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CONTEXT OF PRODUCTION CONTROL IN CONSTRUCTION

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ABSTRACT

It is commonly accepted that production control systems should correspond to the context within which they are operating, i.e. the production situation. However, rarely is this context indicated or made explicit; for example, the boundary conditions or the range of validity of a particular production control method. Thus, it is the aim of this paper to analyze how the production context could more systematically be taken into account when determining which production control system to use.

Whilst it is acknowledged that contextual issues can be approached in a variety of ways, this is dependent on the perspective being considered (e.g. from a management hierarchy perspective, or a process stage perspective). This investigation looks at context from a process stage perspective and firstly considers the major production control approaches (such as CPM, Line-of-Balance, Last Planner System and Critical Chain) to determine their range of validity. Secondly, we endeavour to identify a typology of production control situations (ideal types), together with a suggestion for production control in each case. Finally, we attempt to deconstruct production control into its constituent elements and evaluate the alternative suggestions at this elemental level in relation to their contextual assumptions.

In the paper, all three approaches are discussed and illustrated, based on prior literature and field observations.

KEY WORDS

Production control, Methods, Typology, Decision functions.

INTRODUCTION

It is commonly accepted that any production control system should correspond to its context, i.e. the production situation (Chenhall, 2003). However, rarely is the context indicated or made explicit—for example, the boundary conditions or the range of validity of a particular production control method. Thus, it is the aim of this paper to analyse how the production context could more systematically be taken into account when determining which production control system to use.

To do this, we shall firstly discuss the issue of context in a production management environment. We shall then investigate the major production control methods (such as CPM, Line-of-Balance, Last Planner System and Critical Chain) to determine their range of validity. Next, we shall endeavour to identify a typology of production control situations (ideal types), together with suggestions for production control in each case. We shall also look at deconstructing production control into its constituent elements, and evaluate alternative suggestions at this elemental level

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based on contextual assumptions. Finally, conclusions are drawn from the preceding analysis.

WHAT IS CONTEXT IN PRODUCTION MANAGEMENT?

When considering the issue of context in production management, Chenhall (2003) stated:

“The identification of contextual variables potentially implicated in the design of effective MCS (management control systems), can be traced to the original structural contingency frameworks developed within organizational theory.”

Based on this theory, key variables have been confirmed as descriptors of fundamental generic elements of context. These contextual variables involve the external environment (uncertainty and risk), technology (traditional and contemporary), organizational structure, size, strategy and national culture.

There are also opportunities for determining the feasibility of introducing context in construction in such areas as: project uncertainty, project complexity, the type of contract, production control methods, project typology, space availability on site, risk, technology, tasks interrelationship, decision-making, etc.

However, contextual issues can be approached in a variety of ways, with the approach dependent on the perspective being considered (eg. from a management hierarchy perspective, or a process stage perspective). If considering context from a management hierarchy perspective, this would expectedly relate to the differing levels and type of information required at each level of the management hierarchy to ensure efficiency, progress and control over different areas of the production process and how this may impact on the organisation's business outcomes as a whole.

Furthermore, considering production control in relation to the specific peculiarities and information needs of the various stages of the production process provides another way to consider context. As an example, a particular control mechanism that may be suitable at the start of a production process may be equally unsuitable at later stages of the same process. For a process to be efficient, it requires the correct control procedures to be in place at all stages. Both perspectives are considered valid and are considered in this paper.

THE RANGE OF VALIDITY OF MAJOR PRODUCTION CONTROL APPROACHES

There are different kinds and varieties of production management methods; the most common of

which are introduced and analyzed—regarding their range of validity—in the following sections.

CRITICAL PATH METHOD—CPM

Fundamentals

The Critical Path Method (CPM) basically developed as an extension of the Gantt/Bar chart, to determine mathematically, the sequence of activities that would need to be followed to allow the project to finish in the minimum time possible. First developed by DuPont and Remington Rand (UNIVAC) around 1957 (Kelley & Walker 1959), CPM networks not only included activity dependencies, but also provided each activity with a unique numerical identifier and an estimate of the activity's duration. Apart from determining which sequence of activities was 'critical' for the timely completion of a project, it was also possible to calculate the amount of 'float' that could be used before a delay to the start of a 'non-critical' activity impacted on the overall programme—considered to be very important on large and complicated projects. A variation of the CPM approach is the Programme Evaluation and Review Technique (PERT), which tries to allow for activity duration uncertainty, by using best, worst and most likely duration assessments to calculate each activity's approximate duration.

