM commercial

[1] mendesjr@cesec.ufpr.br, http://www.cesec.ufpr.br/~mendesjr/lob

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software widespread availability. The main concept is the work continuity of the labour teams over the construction units. The labour teams work with rhythmic production, and no wastes are willingly planned or introduced into the schedule. This planning methodology fits much closer to a modern construction philosophy.

The 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 analysed the fundamental information needed for planning with LOB, which include production rates and productivity, construction strategies, labour team allocation, among others. These information was collected from multi-storey building projects undertaken in the city of Florianópolis (SC), Brazil. These buildings had from 6 to 16 floors and 380 to 625 m^2 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 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. This spreadsheet uses the planning information generated by GERAPLAN and permits to obtain more detailed graphic visualization of the schedule, 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. This was the LOB application on multi-storey building sites in order to prove its usefulness and allow the effective use of computer tools for aiding planning and control tasks. 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 1997). The line of balance technique has many concepts close to this new model and the research is investigating them on practical site applications.

The paper proceeds as follows. Firstly, it describes main characteristics of LOB application in multi-storey buildings. Later it presents the planning methodology. Finally it briefly describe the computational tools and conclusions on practical site applications.

LINE OF BALANCE TECHNIQUE

Since the early 1970s, 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. This family of techniques is known as linear scheduling or line of balance (LOB). A review on the line of balance was presented by Lutz and Hijazi (1993).

The schedule procedures have to take account of the phenomena of production rate imbalance which has the potential for negatively impacting project performance by causing work stoppages, inefficient labour team allocation, and excessive costs. This technique has been applied to repetitive construction projects on most building and civil engineering applications (Cole 1991). Because the immense popularity of network scheduling techniques including CPM (critical path method) and inexistence of a commercial software package the LOB technique has never been fully developed and implemented in most countries (Lutz and Hijazi 1993). In Brazil this technique is almost unknown and cases of application are very scarce outside the academic environment.

To automate linear scheduling techniques, a number of computerized tools have been developed by researchers in the last thirty years (Lutz 1990, Moselhi and El-Rayes 1993, Thabet 1997). These tools employ a variety of approaches including linear programming, dynamic programming ,and discrete event simulation. The most recent tools of line of balance application address many practical construction decision variables not well treated in the early models, such as direct and indirect costs, variable production rates, concurrent activities, and work-space limitations. Many of these approaches may result on complex systems that may not be user-friendly, and well suited for rapid scheduling demands or on site usage.

A formal development of a line of balance algorithm was developed by Al Sarraj (1990) which is used in the developments presented in this paper. Wang and Huang (1998) analyses the inability of the LOB technique to control interval time s between adjacent activities in a repetitive unit and proposed a new scheduling linear method, the multistage linear scheduling (MLS) method. It is applicable when scheduling a repetitive project with buffer time limitations between activities for the purpose of safety factors, maintenance or construction improving.

PLANNING METHODOLOGY

Repetitive projects such as multi-storey 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 for multi-storey buildings in the applications described in this paper and by others (Ghio *et al*. 1997).

Construction procedures

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 functions description

- Daily construction volume
- Crew sizes
- Required tools and equipment
- Supporting crews and activities
- Activity starting and finishing time

Schedule and budget

Schedule and budget are typically calculated (as per Brazilian standards) using the "experience" developed in previous projects. This is the expected construction completion time being derived from a first approximation regarding the construction time that has been obtained in previous projects (and the time constraints given by the owner, of course). A similar case can be observed for generating the budget. The construction materials volume is calculated for each activity, and these numbers are multiplied by construction rates, expressed in terms of "man hours/construction unit" and "equipment hours/construction units". The addition of the dollars obtained from this procedure results in the final direct budget. Although some input is introduced into the initial schedule regarding the construction technology to be applied as well as the management and control systems, usually no specific or accurate considerations are really introduced into initial budgets and planning. Since no formal detailed preplanning is conducted, there is quite a bit of uncertainty (Ghio *et al*. 1997). This is taken to account in the form of general rates in which the experience of the firm is summarized. This approach, as well as the CPM, includes much waste which is "willingly" introduced into the budget and schedule.

