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## **Handling and Reducing Variation in On-site Production**

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### **ABSTRACT**

Variation is undesirable in a production system because it complicates production management. Variation caused by completing activities too early (positive variation) or too late (negative variation) is studied through a questionnaire survey where focus was on how to reduce or handle this variation. It was found that the top initiatives to handle variation were: mutual core values, collaboration, process transparency, control of interdependencies and schedule robustness while the top initiatives to reduce variation were: collaboration, output quality, buffering, standardization, and multi skilled craftsmen. The results are compared and discussed according to the construction control principles Last Planner System (LPS). LPS is found to focus on removing negative variation to improve the efficiency of the planning system. Therefore, LPS has only minor focus on the actual process, on communication and collaboration on-site, on how the process is managed by the construction managers in relation to mutual core values, leadership and motivation, and on the quality of the production output.

### **INTRODUCTION**

Variation is in this study defined as the time difference between scheduled and actual duration (Wambeke *et al.* 2011). Variations are not desirable in a production system as they can decrease project performance (Wambeke *et al.* 2011). To avoid variations, production is by construction managers controlled and synchronized to follow specific takt times.

Production control has to consider the production characteristics. On-site production is characterized by being on-site and fixed position manufacturing, unique designs and one-of-a-kind production. The project structure induces temporary organizations which in construction consist of competing contractors. Due to limited space and time the contractors have to complete highly interrelated, interacting, and overlapping activities with multiple components, and a lack of

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standardization (Salem *et al.* 2006; Bertelsen 2003; Ballard 1998; Schmenner 1993). It is in this context that production control has to structure the work process to keep track of the production and to create overview.

Negative as well as positive variation is undesirable in a production system (Hughes *et al.* 2004). Negative variation is destructive to plans and schedules, because it introduces delay (Howell and Ballard 1994) while positive variation creates unexploited gaps in the production which result in unexploited capacity (Lindhard and Wandahl 2013b; Yeo and Ning 2006). Negative as well as positive variation is everyday life in on-site production (Wambeke *et al.* 2011; Thomas *et al.* 2002). Thus, in theory the effects of negative variation can be counterbalanced by the effects of positive variation (Yeo and Ning 2006).

To help construction manager in gaining control of the production, several approaches exist, in this research the handling of variation in "Last Planner System" (LPS) is compared with the experience of construction professionals.

LPS focuses on the handling of negative variation in an attempt to increase schedule robustness. In this framework the objective of production control is regarded as to identify problems or negative variations, to enable corrective actions (Ballard 2000).

To reduce negative variation LPS focuses on improving the quality of the sequence and by ensuring sound activities. Sequence quality is handled by a Phase Scheduling process where the duration and interdependencies between activities are identified. Sound activities are ensured by introducing a Look-ahead schedule containing a making ready process. Throughout the making ready process it is ensured that all preconditions to the activities are fulfilled. Unexpected variations are handled by implementing a buffer of ready work activities. To follow-up on the production the percent planned completed (PPC) measurement is introduced to identify variations. An introduction to LPS can be found in (Ballard *et al.* 2009; Ballard 2000).

Two initiatives exist to handle positive variation: minimizing variation by working towards realistic estimates, and handling variation by working towards exploitation of the emerging gaps (Lindhard 2013). Gaps are exploited by ensuring that a contractor if finishing an activity before deadline can continue his work, and by ensuring that any connecting activities are starting as quickly as possible.

## METHODS

To collect managers and practitioners' own experience with handling variation in the production, an online questionnaire survey was conducted. To form the basis for the questionnaire survey, a literature review was conducted. Based on the findings from the literature review questions and parameters were identified. There is a risk that the

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reviewed literature might oversee a brand new approach to handling variation, but the identified topics are nevertheless by construction professionals rated with regards to relevance. Thus, the result of this study is a guidance of where to focus the effort in an attempt to reduce variation in on-site production.

The questionnaire survey was conducted during a period of 40 days. Forza's (2002) designing theory was applied to ensure the quality of the questionnaire. Forza (2002) identifies four topics which need to be considered: wording, scaling, respondent identification, and rules of questionnaire design.