Whilst the majority of CPM networks are displayed in the Activity on Arrow (AoA) format, it is also possible to use the Activity on Node (AoN) or Precedence format to display a programme. However, the AoA method is often preferred due to the way the length of an activity is generally related to its duration on a project time scale.

Major benefits of using the CPM approach include providing a disciplined method for planning construction, showing the logic and construction methodology being used, showing the interdependencies between both critical and non-critical activities and assessing the impact that various resource options might have on the project (Kelley & Walker 1959; Jaafari 1984).

Over the years, as CPM became more popular as a method of Project Management, the software that was developed to analyse the data has become more and more sophisticated, allowing for full project monitoring, activity splitting, resource levelling, cost control and variety of other functions to be included.

Range of validity in prior literature

However, over the years, CPM and the network approach have been criticised as being unsuitable for the effective management of construction pro-

jects. Peer (1974) cites the assumption of unlimited resources, the fixed duration of independent activities and a disregard for continuity of work effort through a production system that is not integrated, as being major drawbacks of this approach. Similarly, Birrell (1980) also feels that the CPM approach fails to properly consider the efficient use of construction resources and that the network technique does not provide a true model of the construction process. Other criticisms included the static nature of CPM programmes and the assumption of central control over the allocation of resources. In the opinion of Laufer and Tucker (1987), the major problem with construction planning as a whole, relates to an over emphasis on project scheduling (the “when”) as opposed to project planning (the “what”, “how” & “who”), and that this problem is carried over to the system being used.

To consider these issues, it is necessary to revisit the original concepts and ideas that went into developing CPM initially (Kelley & Walker, 1959). When developed as a system, CPM was designed to be a method by which planning and scheduling were carried out as two separate functions. Planning was carried out to identify and visualise the methodology and resources required to complete the project as efficiently as possible, using a logic network diagram to show the interrelationships between discrete activities. Then, after both logic and resource constraints were considered, the time element was added to the process, specifically taking into account the productivity and availability of particular resources. Based on these basic principles, it would appear that some of these criticisms may not necessarily be appropriate and that Jaafari’s (1984) contention that most problems identified with the CPM approach, are more likely to be attributable to how it is actually used in practice as opposed to any fundamental problem with the concept, may be valid.

Some construction projects contain multiple units wherein activities repeat from unit to unit and also some organizations are dealing with multiple repetitive construction projects. These projects require schedules that ensure the uninterrupted usage of resources from an activity in one unit or project to a similar activity in the next unit or project. It has been said that CPM cannot assure this requirement because only technical precedence and resource availability constraints are explicitly shown in CPM networks (Ahuja & Thiruvengadam, 2004). However, Yamín and Harmelink (2001) argue that with the incorporation of resources levelling/allocation techniques, CPM schedules can improve the overall completion time and cost by affecting produc-

tion (add or remove resources). On the other hand, some limitations have been identified when scheduling continuous projects, because of the difficulty to maintain continuity in crew utilization.

However, probably the most important criticism of CPM networks and their application, is that they tend to be the central component of Project Management and that their emphasis on managing and controlling activities neglects the issues of workflow management and the creation and delivery of value (Howell & Koskela, 2000). For Project Management to be effective, the ‘management-as-planning’ approach currently being used and epitomised by the use of CPM networks, needs to be augmented by the “management-as-organizing” approach (Koskela & Howell, 2001).

Discussion

When considering the issues and criticisms relating to CPM, part of the problem may be due to an overall change in the nature of the construction industry, from when CPM was originally developed (in the late 1950’s)—when most construction companies had a construction workforce. In the years that followed, construction companies moved away from having their own trade labour force (over which they had direct control)—to today’s situation, where most work is carried out by specialist subcontractors.

Due to this, as well as changes in the allocation of risk on construction projects and the move to more adversarial contracts, CPM programmes were no longer just being used as tools to aid management in the control of construction activities on site, but became contract documents used to determine the validity and extent of contractual claims (Jaafari, 1984; Laufer & Tucker, 2001)—a purpose for which they were not originally intended.

Whilst there are conflicting views regarding its suitability in the literature, CPM obviously has its place and the extent of its use probably also has as much to do with the industry’s familiarity with the system and the fact that it is what is taught in schools of construction management. Although no one method of production/project control is right for all situations, CPM is probably among the most versatile planning method devised to date and that is why it is used in so many production/project situations. Software tools for CPM (which was originally designed as a computerised system) are also more abundant and sophisticated, even though other systems have been developed. However familiarity with CPM should not deter Project Managers from seeking other techniques which are either simpler or more suitable for spe-

cific projects or to meet the needs of specific management situations.

