Ranking and comparing key factors causing time-overruns in on-site construction

Lindhard, Søren Munch; Neve, Hasse Højgaard; Kalsaas, Bo Terje; Møller, Dan Eggert; Wandahl, Søren

Published in:
The International Journal of construction management

DOI (link to publication from Publisher):
10.1080/15623599.2020.1820659

Publication date:
2022

Document Version
Accepted author manuscript, peer reviewed version

This is a pre-published version

Lindhard, S.M., Neve, H., Kalsaas, B.T., Møller, D.E. & Wandahl, S. (2020): Ranking and comparing key factors causing time-overruns in on-site construction, International Journal of Construction Management, https://doi.org/10.1080/15623599.2020.1820659

Ranking and comparing key factors causing time-overruns in on-site construction

Abstract

For years, the construction industry has looked for ways to avoid time-overruns in construction. Despite previous research mapping the factors affecting time performance, site-managers have difficulties in reducing the time-overrun. In order to create a clearer guidance on how to control time-performance, this study investigates the resource related factors because they are within the site-manager's control. Three Case studies were followed and a survey including 36 participants where conducted. Both investigated and ranked the likelihood of delay due to the seven different resource factors. The ranking of the resource factors was identified as: 1) Construction design, 2) Connecting works, 3) External conditions, 4) Work force, 5) Components and materials, 6) Space, 7) Equipment and machinery. The site-manager's focus should be avoiding the factors that most often is found to cause time-overrun, which are construction design and connecting work that constitute about 60% of the time-overruns. The comparison of the studies revealed that construction professionals were unable to distinguish between the less and the low frequent factors causing time-overrun. Future survey studies should take into consideration that construction professionals' preserved reality does not always correspond to the observed reality. Indicators include low variation between factors and limited use of the scale.

Keywords:
Scheduling, Delay, Preconditions, Productivity, Key factors, Lean

Introduction

In construction, traditional on-site production has not experienced any significant performance improvement compared to the manufacturing industry, nor compared to the increasing offsite construction production (Winch 1998; Höök and Stehn 2008; Fernández-Solís 2009). This, despite a continuously enhanced focus on improving the productivity by management as well as by technology. Several work samplings studies have shown that a significant part of the production time is non-value adding (Horman and Kenley 2005, Kalsaas 2016, Neve and Wandahl 2018, Neve et. al. 2020).

Among other things, low productivity in construction is caused by the complexity of production in construction inherited from the production characteristics (Ballard and

Lindhard, S.M., Neve, H., Kalsaas, B.T., Møller, D.E. & Wandahl, S. (2020): Ranking and comparing key factors causing time-overruns in on-site construction, International Journal of Construction Management, https://doi.org/10.1080/15623599.2020.1820659

Howell 1995; Bertelsen 2003; Bertelsen and Koskela 2004). Here, the production process is managed by a temporary organization comprised of competing contractors with highly interdependent and overlapping activities, which must be conducted with strict space constraints. Additionally, change orders occur during construction, where the project design or the scope of the project might fluctuate from original planned (Hanif et al. 2016). The result is an uncertain and unpredictable process full of pitfalls and risks, which needs to be competently managed (El-Sayegh and Mansour 2015; Shayan et al. 2019). Uncertainty is related to complexity and creates variation in the production system, which decreases productivity (Tommelein et al. 1999; Lindhard and Wandahl 2014a; Lindhard et al. 2019). The productivity decrease is induced by increased (Neve et al. 2020) waste , which surfaces as an extended use of working hours in the completion process and leads to delay (Koskela 2004; Rooke et al. 2007). Therefore, variations are critical and must be avoided in an attempt to reduce time-overrun in construction projects (Hopp and Spearman 2000; Jang and Kim 2008; Brodetskaia et al. 2011).

1.1 Background

Wasted capacity and low productivity make construction projects hard to schedule and cause delays and time-overruns (Johnson and Babu 2018; Abou-Ibrahim et al. 2019). Several studies have investigated time performance. For instance, Love et al. (2005) who, by investigating the time performance at 161 Australian construction projects, found the average time-overrun to be 20.7%. Singh (2010) studied the time-performance at 894 construction projects in India, and found that 82.3% of all projects were delayed with an average delay of 79.3%. Moreover, McKinsey investigated 63 megaprojects and found that the average time-overrun was 20 months (Changail et al. 2015). Finally, Singh (2010) found that time-overrun is an explanatory variable for cost-overrun.

The time studies clearly indicate that on-site production has issues regarding time-performance. Murphy et al. (1974) found a direct relation between the consensus of the success criteria and the project success. In order to improve this, several researchers have looked into the identification of critical success factors (e.g. Rachid et al. 2018;

Lindhard, S.M., Neve, H., Kalsaas, B.T., Møller, D.E. & Wandahl, S. (2020): Ranking and comparing key factors causing time-overruns in on-site construction, International Journal of Construction Management, https://doi.org/10.1080/15623599.2020.1820659

Sanni-Anibire et al. 2020). Many studies have a general focus on securing project success and, therefore, investigate factors affecting time, cost, and quality (Johansen and Wilson 2006). Few studies attempt to correlate different delay factors (Mahdi and Soliman 2018; Shrivas and Singla 2020). A list of identified critical success factors affecting time performance are shown in Table 1.