The wording topic is concerning how the questions are formulated and understood by the respondent. It is important to ensure a language which is consistent with the respondent's level of understanding, and to avoid leading or emotionally loaded questions. A consistent and understandable wording has been ensured by beta-testing the survey. As a part of the beta-test the test respondent's apprehension of the question was discussed.

Relevant respondents were ensured by securing that they were familiar with production control by A) practical experience or by B) theoretical knowledge achieved through their education. The respondents included: project managers, construction managers, site managers, and foremen with varying education and experience. In total 192 respondents were included in the survey whereof 34 filled out the three questions resulting in a response rate of 17.7 %. The questionnaire process took its outset in the strategy presented in (Akintoye and MacLeod 1997). First, an initial invitation was sent out to the participant. Secondly, if not replied, a reminder was sent out two weeks later.

Forza's (2002) final topic (rules of questionnaire design) is concerning the presentation of the questionnaire. To obey Forza's (2002) rules, the questionnaire is supported by including an appropriate introduction and instructions. By supporting the questionnaire with instructions the risk of misapprehensions and misunderstandings is decreased.

## RESULTS

Variation is a common problem to production control in on-site production. The relationship between variation in input and productivity has not been examined exhaustively; therefore, respondents consisting of project managers, construction managers, site managers, and foremen, were asked to rate this relationship. Looking at the educational background 12 respondents has a master degree in civil engineering, 4 respondents has a bachelor degree in civil engineering, 10 has a bachelor degree in architectural technology and construction management, and finally 8 has a craftsman background. The results are presented in Table 1. From the results it can be identified how the industry grasps the relationship, if it considers variation as a problem.

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**Table 1:** Do you think that reduced variations in the production will increase on-site productivity?

|                       | Respondents (n) | Percent (n/N·100=) |
|-----------------------|-----------------|--------------------|
| To a very high degree | 15              | 44.1%              |
| To a high degree      | 12              | 35.3%              |
| To some degree        | 4               | 11.8%              |
| To lesser degree      | 0               | 0.0%               |
| Not at all            | 3               | 8.8%               |
| Do not know           | 0               | 0.0%               |
| Total (N=)            | 34              | 100.0%             |

A quick glance at Table 1 reveals a unity in the industry to consider a strong relationship between variation and productivity. Two approaches for handling the effect of variations exist. A) To reduce the variation and causes to variation or B) to reduce the effect of variation. To identify how to reduce variation the respondents were asked to determine whether or not the identified parameters have an effect on variation in the production. The results are presented in Table 2.

**Table 2:** How do you think that variations in the production can be reduced?

|                                | Yes  | No   | Do not know |
|--------------------------------|------|------|-------------|
| Improved collaboration on-site | 94 % | 0 %  | 6 %         |
| Improved output quality        | 76 % | 12 % | 12 %        |
| Sound buffer activities        | 74 % | 6 %  | 21 %        |
| Standardize the production     | 68 % | 24 % | 9 %         |
| Multi skilled craftsmen        | 62 % | 26 % | 12 %        |
| Mixed crews                    | 59 % | 26 % | 15 %        |
| Flexible workforce             | 53 % | 38 % | 9 %         |
| Improved adaptability          | 47 % | 26 % | 26 %        |
| Scenario planning              | 44 % | 21 % | 35 %        |
| Respondents                    | 34   |      |             |

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To identify how to reduce the effect of variation the respondents were asked to determine whether or not the identified parameters have an effect on variation in the production. The results are presented in Table 3.

**Figure 3:** How do you think the effect of variation in the production can be reduced?

|   | Yes  | No   | Do not know |
|---|------|------|-------------|
| Mutual core values and increased responsibility | 94 % | 0 %  | 6 %         |
| Improved collaboration                          | 88 % | 6 %  | 6 %         |
| Increased transparency of the work process      | 85 % | 3 %  | 12 %        |
| Increased control of interdependencies          | 82 % | 9 %  | 9 %         |
| Improved schedule robustness                    | 76 % | 15 % | 9 %         |
| Respondents                                     | 34   |      |             |

## DISCUSSION

Most of the respondents support Ballard's (1999) claim and believe that reducing variation is one road to increase on-site productivity; thus, 79.4 % of the respondents answer that on-site productivity to a very high degree or to a high degree will increase if variations in the production are decreased. Acknowledging a relationship between variation and productivity is the first step to establish a sense of urgency cf. Kotters (1995) traditional 8-steps to ensure successful change.