THE LINE-OF-BALANCE—LOB

The Line-of-Balance (LOB) was originally derived from the manufacturing industry and was developed by the U.S. Navy Department in 1942 for the programming and controlling of repetitive or one-off projects. It was later developed by Nation Building Agency (in UK) for repetitive housing projects, where a resource-oriented scheduling tool—that considered resources as the starting point—was considered to be more appropriate and realistic than one that was more activity-dominated. This method was later adapted to planning and project control (Lumsden, 1968), where resource productivity is considered to be of particular importance.

Fundamentals

Line-of-Balance proposes that activities should be planned within their production rhythms, in other words, the number of units that a crew can produce in a determined time unit. These rhythms are shown in a graph ‘time x units’ and it can represent the real production of units. The LOB helps the foreman of a production line, at anytime; to observe the progress of each activity by its ability to maintain a set rate of productivity. In many phases of its application many decisions have to be taken by the foreman such as: level of detachment in activities planning, crew size, production expected and achieved, production rhythm and learning, that result in the number of crew simultaneously on the site, their position/location; the direction of production and technologies available or able to be used (Mendes, 1999).

A common characteristic of Line-of-Balance techniques is the typical unit network. LOB is a variation of linear scheduling methods that allows the balancing of operations such that each activity is seen as being continuously performed, even though the work is carried out in various locations. The major benefit of the LOB methodology is that it provides production rate and duration information in the form of an easily interpreted graphics format (Figure 1 from Arditi *et al.* 2002).

Range of validity in prior literature

In their criticisms of the CPM approach, both Peer (1974) and Birrell (1980) put forward alternative planning methods based on the LOB approach. However, in terms of the limitations of the LOB method, Kavanagh (1985) indicated that this technique was designed to model simple repetitive

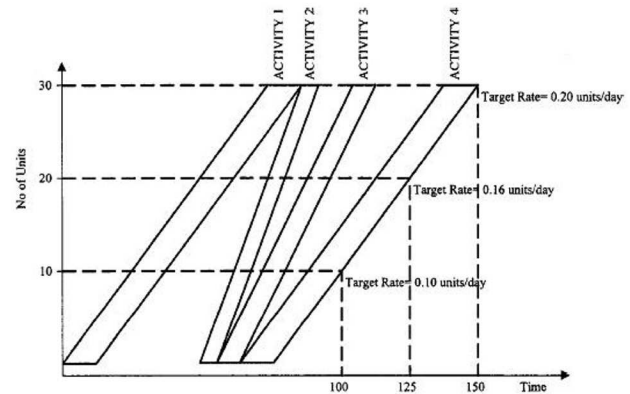


Figure 1: Line-of-Balance and production rate (Figure 1 in Arditi *et al.* 2002)

production processes and, therefore, does not transplant readily into a complex and unpredictable construction environment. Neale and Neale (1989) mentioned that LOB can show clearly only a limited amount of information and a limited degree of complexity, especially when using the technique to monitor process.

On the other hand, LOB has been successfully used as the principal scheduling tool in large construction companies in Finland, where it was used to improve the production flow in the projects involved (Soini *et al.*, 2004). Soini *et al.* (2004) affirm that in their practical implementation of LOB and with the help of specific commercial software to do it, the benefits achieved included: less schedule risk, improvements in analyzing alternatives, reduced project durations, quick checking of schedule feasibility, real-time standardized reporting of progress to management and the ability to optimize control actions and actually get the sites under control. It should be noted however, that whilst the software identified utilises a modified LOB approach, it combines this with “well established integrated CPM methods” (DSS 2005).

Kenley (2004) provided the following description of a particular commercial software package that is based on a LOB approach:

“...a powerful management and control system, allowing rapid and early development of project schedules based on location-specific measures of the building. Control emerges through the hand-over of locations from one work package to another. The emphasis is on minimizing risk of disturbance by allowing buffers between activities”.

Discussion

To a large extent, LOB has mainly been used for projects where there is a large degree of repetition over a relatively small number of discrete activities—such as with multiple dwelling units of a

similar type or in the construction of roads, pipelines and the like. In these types of projects, the LOB's resource-centric/production-rate style is a particular advantage, as continuous monitoring is able to quickly identify when and where changes to estimated productivity occurred and allow remedial actions to be swiftly put in place. However, on more complex projects, the system's simplistic approach has been considered to limit the level of managerial and production control considered necessary for these types of projects. Recent software developments which combine both LOB and CPM would appear to provide a planning and control process that provides the best of both, whilst at the same time eliminating the deficiencies of either.

