DEVELOPMENT OF CONSTRUCTION WORK METHODS AND DETAILED PRODUCTION PLANING FOR ON-SITE PRODUCTIVITY IMPROVEMENT

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Abstract
This paper describes the work conducted to improve productivity during the construction of a Shopping Centre in South America. The work was based on: detailed “design” of construction methods, including the equipment, optimum crew, work procedures, and; detailed production planning, generated in weekly and daily basis. The construction job was particularly complicated due to the hundreds of change orders demanded by the owner and the owner’s clients. The construction followed a fast track scheme, and the contractor was forced to accept last minute changes which generated all sort of delays and work peaks.

As in many countries, the actual construction depends mainly on the foremen and crew leaders. The work presented in this paper empowers the construction field engineer, allowing him to plan, control and optimize on-site construction performance. Despite the many project change orders and the resistance of foremen to change, after 10 weeks the productivity of the job was increased two fold. Numerical results, as well as the methodology applied for this study are discussed in this paper.

Keywords: construction performance, productivity improvement

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INTRODUCTION

The work presented in this paper was conducted during the construction of a shopping centre in South America. The construction cost was 38 million American dollars, and the total construction area was 130,000 square metres. Almost 2 million man hours were consumed during the construction project. The construction company managed to complete the project in record time, as compared to other shopping centres in South America, one month ahead of schedule.

PRODUCTIVITY BEFORE THE CHANGES

Productivity and construction technology were the main issues from the conception of the project. More than 4,000 square metres of modular formwork, post-tensioned slabs, prefabricated elements, special concretes, and diverse heavy and light construction equipment were used in order to reduce the construction costs and schedule. The project was managed using an EPC fast track scheme. The fast track approach was required to allow fast delivery of the 180 stores included in the mall.

Fast track allows early project start, as well as early project delivery. However, the productivity and man hour consumption will be seriously affected when "180 owners" are allowed to modify the original design in order to accommodate their own needs. The shopping centre rented most of its 180 stores during the construction phase. The shopping centre owner's policy, directed by the sales effort, accepted all sorts of project changes. These ranged from including rest rooms in every store (although this was not considered in the original design), to retrofitting columns and vertical elements to accommodate an additional floor in one of the stores. Changes were quite common during the entire construction phase. The hundreds of change orders produced all sort of construction delays and work peaks, not scheduled originally. Additionally, although the construction work started on April 1996, most of the detailed design was generated by September 1996. The combination of the change orders with the "avalanche" of detailed design information generated profound effects in the original plans and schedule. Managing the 800+ workers got quite complicated. Production rates and productivity fell down considerably as compared to the original plans. To cover last minute changes, it was necessary to increase the work periods, in many cases up to 8 hours of overtime (on average). The crews were demotivated and tired, and it was quite difficult to generated work plans with more than a few days in advance. On top of this, the foremen demanded more construction labour in order to cover the work peaks. In many cases, the total work force was hired on the basis of few but intensive work peaks. Moreover, foremen generated all sort of complications during the implementation of the optimization program. Poorly educated foremen based their work on their experience, and were afraid of new concepts and systems.

In order to control the different productivity related problems, it was decided to conduct a productivity improvement effort directed to: (a) Rapidly control the production, (i.e. productivity reduction rates, the increasing overtime, and production rates). This had to be done in a short but intensive effort directed to mitigate the immediate problems. (b) To introduce a system which will avoid future problems under similar situations and allow the construction management to know precisely the labor required for each construction period.

PRODUCTIVITY IMPROVEMENT METHODOLOGY

The productivity improvement effort was based on two main tactics (Ghio 1997): (a) the detailed design of construction methods, combined with (b) a detailed production planning. The former eliminates waste within the construction procedure, and the latter eliminates non-contributory work and increases the percentage of planned activities completed (PPC).

Productivity measurements

It was absolutely clear that the production rates (expressed in man hours/construction units) were scaling fast. However, it was not clear which were the most troubled areas, as well as where to start the productivity improvement effort. Thus, it was decided to start measuring the most important construction activities in order to determine which activities will generate the most profitable productivity improvements. This was combined with parallel field improvements, centred on construction methods design and crew balance. These are discussed below.

Productivity measurements were performed as recommended by Serpell (1993) and Oglesby et al (1989). The measurements were divided into two groups: measurements for crews up to 12 people working on the same area, and; for crews bigger than 12 people, or smaller crews working on extended areas. In the first case, the productive work (PW), contributory work (CW) and non-contributory work (NCW) were measured for each individual. The second case only considered global percentages for each work category.