Table 1. Summary of the identified top five success factors on time performance

Reference	How examined	Number of respondents/cases	Factors
(Arditi et al. 1985)	Questionnaire	78	(1) Shortages of resources; (2) Financial difficulties; (3) Organizational deficiencies; (4) Shortage of labour; (5) Extra work.
(Sullivan and Harris 1986)	Questionnaire	20	(1) Waiting for information from the client; (2) Change orders; (3) Ground problems; (4) Bad weather; (5) Design complexity.
(Chan and Kumaraswamy 1997)	Questionnaire	148	1) Poor site management and supervision; 2) Unforeseen ground conditions; 3) Low speed of decision making involving all project teams; 4) Client-initiated variations; 5) Necessary variations of works.
(Mezher and Tawil 1998)	Questionnaire /Interview	36	1) Contractual relationships; 2) Project management; 3) Financing; 4) Changes; 5) Government relations.
(Al-Khalil and Al-Ghafly 1999)	Questionnaire	35	(1) Contractors financial problems; (2) Difficulties in obtaining work permits; (3) Requirement of selecting lowest bidder; (4) Delay in progress payments; (5) Effects of subsurface.
(Frimpong et al. 2003)	Questionnaire	72	(1) Monthly payment difficulties; (2) Poor contract management; (3) Material procurement; (4) Inflation; (5) Contractor's financial difficulties.
(Koushki et al.2005)	Structured Interview	450	(1) Change orders; (2) Financial constraints; (3) Owner's lack of experience; (4) Materials; (5) Weather.
(Lo et al. 2006)	Questionnaire	158	(1) Inadequate resources due to lack of capital; (2) Unforeseen ground conditions; (3) Exceptionally low bids; (4) Inexperienced contractor; (5) Work in conflict with existing

Lindhard, S.M., Neve, H., Kalsaas, B.T., Møller, D.E. & Wandahl, S. (2020): Ranking and comparing key factors causing time-overruns in on-site construction, International Journal of Construction Management, https://doi.org/10.1080/15623599.2020.1820659

			utilities.
(Faridi and El-Sayegh 2006)	Questionnaire	105	(1) Preparation and approval of drawings; (2) Inadequate early planning of the project; (3) Slowness of the owner's decision-making process; (4) Shortage of manpower; (5) Poor supervision and poor site management.
(Le-Hoai et al. 2008)	Questionnaire	87	(1) Poor site management and supervision; (2) Poor project management assistance; (3) Financial difficulties of owners; (4) Financial difficulties of contractor; (5) Design changes.
(Enshassi et al. 2010)	Questionnaire	66	(1) Strikes, (2) Lack of material, (3) Economical problems, (4) Poor site management, (5) Lack of equipment
(Hwang et al. 2013)	Questionnaire	36	(1) Coordination between various parties; (2) Availability of management staff; (3) Site management; (4) Availability of material; (5) Availability of labour.
(Lindhard and Wandahl 2014b)	Case study	3	(1) Connecting works, (2) Change in work plans, (3) Work force, (4) Weather, (5) Components and material
(Jarkas et al. 2015)	Questionnaire	132	(1) Errors and omission in design drawings; (2) changes orders during execution; (3) delay in information; (4) lack of labour supervision; (5) clarity of project specifications
(Larsen et al. 2016)	Questionnaire	56	(1) State of marked conditions; (2) Weather conditions; (3) Selection and assignment criteria; (4) Soil conditions; (5) Change of partners in the project organization.
(Sinesilassie et al. 2017)	Questionnaire	200	(1) Adequate communication between project participants; (2) Availability of resources; (3) Project manager's understanding of scope of work; (4) Project managers experience; (5) Change orders.
(Johnson and Baby 2018)	Questionnaire	53	(1) Design variations, (2) Unrealistic schedules, (3) Permits, (4) Poor procurement strategy, (5) Approval from consultants
(Pheng et al. 2019)	Questionnaire	36	(1) coordination amongst stakeholders, (2) communications, (3) arrival time of materials and equipment, (4) construction methods, (5) availability of drawings

Lindhard, S.M., Neve, H., Kalsaas, B.T., Møller, D.E. & Wandahl, S. (2020): Ranking and comparing key factors causing time-overruns in on-site construction, International Journal of Construction Management, https://doi.org/10.1080/15623599.2020.1820659

Factors affecting schedule performance can be divided into three groups: Actor related factors, Process related factors, and Resource related factors (Hwang et al. 2013; Lindhard and Larsen 2016).

- Actor related factors are factors related to project participants, for instance the competences of site management or the financing capability of the owner.
- Process related factors are factors affecting the conditions under which a process is completed, for instance effective communication and coordination.
- Resource related factors are factors related to resource availability, for instance labor or material.