LAST PLANNER SYSTEM—LPS

The Last Planner System (LPS) was originally developed by Ballard and Howell in 1992. It is designed to increase reliability of planning as a mechanism to improve project performance.

Fundamentals

Last Planner adds a production control component to the traditional project management system. Last Planner can be understood as a mechanism for transforming what SHOULD be done into what CAN be done, thus forming an inventory of ready work, from which Weekly Work Plans can be formed. Including assignments on Weekly Work Plans is a commitment by the Last Planners (foremen, squad bosses) to what they actually WILL do (Ballard 2000).

The phase scheduling technique is used to develop a more detailed work plan that specifies the handoffs between the specialists involved in that phase. These handoffs then become goals to be achieved through Production Control. In other words, it is tried to achieve each handoff between specialists specified in the most highly detailed project schedule. They also recommend using pull techniques and team planning to develop schedules for each phase of work, from design through turnover. The phase schedules thus produced are based on targets and milestones from the APP and provide a basis for lookahead planning. The lookahead has as its objectives to identify and eliminate constraints to achieve the milestones of the project, in a horizon that can be variable from four to eight weeks.

Team planning involves representatives of all organizations that do work within the phase. Typically, team members write on sheets of paper brief descriptions of work they must perform in order to release work to

others or work that must be completed by others to release work to them. They tape or stick those sheets on a wall in their expected sequence of performance. The first step of formalizing the planning and the phase schedule is to develop a logic network by moving and adjusting the sheets. The next step is to determine durations and see if there is any time left between the calculated start date and the possible start date' (Ballard & Howell 2003).

The purpose of phase scheduling is to produce a plan for completing a phase of work that maximizes value generation and one that everyone involved understands and supports; to produce a plan from which schedule activities are drawn into the lookahead process to be exploded into operational detail and made ready for assignment in weekly work plans.

The weekly work planning process is built around promises. The agreed programme defines when tasks should be done and acts as a request to the supplier to do that task. The last planners only promise once they have clarified the conditions of satisfaction and if they are clear that the task can be done.

The LPS assumes that planning means selecting from what 'should' be done to complete a project and deciding for a given time frame what 'will' be done. Recognize that because of resource constraints, not all 'can' be done, and accordingly, if a subset of what 'should' be done 'can' be done, and a subset of what 'can' be done 'will' be done, then there is a high likelihood for what has been planned (will) be successfully completed ('did') (Ballard 2000).

Range of validity in prior literature

It has been implied in (Ballard & Howell 2002) that the LPS is valid in a situation where production is directives-driven, rather than machine-driven. A Danish study on the use of LPS in frame erection (Madsen & Larsen 2002) did not find significant benefits arising, in contrast to several other studies on the LPS on site. Frame erection being largely driven by the capacity of crane, the explanation for the lack of benefits is plausibly related to the range of validity of LPS covering only directives driven production.

Discussion

The LPS has two major focuses: short term planning and development of the social system on site. Where short term planning does not have a prominent role, say for lack of uncertainty or complexity, the method's usefulness is more limited. Also, where there is no considerable need or possibility

for the development of the social system, say in a situation where the organization is very hierarchical or there are language problems, at least the applicability of the corresponding parts of this method is limited. Furthermore, as argued above, the production situations where the work is predominantly machine-driven fall outside the area of high validity of the LPS.

CRITICAL CHAIN

The basic idea underlying Critical Chain Project Management (CCPM) derives from the theory of constraints (TOC), developed by Goldratt (1997). TOC asserts that goal achievement for any system is limited by a constraint.

Fundamentals

Goldratt (1997) took this simple idea into the world of production with five focusing steps for system improvement:

- *Identify* the constraint;
- *Exploit* the constraint (do whatever is necessary to ensure the constraint works at full capacity);
- *Subordinate* everything else to the constraint (eliminate interferences with exploiting the constraint to achieve system throughput);
- *Elevate* the constraint (get more of the constraint);
- Do not let *inertia* keep you from doing the cycle again.

In production planning terms the system’s constraint is the bottleneck. Goldratt (1997) argues that the main reason for project overrun is because of the misuse of the safety time created within the estimated times for each activity. The tendency is overestimate the times to give a reasonable degree of certainty of completion. The approach of TOC is to relocate the safety times in strategic positions. Time estimates may be reduced, but safety buffers of time at the end of the project are added. This will have the effect of reducing the length of the critical path.