Additional information captured during the measurements

In order to get into a “construction method design phase”, it was necessary to understand how was the work being carried out on the field. Besides the field observations, it was necessary to obtain detailed current construction methods information. In this regard, each crew was categorized by: the crew components; tools and equipment being used; clients and servers; materials; final product; detailed construction method description; productivity; general observations, and recommendations. This information was fundamental when restructuring the current construction methods in order to rationalize the work being done.

Construction methods “design”

Based on the information described above, a new construction method was “design” and a construction procedure was generated for the most important construction activities (importance was determined based on man hours weekly consumption). The term “construction method design” is used here, because in many cases the construction methods were restructured completely, or a new construction method was generated from scratch. Therefore, it was necessary to re-engineer most of the construction methods in order to obtain the best combination of construction velocity and minimal man hour consumption. The construction procedure included: the new construction crew, as well as the precise responsibilities of each crew member; tools and equipment required for the new construction methods. The new construction procedure was transferred to the field engineer, who trained and supervised the crew leader in order to assure the appropriate implementation of the improved crews and methods.

Optimum crew

Two steps were followed in order to obtain the optimum crew. Firstly, from the productivity measurements it was possible to restructure many crews in order to reduce both the contributory and the non-contributory work. This was possible without requiring any construction method change. However, in order to get the maximum benefit from the productivity improvement effort, the initial crew optimization was further improved with the construction method design. An optimized crew was obtained, proved, and re-optimized on the field. In most of the cases it was found that the crews could be optimized again, once the new construction method was learnt by the crew.

Initial (budget) planning

The initial budget was developed based on assumptions that did not apply to the actual construction project. Change orders and delays on the engineering and design phases generated a new and compressed construction schedule. Although engineering was several months late, construction delivery date was kept constant. Moreover, 5 months before construction due date, the schedule was shortened one month by the owner. On the other hand, the new construction methods generated new construction velocities for many of the construction activities. In order to cope with these factors, it was deemed necessary to work with a modified version of the "last planner scheme", discussed by Ballard (1993). The proposed planning scheme is presented in Figure 1, and discussed in the following sections.