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 revealed the potential reductions in costs due to better manpower utilization.

Preplanning methodology

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;
2. Determine the construction phase "rhythm": Based on the time constraints given by the owner, a work rhythm was determined for every "construction phase";
3. List all the activities, along with their crews: A complete list of all the construction activities and their corresponding crews was generated;

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, the optimum crews were designed in detail;
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 labour consumption, and hence small durations. 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 or 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 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 was adjusted. In this way, every activity would be performed in almost the same time. Crews shall be designed in such way that all of them will be performing productive work continuously. Table 1 presents a simple case;
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. Table 2 shows the schedule for an eleven-floor residential building of 469,81 m^2 on each floor.

Table 1: Construction volumes and rhythm for walls

Activities Walls	Nº labour	Const volume	Units	Production velocity	Units	Duration with 1 crew (days)	Nº of crews	Duration (days) RHYTHM
Setting out	1	430	m	44	m/day	10	1	10
Bricklaying	4	855	m^2	28	m^2/day	30	3	10
Internal Plastering	7	2200	m^2	105	m^2/day	21	2	10

Table 2: Line of balance scheduling for the construction phases

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

CONTROL TOOLS

Several control tools have been applied in order to assure a thorough and timely implementation of the planning effort.

1. Work daily report: This is a daily report in which the amount of work actually performed in the area (floor/apartment) and the crew components are pointed. It may also specify the exact area of work, the materials used;
2. Man Daily Report: This report shows the personnel on site each day. It may be used together with the previous one;
3. Line of Balance Control: The rhythmic planning is controlled daily with a visual tool. A line of balance control diagram is printed in which the actual construction performed is marked using different colours for different buildings and floors. This is a visual tool to control the units (floors/apartments) of planned activities completed.
4. Weekly control of percentage of planned activity completed: This a form to control the actual percentage of planned activities completed (PPC). The problems which generated any delay are also noted and described in detail (e.g. rain, problems with the equipment, etc.). These problems are accompanied with the solutions and the measures that should be taken to avoid future delays or activities not completed on time.

SOFTWARE TOOLS

Since no software tool was available to process the line of balance computations three different paths were conducted from the beginning of the research: (1) use some commercial package for project management based on CPM method - the Microsoft Project and Time Line programs were used; (2) use a spreadsheet - the Excel for Windows were selected; and (3) develop a new package.

The recent advances in the field of Artificial Intelligence, specifically in Expert Systems, is aiding to capture the professional knowledge, structuring it in a proper way in order to reproduce this process of planning. Different expert systems (Al Shawi *et al.* 1990; Echeverry *et al.* 1991 among others) have been proposed for construction planning, and more recently a number of expert systems based on the line of balance technique has been developed (Formoso 1991, Shaked and Warszawski 1995, Thabet and Beliveau 1997). These expert systems deal in various manners with some or all the following aspects of automated construction planning: building representation; activities generation; determination of precedence among activities; allocation of resources to activities; activities scheduling.

The use of a CPM oriented package demonstrated to be useful because the great amount of details which may be incorporated to the model and the flexibility on getting reports. However the line of balance computations has not been successfully made into the packages and the resource. Some external computations regarding the time buffers between consecutive activities or construction phases must be done as input to the model.

Based on these findings the authors decided to use the knowledge-based approach.

The expert system: GERAPLAN

The expert system developed uses the knowledge-based approach to operate the planning methodology presented above. Using this kind of approach much more “intelligence” might be incorporated into the software surpassing the scheduling function itself. The construction planning functions performed by GERAPLAN include: (1) the enumeration of the required tasks; (2) the determination of precedence among tasks; (3) the determination of the various parameters that affect the duration of the tasks; (4) the allocation of resources to task and (5) determination of resources production rate and timing. The planning is guided by managerial empirical considerations such as least cost, fast completion, and efficiency of employed labour.

The GERAPLAN user interface has been built using Web browsers concepts. This feature allows an easier way to learn and navigation through out the software. This approach also permits future developments towards integration between knowledge based systems and Internet Web browsers. This new type of system requires a novel interface and structure design formed by mini-applications (applets or plug-ins) that query a large information system.