The first requirement is to ensure that preparations are made to start activities when they are

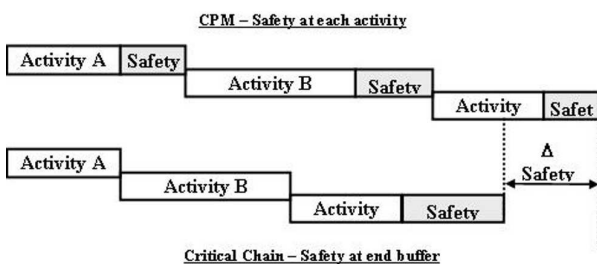


Figure 2. Comparison between CPM and TOC with regard to safety time

passed over. One aspect of this is the creation of a resource buffer for activities on the critical path. The time of completion of ongoing activities is estimated, and the appropriate resources required for the subsequent activities are told to be available. The aim is that people know that when the time comes they must drop everything and work on the critical path. They are encouraged to start immediately, work only on the critical task and finish promptly. It is clear that is necessary to prevent multi-tasking is a crucially important aspect of project management that needs to be controlled (Rand, 2000).

The critical chain is defined as the longest chain of dependent steps: in other words, the constraint. To determine this, it is necessary to take into account any dependencies that might exist between activities because they require the same resource. If that is the case, they must be carried out sequentially rather than in parallel. This can be analyzed in the diagram shown in Figure 3.

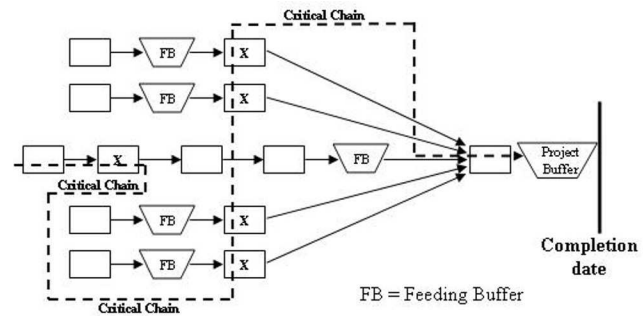


Figure 3. An example of critical chain (Goldratt, 1997).

Range of validity in prior literature

The Critical Chain method assumes that all task owners overestimate task duration by a certain safety factor, and that the duration of the actual execution of each task will expand to fill the time allotted. According with Raz et al. (2003) this assumption is plausible, but Critical Chain theorists fail to provide any supporting scientific evidence. And although the various types of buffers play a key role in CCPM theory, there does not provide any specific or objective basis for determining the buffer size—which raises several problems. On the other hand, Jaafari (1984) indicated that insufficient buffers between dissimilar trades or crews were one of the main problems affecting the success of CPM.

Regarding resource utilization, a cardinal rule of CCPM is that all resources should work on only one project activity at a time and turn in their result as soon as it is complete (Leach, 2000).

Some good points of CCPM method, where it goes especially beyond the CPM oriented thinking, are (Raz et al., 2003):

- Accounts for duration uncertainty by making buffers explicit, sharing the knowledge of buffer sizes and placement with workers, management, and sponsors;
- Considers resource availability;
- Focuses on the key tasks and resources;
- Constantly monitors the amount of buffer in your schedule;
- Provides advance notice of upcoming work to critical resources;
- Does not split your attention among numerous tasks.

Discussion

Working in all bottlenecks of the project has some advantages. First, it is possible to use the maximum of the resources capacity. Second, it avoids that one ‘path’ will not become critical, like is vulnerable in the CPM method. The Critical Chain method also identifies three kinds of buffers: Project buffer, Feeding buffer and Resource buffer, which would appear to allow for the high level of uncertainty in activity duration estimates. Thus, more case studies using CCPM have to be done to prove its validation.

Some researchers argue that is difficult handle with crews’ relocation in companies that have multi-projects and all of them are using Critical Chain. This also happens in projects where the bottleneck is constantly changing. Furthermore, depending of the type of contract, it might be dif-

ficult to either explain or justify to the client the various buffers used throughout the project and how they might be administered.

Once again, when it is suggested that the crews are encouraged to start immediately the work on the critical task, must take into account if all resources required for the realization of the task are available, avoiding the already commented ‘making do’ kind of waste (Koskela, 2004).

FEASIBILITY OF INTRODUCING CONTEXT IN THIS WAY

As the preceding discussion shows, it is possible to indicate appropriate context and range of validity for each production management method. However, the authors on methods only sparingly cover contextual issues. Furthermore, the feasibility of introducing context in this way is somewhat limited, as the proposed approaches as such may not be applicable in totality or applicable to the totality of the project.