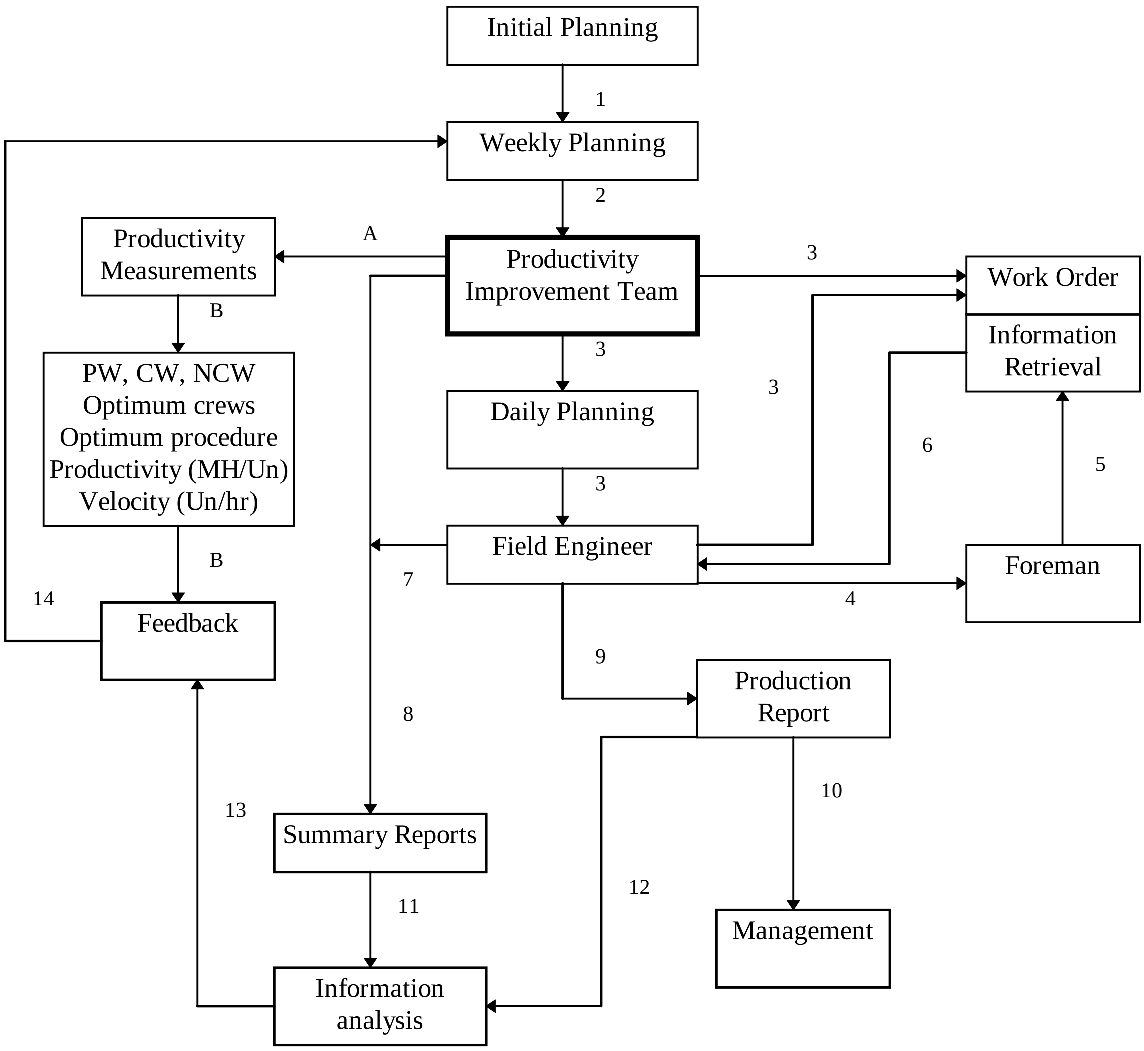

Figure 1 Production planning information flow.

Production planning

As described before, the productivity improvement effort was conducted 6 months after the project was started. The man hours were scaling quite fast, therefore it was necessary to apply an effective and efficient productivity improvement scheme. The initial planning was significantly modified, in order to recover from the existing delays, as well as to cope with the new schedule restrictions. The construction methods design, the productivity measurements, and the crew optimization were combined in a production planning scheme. This scheme was used in order to take all the optimizations and apply them to the actual field work. The productivity improvement effort was tremendously beneficial as it will be discussed later in the productivity improvement section.

- Weekly Planning: The initial planning was re-structured to accommodate both the existing delays as well as the shortened schedule. Weekly plans were developed based on the new work plan. These weekly plans, however, were designed considering the possible future change orders and engineering delays (these showed to be wise after implementing the production planning). The production velocity of every crew was obtained from the productivity measurements, and used in order to design similar work volumes per crew, per day (a work "rhythm" was designed for every optimized crew, although the job did not show repetitive operations). The results from the weekly planning were used to generate a daily planning.
- Daily Planning: Based on the weekly planning, a daily planning was developed. This considered all the field problems and delays, in order to adjust the next day planning. Changes were so frequent during the project, that it was impossible to think that planning could be developed even for a few days, without a major change. Although the contractor might have had some responsibility in allowing the thousands of change orders, the client's main concern was sales. Thus, he was willing to accept all sort of changes from the store buyers and disregard the contractor complaints. In any case, the daily planning played a highly important role by incorporating into the project plan all the changes, and by generating efficient ways to complete the remaining work without increasing the field personnel.
- Work Orders/Information Retrieval: The daily planning was transformed into daily work orders. This order included the responsible foremen, the location of the work to be realized, the crew leader , the equipment required, the volume of work and, the time at which the work shall be started an finished. If more than one activity shall be performed by one crew, similar information was included for each activity. Even the transportation time was considered in the work orders. The works orders included input formats for actual performed volumes, actual starting and finishing time. These were filled up by the crew leader. The information was collected by the foremen. The information was also processed to generate the next day planning. Additionally, the causes of delays an work not completed were analyzed. Solutions were implemented immediately, when feasible. If possible re-optimization was detected, the crews' productivity was measured again, and appropriate measures were taken. Production rates were also obtained from the information retrieval system.
- Feedback: A combination of productivity measurements with daily information obtained from the field was re-entered in the productivity improvement methodology. The new crews, production rates and velocities were used in the next weekly planning. Additionally, the percentage of planned activities completed (PPC) was also reviewed, and appropriate actions taken in order to improve the PPC. A continual optimization procedure was generated by these means.