Collaboration is regarded respectively as the most and the second most important parameter both in relation to reducing variation and the effects of variations. In question b) 94 % and in question c) 88 % of the respondents rated collaboration important. This underlines why the industry has to be aware of collaboration on-site.

In LPS communication and collaboration within the scheduling process is used to increase schedule quality (Ballard and Howell 1994), but no initiatives in LPS exist to support communication on-site (Lindhard and Wandahl 2013a).

In relation to reducing variation, the other parameters in top five are: improved output quality with 76 %, Sound buffer activities with 74 %, standardizing the production with 68 %, and multi skilled craftsmen with 62 %.

The importance of output quality is increasingly being acknowledged in the construction industry and new concepts. A direct measurable benefit from increased output quality is a reduction of rework. One of the critics to LPS is that it entirely

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focuses on schedule quality (Lindhard and Wandahl 2013a; Ballard 2000); therefore, the PPC measurement should be complimented by an output quality measurement.

Changed soundness of scheduled activities necessitates the possibility to replace the non-ready activities in order to keep production on track. In LPS a buffer of sound activities ensures that the activity can be replaced. Besides the buffer, LPS contains a making-ready process which reduces the risk of non-ready activities emerging in the Weekly Work Plans (Ballard 2000).

LPS is one of many elements in the Lean Construction community in which standardizing the production has an increased focus, especially takt time, sequence (process transparency), and work-in-process (Fiallo and Howell 2012; Mariz *et al.* 2012).

Multi skilled craftsmen can due to the broader variety in skills be utilized more flexible than single skilled craftsmen (Lill 2009). Correct usage of multi skilled craftsmen will induce labour cost savings, reduce the number of craftsmen needed and is suited to complete varying work operations and technical complex tasks (Lill 2009; Clarke and Wall 2000). Multi skilling does not play a key role in the Lean Construction community, but Bertelsen (2004) acknowledges from a complexity view the possibilities within applying multi skilled work crews.

In relation to handling variation the other parameters in top five are: mutual core values and increased responsibility with 94 %, increased transparency of the work process with 85 %, increased control of interdependencies 82 %, and improved schedule robustness 76 %.

Mutual core values are important to site-mangers who are incited to guide and support the production through ethical values and leadership to foster motivation and mutual trust and to increase job-satisfaction (Lindhard 2013). Despite that mutual core values, leadership and motivation all are important to the output quality and quantity during the construction process it has only very limited focus in LPS.

Process transparency, control of interdependencies, and improved schedule robustness are all handled in the LPS. Process transparency and control of interdependencies are linked to sequence quality and to underline the importance of creating a thought through lucid sequence.

Schedule robustness is ensured by making activities ready for conduction. In theory the making-ready process should ensure that only sound activities are selected to the weekly work schedules, but Lindhard and Wandahl (2012) find that variation in the activities preconditions creates variation in activity soundness. It is important to identify emerging conflicts as early as possible in order to release time to make adjustments to avoid interruptions and stops in the workflow.

## CONCLUSION



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In the presented study the research focus has been on how to handle and if possible reduce variation. The experience of construction practitioners have been collected in a questionnaire survey. The survey revealed that the industry sees a strong relationship between variation and productivity. According to construction managers and practitioners the top five initiatives to handle variation were: mutual core values and increased responsibility, collaboration, process transparency, control of interdependencies, schedule robustness while the top five initiatives to reduce variation were: collaboration, output quality, buffering, standardization, and multi skilled craftsmen.

As a construction manager it is important to have insight to how the chosen production control system is designed. LPS is in general found to only focus on negative variation and on the efficiency of the planning system (the telling of what to do) and not on controlling how work is carried out. By controlling how work is carried out, initiatives such as: on-site collaboration, output quality, mutual core values and increased responsibility have an increased importance.

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