TYOLOGY OF PRODUCTION CONTROL SITUATIONS

According with Oxford English Dictionary, TYPOLOGY is “The study of classes with common characteristics; classification, especially of human products, behaviour, characteristics, etc., according to type; the comparative analysis of structural or other characteristics; a classifica-

Table 1: Different Types of Projects (Based on Yamín & Harmelink, 2001)

Type of Project	Main Characteristics	Recommended (Authors) Production Control Methods
Linear and continuous projects (pipelines, railroads, tunnels, highways)	<ul style="list-style-type: none"> - Few activities - Executed along a linear path/space - Hard sequence logic - Work continuity crucial for effective performance 	<ul style="list-style-type: none"> - LOB - Gantt/Bar Chart
Multiunit repetitive projects (housing complex, building)	<ul style="list-style-type: none"> - Final product a group of similar units - Same activities during all projects - Balance between different activities achieved to reach objective production 	<ul style="list-style-type: none"> - LOB - CPM
High-rise buildings	<ul style="list-style-type: none"> - Repetitive activities - Large amount of activities - Hard logic for some activities, soft for others - Every floor considered a production unit 	<ul style="list-style-type: none"> - CPM - LOB - LPS
One one-of-a-kind project (Industrial, bridge, complex projects)	<ul style="list-style-type: none"> - Extremely large numbers of activities - Complex design - Activities discrete in nature - Crucial to keep project in critical path 	<ul style="list-style-type: none"> - CPM - LPS
Simple project (of any kind)	<ul style="list-style-type: none"> - Relatively few activities - Indicates only time dimension (when to start and end activities) 	<ul style="list-style-type: none"> - Gantt/Bar Chart

tion or analysis of this kind”. In the methodology for developing a production control typology, the following can be taken into consideration (Melles & Wamelink, 1997):

The point of view—this typology have focus primarily on distinguish between various types of production control situations. In other words, identify the kinds of construction existent.

The objective—the typology should provide an overview of the production control methods and how they lead with each type of decision function.

The domain—the characteristics used to distinguish between the types of construction are number of activities, continuity, logic sequence, repetitively, and complexity. Here the kinds of contract and multi-projects control are not involved.

Regarding the ‘point of view’, Yamín & Harmelink (2001) have identified five main types of project in construction as well as their main characteristics. Their typology is very useful as a reference to find the most suitable method of production control and Table 1, adds to this by providing an indication of the most appropriate production control method under each situation.

FEASIBILITY OF INTRODUCING CONTEXT THROUGH THIS WAY

The use of ideal types of production situation is a pedagogically effective way of introducing contextual issues into consideration. However, there are limitations. Rarely does a real project fit exactly into an ideal type, and often it may be of mixed type, with different parts of the project belonging to different ideal types.

DECISION FUNCTIONS IN CONSTRUCTION

Bertrand et al. (1990) developed an approach to do Production Control in manufacturing industry that is feasible to transport to the construction industry. It is based in four main decision functions. Each one corresponds to one hierarchical level of decision-making. The highest one is the ‘Aggregate Production Planning’ that in construction can be associates with the Master Programme. Based upon a number of historical databases a high-level plan is developed to schedule the utilization of the production resources capacities for the medium to long term.

Other decision function is the ‘Material Coordination’ that involves making decisions concerning the flow of materials. The ‘material coordination’ decision function is authorized to make delivery agreements with clients (order

acceptance). The planned production volume from ‘aggregate production planning’ is specified in work orders based upon the tasks to be made, the points in time and the quantities required. Based upon the assigned due dates, the ‘material coordination’ function can then determine the proper sequence for executing the work.

The ‘Work Load Control’ is linked with the use of production capacity. In other words, ‘work load control’ specifies the degrees of freedom and the restrictions which need to be taken into account by the material coordination function. This decision function ensures that the expected capacity loading percentage for the available resource capacities does not exceed the levels determined by the crews (production units).

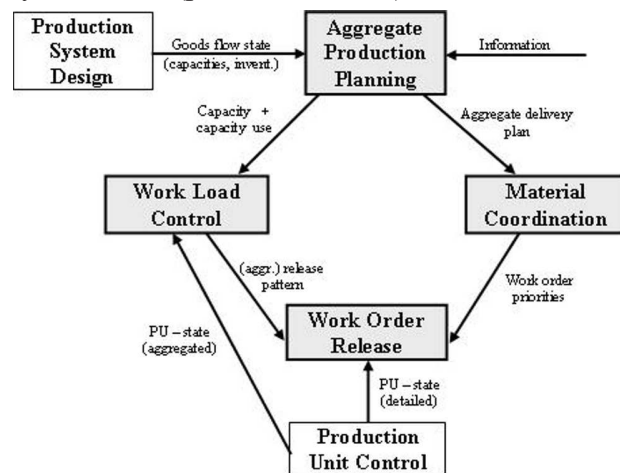


Figure 4: Total goods flow structure adapted from Bertrand et al. (1990)