A quick glance at Table 1 shows that the resource factors are well represented amongst the top critical factors. The resource related factors are particularly interesting because they are within the site-manager's control span, and possible to intervene. Therefore, this research will focus on the resource related factors to provide a much-needed direct applicable guidance in where to focus the effort (Zwikael and Globerson 2006).

The research takes its outset in the Lean Construction's theory of soundness, where the production is dependent on seven flows or resources. According to Koskela (1999), these seven flows constitute the preconditions/resources, which for every work task, need to be fulfilled in order to complete the task. Hence, if one of the seven preconditions is not fulfilled, the activity is un-sound, and should not be conducted, thus, productivity will go down (Koskela 1999, Brodetskaia et al. 2011). The seven flows are the following:

1) Construction design and information: correct plans, drafts, and specifications are present
2) Components and materials are present
3) Workers with right competence are present
4) Equipment and machinery are present
5) Possible to have access to the workspace

Lindhard, S.M., Neve, H., Kalsaas, B.T., Møller, D.E. & Wandahl, S. (2020): Ranking and comparing key factors causing time-overruns in on-site construction, International Journal of Construction Management, https://doi.org/10.1080/15623599.2020.1820659

6) Connecting works: previous tasks must be completed
7) External conditions must be in order

Due to the complexity and uniqueness of construction, the success factors are project specific. The differences are evident when reading through the identified factors listed in Table 1. Thus, it will not be possible to identify a universal list, but it will be possible to identify some tendencies (Toor and Ogunlana 2009). It is evident that most of the research that reports delay factors are based on questionnaire rather than actual performance based measures. Thus, the identified factors will depend upon the respondent's subjective knowledge and experience. This constitutes an important gap in research knowledge as there may be a difference between how critical a factor is when experienced or perceived and how critical it is when measured. Few studies have triangulated survey data with case based data, which is part of the data sampling approach in this article.

Based on the identified research gap explained above, the objective of this research to identify, rank, and compared key resource related factors for time-overruns by triangulating case based actual performance data (reality) with survey data (perceived reality). This way, the experience of the site-managers is compared with direct performance based measures. The comparison will reveal possible similarities and differences between the two data collection approaches and, also, provide insights into perceived and actual ranking. Construction managers can use this ranking as guidance for where to focus the effort to achieve flow in production.

Method

This research is based on a mixed methods design leveraging triangulation as described by Creswell and Clark (2007) and consists of three main elements: A questionnaire survey, three case studies, and a statistical data analysis combining the two data sources. Both studies investigate the relative importance of the resource factors in relation to their effect on time performance. By applying two different data collection methods, a triangulation effect is achieved which increases the validity of the results. To look for

Lindhard, S.M., Neve, H., Kalsaas, B.T., Møller, D.E. & Wandahl, S. (2020): Ranking and comparing key factors causing time-overruns in on-site construction, International Journal of Construction Management, https://doi.org/10.1080/15623599.2020.1820659

similarities and diversities between the findings, a statistical analysis of the data is applied.

The survey

The survey is designed with outset in the guidelines presented in Forza (2002). According to Forza (2002), a survey needs to be designed considering: wording, scaling, respondent identification and questionnaire design. Wording is referring to how the questions are asked and the formulation of the questions. The survey is beta-tested among peers to ensure consistent language, and to avoid leading or emotional loaded questions.

In relation to scale, a 7-point scale was applied, here the respondent were asked to rate the seven identified factors in relation to how often they cause delay. Actual values (1,2,3,4,5,6,7) were applied, to ensure that the data can be perceived as “interval data” allowing for statistical testing (Field 2009).

The resource factors are described by terms coined in Lean Construction. Therefore, to increase the validity of the data, it was a requirement that the survey participants had a basic knowledge about Lean or experience with application of Lean. Previous research has shown that many practitioners implement and use Lean Construction concepts wrongly (Wandahl 2014). It is argued that people applying Lean concepts are used to identifying interruptions in the production and relating the causes to the preconditions. Thus, they will have a good insight into the relative importance of the resource factors. In that light, it is paramount that respondents have knowledge or experience with Lean Construction. To ensure this, the selected respondents were A) members of leanconstruction.dk, which comprises 16 contractors representing the major contractors in Denmark. B) Former students at the MSc in construction management program at Aalborg University working as contractors. Finally, duplicates were removed from the list of participants. In total 192 respondents were included in the survey. 36 persons completed the survey giving a response rate of 19%. The completed questionnaires have been checked for inconsistencies, but no questionnaires have been sorted out.

Even though the response rate is low, it is still within an acceptable range (Viser et al. 1996; Malhotra and Grover 1998). Moreover, according to Viser et al. (1996) a low

Lindhard, S.M., Neve, H., Kalsaas, B.T., Møller, D.E. & Wandahl, S. (2020): Ranking and comparing key factors causing time-overruns in on-site construction, International Journal of Construction Management, https://doi.org/10.1080/15623599.2020.1820659

response rate does not entail low accuracy of the findings. The low response rate can be caused by different factors. First, web based surveys does result in a lower response rate that other survey modes (Manfreda et al. 2008). In addition, the survey participants consist of construction managers, site managers and foremen, who all work in a busy industry and have long working days. Thus, in a busy and stressful working day, filling out the questionnaire may not have been the priority.