The knowledge base of GERAPLAN involves an object-oriented representation of the building and the scheduling procedure, methods used by activities objects concerned with net procedures, and production rules. Functions are used to control the user interface and the generation of the construction plan. In the latter case the functions trigger the right set of production rules in order to generate or modify the plan.

In this way GERAPLAN permits the user to generate an initial planning for the whole construction project very fast and with a few strategic decisions.

Many of the steps for planning generation can be done automatically by the system using production rules applied to the generation stages. Also a user pre-defined building configuration with default parameters (a template) may be used to define the building product and works. A first plan is generated with all the units of work built in a linear sequence way. It means that one unit has only one successor. This situation allows the better use of the humans resources as well as an improved managerial efficiency. In this sense the system tends to rely on Finish-Start approach to planning to the labour teams stable. In this case the overall duration of the project may be delayed. Thus user may indicates if some tasks in the same unit can be done concurrently.

After this first plan is concluded GERAPLAN suggests adjustments for a plan aiming to reduce the overall duration, and shows the new schedule table and graphic that the user may accepts or rejects. The procedure will stop when the duration were less than the maximum established by the user or when it is decided to change the data and restart the process.

GERAPLAN suggest at any step of the adjustments process one modification in the construction plan that may be about: personnel assignment (resources) in labour teams which changes the duration of the task at one floor; number of concurrent teams doing the same task that affects the pace (production rate) of the task; production rates; and activities' precedence.

All decisions are rule based which means that they are not infallible. There are no priority on what attribute will be changed. This is dependent of the activities candidates for adjustment in the current step and the priorities of the rules checked for the task. If the user does not agree with the modification suggested by the system he or she may deleted it, and GERAPLAN will not try to do this change again in the future. At each step the system generates the Schedule Table and LOB Graphic. The user may allows the system to repeat the process until it achieves the desired overall duration, or to return back to change another data and restart the process.

The spreadsheet LOB model

The spreadsheet model was built mainly for the purpose of rapid scheduling a larger group of activities, and to present the line of balance graphic automatically. The model also integrates some parts of the budget calculations, labour team distribution, a few material deliver expediting and the activities control.

The model uses the formal method developed by Al Sarraj (1990) based on the line of balance assumptions presented above with some adaptations into its logic as proposed by Thabet and Beliveau (1994) and the CPM method for scheduling into one floor. In order to verify these assumptions the schedule (begin and end dates) usually is checked in the first and in the last floor. It is sufficient to prevent interference in both cases of upward or downward workflow. A critical floors for a task may be introduced based on task continuity, continuity of preceding activities, task duration compared with preceding activities, and workflow direction. A task may begin at a critical floor or may be interrupted in it (for some delay time). The dates of the schedule are checked in all the critical floors.

The final schedule is viewed into a schedule sheet on worked days and a starting and finishing dates. Two kinds of graphics of the production lines are displayed: One using the graphic capability of the spreadsheet software and another using one sheet where the cells indicates the activity being executed. Graphics are also used to display the labour teams distribution over the weeks.

It is very fast to update and generate a graphic visualization of the schedule with this model. Thus the model has been used on the short term team scheduling and simulations aiding the site supervisors tasks.

CONCLUSION

An important effort in terms of practical application of the line of balance technique has been presented in this paper. The planning methodology is described and two new computational tools are introduced. The first software developed is a knowledge-based expert system - GERAPLAN - for initial scheduling. The system uses the line of balance technique to control the resources allocation and the schedules generation. The advantage of this approach is the flexibility given to the system. Is flexible in the sense that it can be adapted by the user to add new objects (floors, unit of work, works and labour teams); It is flexible to generate precedence among new works. The other software is a spreadsheet model, which permits rapid activities scheduling, graphic visualization, the generation of a line of balance schedule sheet, and budget forecast. The model also permits the production control using line of balance concepts.

The usage of both the software for initial scheduling and on site simulations and production control, demonstrated that the line of balance is simple, easy to understand and graphically attractive. These characteristics are considered very important for the production planning and control of building construction.

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