The lowest level of decision-making is the ‘Work Order Release’. At this level, the sequence of work orders determined by the material coordination function is not necessary the most desirable, from the perspective of production unit control. New information may become available, on the basis of which a different sequence may be desired. However, the decisions made at the ‘work order release’ level will determine which work orders can be produced, when new information about the availability of materials or resources capacities is provided (Melles and Wamelink, 1997).

FEASIBILITY OF INTRODUCING CONTEXT THROUGH THIS WAY

It is possible to introduce context through the decision functions. The four levels of decision-making are applicable to the totality of the project. But for that, a clear definition of task and process is needed as well as the project has to be this up-down hierarchical level structure. Apart from these two requirements all project types can be fitted into this framework. However, we probably

Table 2: Interpretation of the Decision Functions in construction

Decision Function	Involved with	Recommended approaches for each Decision Function
Aggregate Production Planning	Master Programme	Critical Path Method—CPM Line-of Balance—LOB
Material Coordination	Basic flow of production materials	Line-of Balance—LOB Material Requirements Planning—MRP
Work Load Control	Use of production capacity	Critical Chain—CCPM
Work Order Release	Which tasks can be started	Last Planner System™—LPS Command & Control

cannot use this for the whole system of construction⁴.

Thus, we can assume that each decision function might have a context of its own which can be taken as a basis. This means that we should set up the decision functions according to their respective contexts (Missbauer 2002; Portougal and Robb 2000). This invites two questions: Do the different decision functions really have different contexts? How do we ensure that the decision functions, as realized, match with each other?

Regarding the first question, examples may be given on contextual issues that touch in practice strongly one (or two) decision function(s) only. For example, the attitudes, behaviour and linguistic skills of the workforce relate mostly to work order release. In turn, the lack of storage space relates to material coordination.

Regarding the second question, we contend that the decision functions are relatively independent, which allows choices to be made, even if the possibility of mismatch exists.

How could the decision functions be contextually used in the construction industry?

First of all the 'aggregate production planning' has to be elaborated. As it leads with the Master Programme the most suitable Production Planning and Control method could be chosen according to the type of the project. In practice, either CPM or LOB is applicable at this level.

Based on the 'aggregate production planning' a rough idea of the basic flow of production materials can be drafted. Here the 'material coordination' decision function is involved and where the basic choices are between Materials Requirement Planning (MRP) or LOB based planning approach and between pushing and pulling. In the same time the use of production capacity has to be analyzed (work load control) and the Critical Chain method might be useful for this.

At lower levels of the Production Control decision hierarchy, the 'work order release' planning requires anticipation the reaction of the production units (crews) and identifies which tasks can be started. As the Last Planner System acts exactly in these points its use is strongly recommended. This level is also responsible to give a feedback to the upper levels of decision functions, 'material coordination' and 'aggregate production planning', supplying a complete control of the project. In some cases, command and control type of procedure is applicable.

To resume, on the Table 2 are presented the four decision functions and with what each one are involved in production Control.

CONCLUSIONS

It would be wrong to say that context has been largely neglected in the production management literature—but it has been sparingly and unsystematically treated, and there is no coherent body of knowledge related to it. The analyses made pinpoint that a comprehensive model of production management is needed, where context could be introduced for each part separately, however trying to maintain the integrity of the system. This findings invite further research regarding contextual issues in production management.

REFERENCES

- Ahuja, V. Thiruvengadam, V. (2004). *Project scheduling and monitoring: current research status*. Construction and Innovation, **4**(1) 19–31.
- Arditi, D.; Tokdemir, O.B.; Suh, K. (2002). *Challenges in Line-of-Balance Scheduling*. Journal of Construction Engineering and Management. **128**(6) December, 2002.

4 Vries et al. (1999) tried to transfer these concepts into a health care production system but difficulties were encountered. They pinpointed as the main causes of failure 'the unclear definition of concepts as products and process, in combination with the high variability in practice between specialists and the strong orientation on the medical profile of the patient, do not allow the straightforward application of the standard production control concepts'.