Case studies

In addition to the questionnaire, a case study including three construction projects was conducted. All construction projects were followed in the entire construction period. The construction cases were followed with a focus on observing and determining the relative importance of the resource factors in relation to their effect on time performance. When conducting case studies, a clear research focus is important, otherwise there is a risk of being overwhelmed by the massive data volumes (Eisenhardt 1989). Mintzberg (1979) stated it like this *"No matter how small our sample or what our interest, we have always tried to go into organizations with a well-defined focus - to collect specific kinds of data systematically."*

The cases were selected based on one basic requirement: The constraints related to non-completion had to be reported and described in accordance with the resource factors. The requirement enabled the direct observations to be supplemented with archived data. Here, summaries from scheduling meetings were explored. To ensure consistency in the results and to make comparison possible, the site manager was the same on all three construction projects.

Data from the entire construction period is collected from archives. Additionally, the archives are supplemented with on-site observation and meeting participation in one construction case. Since all cases have the same site manager in charge, insight into the scheduling process for all projects is achieved. It is important to know the context since the context can influence the results (Hartley 2004). This secures validity in the data collection and removes the possibility of biased data. The cases are briefly presented in *Table* 2.

Lindhard, S.M., Neve, H., Kalsaas, B.T., Møller, D.E. & Wandahl, S. (2020): Ranking and comparing key factors causing time-overruns in on-site construction, International Journal of Construction Management, https://doi.org/10.1080/15623599.2020.1820659

Table 2. Data collection for the three case-studies

	Case 1	Case 2	Case 3
Contract form	Turnkey contractor	Turnkey contractor	General contractor
Project followed	Entire construction period	Entire construction period	Entire construction period
From archives	Reports from LPS meetings	Reports from LPS meetings	Reports from LPS meetings
Construction period	50 weeks	23 weeks	60 weeks
Activities registered	1570 activities	593 activities	2592 activities
Constraints registered in	453 activities	134 activities	570 activities
Average PPC	71.1 %	77.4 %	78.0 %

The data collection from the three case studies produced in total 4755 data points. In relation to 1157 of these data points, the observed activity was delayed. The factors causing these delays have been identified for 703 of these data points. The remaining 454 data points have been removed from the data set.

Statistics and comparison

All observations from both the questionnaire and the case study are considered statistically independent. The dependent variables are measured on a fixed interval scale set to vary between 1 and 7 depending on the frequency of the constraint. Furthermore, all incidents of differences are assumed to be normally distributed in the population.

In the questionnaire the participants were asked to number the likelihood of constraints in relation to the resource factors. The minimum value (1) represents a most unlikely occurrence while the maximum value (7) represents the most likely occurrence.

The case studies consist of a weekly observation of constraints in three construction cases. To be able to compare and test results, the percentage-wise allocation of the constraints was calculated in relation to the total number of activities in the corresponding Weekly Work Plans. To strengthen the frame of reference, the weekly registered data points are compiled in clusters of three. Afterwards, the distribution of occurrences of constraints was transformed to the 7-step scale using the transformation diagram shown in Table 3. The transformation diagram serves to relate and compare results from the two research studies.

Lindhard, S.M., Neve, H., Kalsaas, B.T., Møller, D.E. & Wandahl, S. (2020): Ranking and comparing key factors causing time-overruns in on-site construction, International Journal of Construction Management, https://doi.org/10.1080/15623599.2020.1820659

Table 3. Transformation diagram from occurrence in percentage of the total activities in the three-week cluster to the fixed 7-step scale. The transformation diagram is developed to enable a comparison between the results from the questionnaire and the case studies.

$6{,}25\% \le x \le 100\%$ $\Rightarrow$ value 7

$4{,}50\% \le x \prec 6{,}25\%$ $\Rightarrow$ value 6

$2{,}75\% \le x \prec 4{,}50\%$ $\Rightarrow$ value 5

$1{,}75\% \le x \prec 2{,}75\%$ $\Rightarrow$ value 4

$0{,}75\% \le x \prec 1{,}75\%$ $\Rightarrow$ value 3

$0\% \prec x \prec 0{,}75\%$ $\Rightarrow$ value 2

$x = 0\%$ $\Rightarrow$ value 1

First, a hypothesis test of means from the individual results is carried out. Since the sample deviation (σ) is unknown, a one sample t-test is applied to test the means. The H_0 and H_A hypotheses are respectively:

$$H_0 : \mu = \mu_0$$
$$H_A : \mu \neq \mu_0$$

The test statistic applied is: $t = \dfrac{\overline{X} - \mu_0}{s / \sqrt{n}}$; with the level of significance set to: $\alpha = 0{,}05$.

The calculated confidence interval represents the interval within which the population mean would be situated with a likelihood of 95%. By stating that $\mu_0 = \overline{X}$ the lower and upper boundaries for the population mean is calculated. These boundaries are subtracted or added, respectively, to the sample mean.