- Information flow[1]: Frequently, *initial planning* gets outdated quite fast. During the optimization job presented in this paper, it was necessary to recalculate a new schedule. This schedule shall be updated weekly *(weekly planning)* in order to comply with the construction delivery date. Considering the remaining amount of work and the remaining time, a weekly plan was developed. The weekly plan was also adjusted considering the information generated from the field measurements as well as from the PPC *(feedback).* The *productivity improvement team* (PIT) consisted of an assistant engineer, and two technicians who were in charge of field measurements and data processing. Based on the field measurements related to the production velocity, the PIT developed the *daily planning*. The daily planning was focused onto adjusting schedule changes which deviate from the weekly plan. The field engineer was in charge of supervising that the daily plan was actually being built in the field. He also informed the PIT if delays occurred in order to modify the next day planning. *Work orders* were developed based on the daily plan. The field engineers passed this information to the foremen and to the crew leaders. At the end of the day, this same work orders were used as *information retrieval* tools. They captured actual construction volume performed, and production velocities for each activity. They were collected by the field engineers. At the end of the week a *production report* was developed and sent to management. Based on the same information, *summary reports* were developed, and the *information analyzed* in order to be used as *feedback* to the productivity improvement effort. *Productivity measurements* were taken along side the planning scheme. They were designed to assess *productive work (PW), contributory work (CW), non-contributory work (NCW),* to develop *optimum crews*, and to assess actual *productivity* (in man hours per work unit) and *production velocity* (in production unit per hour). This information was also used as *feedback* to the optimization effort. The loop continued once again on the weekly planning.

PRODUCTIVITY IMPROVEMENT RESULTS

The productivity improvement program started on week 38 the year. At this stage, the productivity had gone out of control due to several reasons mentioned in this paper. It was decided that the productivity shall be controlled immediately, and therefore, the productivity improvement program shall yield results accordingly. As can be seen in Figure 2, man hour consumption kept growing until week 39. This was found to be the case in most of the main construction activities. The productivity improvement work conducted during weeks 38-39 was mainly directed towards field measurements and work methods design. However, from week 40 actual field productivity improvement measures were applied through the use of the production planning scheme discussed before. A considerable man hour reduction was observed since the implementation of the program as can be seen in Figure 2 and Table 1.

[1] The flow information sequence is numbered in Figure 1.

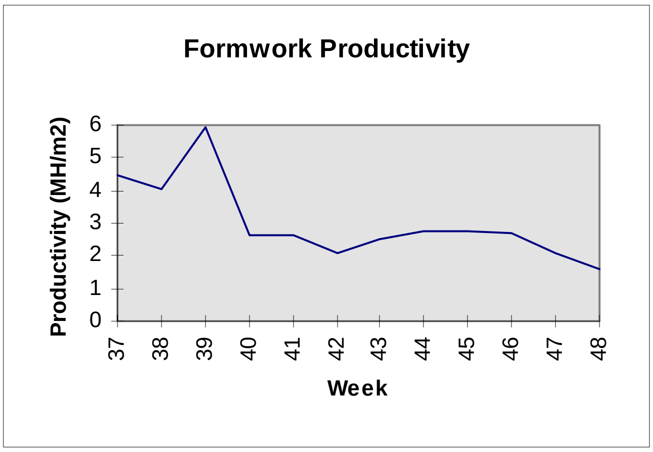

Figure 2 Formwork productivity.

Table 1 Percentage productivity improvement**.**

Activity	**% Productivity Improvement** (10 weeks productivity improvement program)
Concrete Slabs (MH/m^3)	300
Total Concrete (MH/m^3)	200
Formwork-walls (MH/m^2)	145
Formwork-Slabs (MH/m^2)	347
Formwork-Columns (MH/m^2)	482
Total Formwork (MH/m^2)	200

CONCLUSIONS

A productivity improvement program was implemented based on the use of detailed "design" construction methods, and detailed production planning. An appropriate scheme that assured that the optimized crews, methods, and planning were actually incorporated in the field operations has been developed. The application of the proposed scheme generated significant reductions in man hour consumption, as well as faster production rates.

The productivity improvement methodology described in this paper empowered the field engineers and management by giving them an accurate day-to-day control of the plans and actual percentage of planned activities completed at the field. It is rather typical that South American construction firms depend quite heavily on their foremen. This is mainly because the latter have the direct control of field work, and a definite influence on productivity and production rates. The proposed methodology re-structures the on-site "power" organization assigning the right responsibilities to the right persons. It is necessary that field construction engineers assume their roles and responsibilities accordingly to their education.

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