- Ballard, G. & Howell, G. (1998). "What kind of production is construction". *IGLC-6. Sixth International Group for Lean Construction Conference Proceedings*.
- Ballard, G. (2000). "The last planner system of production control". PhD. Thesis. Faculty of Engineering of The University of Birmingham, UK.
- Ballard, G.; Howell, G. 2003. An update on last planner. *11th Annual Conference on Lean Construction*, IGLC, Blacksburg, Virginia - United States.
- Bertrand, J.W.M.; Wortmann, J.C.; Wijngaard, J. (1990). "Production control: a structural and design oriented approach". Elsevier—The Netherlands. pp. 322.
- Birrell, G.S. 1980, "Construction Planning—Beyond the Critical Path". *Journal of the Construction Division, Proceedings of the American Society of Civil Engineers*, **106** (CO3) Sept. 1980.
- Chenhall, R. H. (2003). "Management control systems design within its organizational context: findings from contingency based research and directions for the future". *Accounting, Organization and Society*, **28** 127–168. Pergamon.
- Goldartt, E.H. (1997). *Critical chain*. Great Barrington, MA: North River Press.
- Howell, G.; Koskela, L. (2000). "Reforming Project Management: The Role of Lean Construction". *8th Annual Conference on Lean Construction*, IGLC. Brighton, UK.
- Jaafari, A. 1984. "Criticism of CPM for Project Planning Analysis". *Journal of Construction Engineering and Management*. **110**(2), 222–234.
- Kavanagh, D. P. 1985. SIREN: a repetitive construction simulation model. *Journal of Construction Engineering and Management ASCE*, **111**(3) 308–323.
- Kelley, J. E. and Walker, M. R. (1959). Critical-Path Planning and Scheduling. *Proceedings of the Eastern Joint Computer Conference*, Boston, MA, **16**, 160–172.
- Kenley, R. (2004). "Project micromanagement: practical site planning and management of work flow". *12th Annual Conference on Lean Construction*, IGLC, Denmark.
- Koskela, L.; Howell, G. (2002). "The Underlying Theory of Project Management is Obsolete". *Proceedings of the PMI Research Conference*. 293–302.
- Koskela, L. (2004). "Making do—the eighth category of waste". *12th Annual Conference on Lean Construction*, IGLC, Denmark.
- Leach, L.P. (2000). *The wiley guide to managing project—critical chain project management* Chapter 13. Boston : Artech House. 805–829.
- Lumsden, P. (1968). *The line of balance Method*. Oxford: Pergamon Press.
- Madsen, M. M. and Larsen, M. (2002). TrimByg—Et produktivitetsfremmende konsept til byggeriet. Eksamensprojekt ved BYG DTU, Afdeling for byggedelse. p13.
- Melles, B.; and Wamelink, J.W.F. (1997). *Production control in construction: different approaches to control, use of information and automated data processing*. Delftse Universitaire Pers. The Netherlands. pp. 318.
- Mendes, R. (1999). Programação na construção de edifícios de múltiplos pavimentos. Doctoral Thesis. Universidade Federal de Santa Catarina PPGEP. Florianópolis Brazil.
- Missbauer, H. (2002). "Aggregate order release planning for time-varying demand". *International Journal of Production Research*. **40**(3). 699–718.
- Peer, S. (1974). "Network Analysis and Construction Planning". *Journal of the Construction Division, Proceedings of the American Society of Civil Engineers*, **100**(CO3), September.
- Portugal, V. and Robb, D.J. (2000). "Production scheduling theory: just where is it applicable?" *Interfaces* **30** (6). 64-76.
- Rand, G.K. (2000). "Critical chain: the theory of constraints applied to project management." *International Journal of the Project Management*. **18**, 173–177. Pergamon.
- Raz, T., Barnes, R. and Dvir, D. (2003). "A critical look at critical chain project management". *Project Management Journal*. December. 24–32.
- Soini, M.; Leskela, I.; Seppanen, O. 2004. "Implementation of line-of-balance based scheduling and project control system in a large construction company". *12th Annual Conference on Lean Construction*, IGLC, Denmark.
- Vries, G., Bertrand, J.W.M. and Vissers, J.M.H. (1999). "Design requirements for health care production control systems." *Production Planning & Control*. **10**(6). 559–569.
- Yamín, R.A. and Harmelink, D.J. (2001). "Comparison of linear scheduling model (LSM) and critical path method (CPM)." *Journal of Construction Engineering and Management ASCE*, **127**(5), September/October. 374–381.
- Yi, K.J., Lee, H. and Choi, Y. K. (2002). "Network creation and development for repetitive-unit projects." *Journal of Construction Engineering and Management ASCE*, **128**(3), June, 257–264.