Afterwards, the results from the questionnaire are compared to the case-observations. Since the sample deviation (σ_1, σ_2) is unknown but equal ($\sigma_1 = \sigma_2$), a squared t-test is applied to test the paired means. The H_0 and H_A hypotheses are respectively:

$$H_0 : \mu_1 = \mu_2$$

$$H_A : \mu_1 \neq \mu_2$$

Lindhard, S.M., Neve, H., Kalsaas, B.T., Møller, D.E. & Wandahl, S. (2020): Ranking and comparing key factors causing time-overruns in on-site construction, International Journal of Construction Management, https://doi.org/10.1080/15623599.2020.1820659

The test statistic applied is: $t = \frac{(\overline{X}_1 - \overline{X}_2) - \delta}{\sqrt{s_p^2 / n_1 + s_p^2 / n_2}}$; with the level of significance set to: $\alpha = 0{,}05$.

When stating that $\mu_1 = \overline{X}_1 = \mu_2 = \overline{X}_2$ the calculated confidence interval represents the interval within which the observed difference in mean would be situated with a likelihood of 95%.

Results

A questionnaire was designed to capture project managers', construction managers', site-managers' and foremens' experiences with the availability of resources. The results, which are presented in

Table 4, show the expected average frequency of constraints in relation to the seven resource factors. It shows a high frequency in constraints related to construction design and connecting works. Furthermore, a two-tailed t-test is performed ($\mu_0 = \overline{X}$) and the related interval for the population mean is stated.

Table 4. Causes for non-completion. Minimum average is 1 representing the most unlikely reason for non-completion while maximum average is 7 representing the most likely reasons for non-completion.

	Respondents	Average	Standard deviation	Standard Error of Mean	One sample t-test 95% Confidence Interval of μ_0	
					Lower	Upper
Construction design	36	5,29	1,90	0,32	4,94	6,23
Connecting works	36	4,58	1,90	0,32	4,19	5,48
Space	36	3,87	1,66	0,28	3,52	4,65
Components and materials	36	3,81	1,72	0,29	3,45	3,61
Equipment and machinery	36	3,36	1,59	0,27	3,02	4,09
External conditions	36	3,28	2,09	0,35	2,76	4,18
Work force	36	3,05	2,02	0,34	2,54	3,90
Total	36					

To gain a triangulation effect and add more validity to the results, three construction cases were subject to observation, thus enabling comparative analysis between questionnaires and observations. Here, failures related to the seven resource factors were detected and constraints were registered. In 703 of the data-points constraints were registered and the root causes determined. The findings are presented in Table 5 in the

Lindhard, S.M., Neve, H., Kalsaas, B.T., Møller, D.E. & Wandahl, S. (2020): Ranking and comparing key factors causing time-overruns in on-site construction, International Journal of Construction Management, https://doi.org/10.1080/15623599.2020.1820659

column named 'number of observations'. Again, a high frequency in constraints related to construction design and connecting work is registered.

To facilitate comparison with the questionnaire, the collected observational data has been split up into weekly registered data points and transformed onto a scale like the scale used in the questionnaire. Furthermore, a two-tailed t-test is performed ($\mu_0 = \overline{X}$) and the related interval for the population mean is stated. The results are presented in Table 5.

Table 5. Causes for non-completion divided between the seven preconditions. Minimum average is 1 representing the most unlikely reason for non-completion while maximum average is 7 representing the most likely reasons for non-completion.

					One sample t-test	
					95% Confidence Interval of the Difference	
	Number of observations	3 week Mean	Standard deviation	Standard Error of Mean	Lower	Upper
Construction design	204	5,14	1,31	0,22	4,69	6,23
Connecting works	194	4,40	2,03	0,34	3,70	5,10
External conditions	105	3,51	1,94	0,33	2,85	4,18
Work force	104	3,42	1,63	0,28	2,87	3,99
Components and materials	72	2,80	1,83	0,31	2,17	3,43
Space	17	1,57	1,01	0,17	1,23	1,92
Equipment and machinery	7	1,23	0,54	0,09	1,04	1,41
Total	703					

One approach to check for similarities between results is to compare differences in mean. In order to enable statistical inferences regarding the relationships and consistency between the results arising from both questionnaires and observations, hypothesis testing is carried out. Specifically, a two-tailed squared t-test is performed, comparing the mean value from the observations (reality) with the mean value from the questionnaires (perceived reality). If the value of t lies within the corresponding confidence interval, the H_0 hypothesis is accepted, if not, H_0 is rejected and instead H_A is accepted. The results are presented in ***Table*** 6. The test reveals a high consistency between the resource factors external conditions, connecting activities, work force, and construction design. Furthermore, a low consistency was revealed between equipment and machinery, materials and components, and space.

Lindhard, S.M., Neve, H., Kalsaas, B.T., Møller, D.E. & Wandahl, S. (2020): Ranking and comparing key factors causing time-overruns in on-site construction, International Journal of Construction Management, https://doi.org/10.1080/15623599.2020.1820659

*Table 6. Squared t-test where the questionnaire (q) is paired to the case (c) results. * indicates that the H_0 hypothesis is rejected.*

	Paired Differences					t
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		
				Lower	Upper	
Construction design (q-c)	,43	2,33	,40	-,37	1,23	1,09
Work force (q-c)	-,17	2,50	,42	-1,03	,69	-,41
Materials and components (q-c)	1,2	2,70	,46	,27	2,13	2,63*
Equipment and machinery (q-c)	2,3	1,83	,31	1,71	2,97	7,57*
Space (q-c)	2,5	1,76	,30	1,91	3,12	8,48*
Connecting activities (q-c)	,37	2,97	,50	-,65	1,39	,74
External conditions (q-c)	,03	2,70	,46	-,90	,95	,06

Discussion

In the case studies, the average PPC is around 75%. This means that for every four planned activities one is not completed in accordance with the production schedule. The delayed activities create uncertainty about the plan and negatively effects the soundness of scheduled activities.

A huge part of these disruptions is caused by resource related factors and can be avoided. This is because the resource related factors are within the site-manger's control, thus he/she is able to ensure resource avalability or to change the plans up front. By changing the plans up front, he/she ensures that all resources are available for all scheduled activities. By avoiding schedules where the resource availability is questionable or unrealistic the time-performance and schedule reliability will improve (Dawood and Sriprasert 2006; Lindhard et al. 2019).

The actual ranking based on the registered data points is: 1) Construction design, 2) Connecting works, 3) External conditions, 4) Work force, 5) Components and materials, 6) Space, and 7) Equipment and machinery.

The resource factors can be divided into three groups, depending on relative occurrence: A) The high frequency group are factors occurring in more than 20 % of the delayed activities, the group contains Construction design and Connecting work constitutes

Lindhard, S.M., Neve, H., Kalsaas, B.T., Møller, D.E. & Wandahl, S. (2020): Ranking and comparing key factors causing time-overruns in on-site construction, International Journal of Construction Management, https://doi.org/10.1080/15623599.2020.1820659

close to 60% of the causes for time-overruns. B) The less frequent group are factors occurring in between 5 and 20 % of the scheduled activities, the group contains External conditions, Work force, and Components and materials is occurring around half as frequently as the high frequent factors. This group constitutes around 40% of the time-overruns. C) The low frequent group are factors occurring in less than 5% of the delayed activities, the group contains Space and Equipment and machinery constitutes only 3% of the causes for time-overruns. As previously stated, the ranking may not be universally valid. Variations in frequency in the resource factors are expected to be project dependent, but even though the ranking might change, the factors in the high frequent, less frequent, and low frequent groups are expected to be the same.

Construction design is found to be the most common reason for delayed activities. The design process is very demanding to keep on track because it includes multiple disciplines, often with strong reciprocal interdependencies, and because of the many iterations to make the design mature (Kalsaas 2019). Even though the design is considered complete, managers experience problems with outdated drawings and drawings with wrong measurements, and often a specific detail needs more clearification (Lindhard and Wandahl 2012). Buildability is a central concern, and the site-manager needs to increase his focus on the design material by carefully examining the it before production. By going through the building process and by comparing the material with the actual site, most issues can be avoided.

The second most common reason for delayed activities is connecting work. Connecting work refers to cases where delays in previous activities hinder the completion. Especially quality issues can create substantial delays, and besides the exstra time spent on rework, the process is costly. The site-manager needs to follow the production closely, and react to delay or bad quality as soon as possible. By discovering the problems early, it might still be possible to take managerial actions to improve the quality or to speed up the production, or maybe the production schedules should be updated to reflect the new situation.

Lindhard, S.M., Neve, H., Kalsaas, B.T., Møller, D.E. & Wandahl, S. (2020): Ranking and comparing key factors causing time-overruns in on-site construction, International Journal of Construction Management, https://doi.org/10.1080/15623599.2020.1820659

The ranking of the last five resource factors vary when comparing the case study with the survey, but when looking at the frequency, the consistency is high for external conditions and work force. Looking at the scores from the survey, the difference between the resource factors is quite low. The two high frequent causes Construction design and Connecting work stand out while the rest roughly score around the mean (3) with the third highest factor scoring 3.87 and the lowest factor scoring 3.05. The difference between frequencies is much more evident when looking at the observations from the case studies. Again, the two high frequent causes stand out with approximately 200 registrations each, but the difference is much more evident in the remaining categories. For instance, the third most frequent factor is registered 105 times while the lowest frequent factors are observed only seven times.

It is important to notice that the survey is based on the experiences and perceptions of the participating construction professionals. The quick comparison reveals that the construction professionals seem to be able to determine the high frequent factors, while the determination becomes more indistinct when distinguishing between the less frequent factors, and they seem to fail in determining the low frequent causes.

The participants' difficulties in distinguishing between the less frequent factors might be affected by how the delay is experienced or by other case-specific explanations. However, nothing indicates that the participants in other survey studies do not have the same difficulties. This is particularly important in studies that rank success factors because they often rely on survey data only. This is evident when looking at the studies mentioned in Table 1. In these studies, at least the possibility that construction professional's understanding of causes for time-overrun should be taken into consideration when ranking the data. A warning sign is if the survey results show only little variation between factors, or when parts of the scale is used for ranking. In such cases, it will be recommended to supplement the survey results with other types of data, for instance, direct observations of the phenomena.

Lindhard, S.M., Neve, H., Kalsaas, B.T., Møller, D.E. & Wandahl, S. (2020): Ranking and comparing key factors causing time-overruns in on-site construction, International Journal of Construction Management, https://doi.org/10.1080/15623599.2020.1820659

Conclusions and Further Research

Factors affecting time-performance were examined through A) three case studies to measure actual frequencies and B) a survey to collect the experiences of construction professionals. Measuring the resource factors in two different research studies allows for comparison between the studies.

Based on the case study, the ranking of the resource factors is as follows: 1) Construction design, 2) Connecting works, 3) External conditions, 4) Work force, 5) Components and materials, 6) Space, and 7) Equipment and machinery. In general, the site-managers need to have all the resource factors in mind; he must monitor and intervene to make sure that the completion date for all activities in the schedule is realistic. But the site manager must keep his focus on avoiding the two high frequent factors Construction design and Connecting work. These two factors were causing more than half of the time-overruns.

Moreover, the findings revealed that construction professional’s causal understanding of the factors causing time-overrun does not correspond with observations as they were unable to distinguish between the less frequent and low frequent factors. To ensure the trustworthiness of the results, survey studies must consider the possibility of participants misperceiving the causes of time-overrun. Indicators to look for are low variation between factors or when only parts of the ranking scale are applied.

Further research will look deeper into the causes for the project managers’ misperception of causes of time-overrun in order to identify if it is physical or psychological factors that affect how the factors and the related time-overruns are perceived.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Lindhard, S.M., Neve, H., Kalsaas, B.T., Møller, D.E. & Wandahl, S. (2020): Ranking and comparing key factors causing time-overruns in on-site construction, International Journal of Construction Management, https://doi.org/10.1080/15623599.2020.1820659

References

Abou-Ibrahim, H., Hamzeh, F., Zankoul, E., Lindhard, S.M. and Rizk, L. (2019), "Understanding the planner's role in lookahead construction planning", *Production planning & control,* Vol. 30, No. 4, pp. 271-284.

Al-Khalil, M.I. and Al-Ghafly, M.A. (1999), "Important causes of delay in public utility projects in Saudi Arabia", *Construction Management & Economics,* Vol. 17, No. 5, pp. 647-655.

Arditi, D., Akan, G.T. and Gurdamar, S. (1985), "Reasons for delays in public projects in Turkey", *Construction Management & Economics,* Vol. 3, No. 2, pp. 171.

Ballard, G. and Howell, G. (1995), "Towards construction JIT", Albuquerque, New Mexico, pp. 1.

Bertelsen, S. (2003), "Construction as a Complex System, Virginia, USA, pp. 1

Bertelsen, S. and Koskela, L. (2004), "Construction Beyond Lean: A New Understanding of Construction Management", In: Bertelsen, S. & Formoso, C. T., *12th Annual Conference of the International Group for Lean Construction.* Helsingør, Denmark, 3-5 Aug 2004.

Brodetskaia, I., Sacks, R. and Shapira, A. (2011), "A workflow model for systems and interior finishing works in building construction", *Construction Management & Economics,* Vol. 29, No. 12, pp. 1209-1227.

Chan, D.W.M. and Kumaraswamy, M.M. (1997), "A comparative study of causes of time overruns in Hong Kong construction projects", *International journal of project management,* Vol. 15, No. 1, pp. 55-63.

Changali, S., Mohammad, A., van Nieuwland, M. (2015), "The construction productivity imperative", *McKinsey Productivity Science Center*.

Creswell, J.W. and Clark, V.L.P (2007), "Designing and conducting mixed methods research", *Sage Publications*, Thousand Oaks, CA.

Dawood, N. and Sriprasert, E. (2006), "Construction scheduling using multi-constraint and genetic algorithms approach", *Construction Management & Economics*, Vol. 24, No. 1, pp. 19-30.

Eisenhardt, K.M. (1989), "Building Theories from Case Study Research", *Academy of Management Review,* Vol. 14, No. 4, pp. 532-550.

El-Sayegh, S.M., Mansour, M.H. (2015), "Risk assessment and allocation in Highway Constuction Projects in the UAE", *Journal of Management Engineering*, Vol. 31. No. 6.

Lindhard, S.M., Neve, H., Kalsaas, B.T., Møller, D.E. & Wandahl, S. (2020): Ranking and comparing key factors causing time-overruns in on-site construction, International Journal of Construction Management, https://doi.org/10.1080/15623599.2020.1820659

Enshassi, A., Kumaraswamy, M., Al-Najjar, J. (2010), "Significant Factors Causing Time, and Cost Overruns in Construction Projects in the Gaza Stripe: Contractors' Perspective", *International Journal of Construction Management*, Vol. 10, No. 1, pp. 35-60.

Faridi, A.S. and El-Sayegh, S.M. (2006), "Significant factors causing delay in the UAE construction industry", *Construction Management & Economics*, Vol. 24, No. 11, pp. 1167-1176.

Fernández-Solís, J. (2009), "An Application Of Popper's Method Of Conjectures And Refutations To The Critique Of Emerging Construction Theories", *Lean Construction Journal*, Vol. 5, No. 1, pp. 37-60.

Field, A. (2009).Discovering statistics using SPSS (and sex and drugs and rock 'n' roll),(3rd ed.). London: Sage.

Forza, C. (2002), "Survey research in operations management: a process-based perspective", International Journal of Operations & Production Management, Vol. 22 No. 2, pp. 152-194.

Frimpong, Y., Oluwoye, J. and Crawford, L. (2003), "Causes of delay and cost overruns in construction of groundwater projects in a developing countries; Ghana as a case study", *International journal of project management*, Vol. 21, No. 5, pp. 321-326.

Hanif, H., Khurshid, M.B., Lindhard, S.M. and Aslam, Z. (2016), "Impact of Variation Orders on Time and Cost in Mega Hydropower Projects of Pakistan", *Journal of construction in developing countries*, Vol. 21, No. 2, pp. 37-53.

Hartley, J. (2004), "Case Study Research", in C. Cassell & G. Symon(Eds.), *Essential guide to qualitative methods in organizational research* SAGE Publications, pp. 323-333.

Höök, M. and Stehn, L. (2008), "Applicability of lean principles and practices in industrialized housing production", *Construction Management & Economics*, Vol. 26, No. 10, pp. 1091-1100.

Hopp, W.J. and Spearman, M.L. (2000), Factory Physics: Foundations of Manufacturing Management, *Irwin/McGraw-Hill*, Boston, USA.

Horman, M.J. and Kenley, R. (2005), "Quantifying Levels of Wasted Time in Construction with Meta-Analysis", *Construction Engineering and Management*, Vol. 131, No. 1, pp. 52-61.

Hwang, B.G., Zhao, X. and Ng, S.Y. (2013), "Identifying the critical factors affecting schedule performance of public housing projects", *Habitat international*, Vol. 38, pp. 214-221.

Lindhard, S.M., Neve, H., Kalsaas, B.T., Møller, D.E. & Wandahl, S. (2020): Ranking and comparing key factors causing time-overruns in on-site construction, International Journal of Construction Management, https://doi.org/10.1080/15623599.2020.1820659

Jang, J.W. and Kim, Y.W. (2008), "The Relationship Between the Make-ready Process and Project Schedule Performance", In: Tzortzopoulos, P. & Kagioglou, M., *16th Annual Conference of the International Group for Lean Construction, Manchester, UK, 16-18 Jul 2008*, pp. 647-656

Jarkas A.M., Al Balushi, R.A. and Raveendranath, P.K. (2015), Determinants of construction labour productivity in Oman, *International Journal of Construction Management*, 15:4, 332-344, DOI: 10.1080/15623599.2015.1094849

Johansen, E. and Wilson, B. (2006), "Investigating first planning in construction", *Construction Management & Economics,* Vol. 24, No. 12, pp. 1305-1314.

Johnson, R.M., and Babu, R.I.I. (2018), "Time and cost overruns in the UAE construction industry: a critical analysis", *International Journal of Construction Management*, DOI: 10.1080/15623599.2018.1484864.

Kalsaas, B.T. (2016), “Measuring workflow and Waste in Project based production”, In: Emuze, F. and Saurin, T.A. (eds) *Value and Waste in Lean Construction* (24 - 42), Routledge.

Kalsaas, B.T. (2019), "Lean construction: A management model for interdependencies in detailed design", *Lean construction: 25 years of development* Taylor Francis, Routledge, Abingdon.

Koskela, L. (2004), "Moving on - Beyond Lean Thinking", *Lean Construction Journal*, Vol. 1, No. 1, pp. 24-37.

Koskela, L. 1999, 'Management of Production in Construction: A Theoretical View' In:,7th Annual Conference of the International Group for Lean Construction. Berkeley, California, USA, 26-28 Jul 1999. pp 241-252

Koushki, P.A., Al-Rashid, K. and Kartam, N. (2005), "Delays and cost increases in the construction of private residential projects in Kuwait", *Construction Management & Economics,* Vol. 23, No. 3, pp. 285-294.

Larsen, J.K., Shen, G.Q., Lindhard, S.M. and Brunoe, T.D. (2016), "Factors Affecting Schedule Delay, Cost Overrun, and Quality Level in Public Construction Projects", *Journal of Management in Engineering,* Vol. 32, No. 1, pp. 0401503.

Le-Hoai, L., Lee, Y.D. and Lee, J.Y. (2008), "Delay and cost overruns in Vietnam large construction projects: A comparison with other selected countries", *KSCE Journal of Civil Engineering*, Vol. 12, No. 6, pp. 367-377.

Lindhard, S.M., Hamzeh, F., Gonzalez, V.A., Wandahl, S. and Ussing, L.F. (2019), "Impact of Activity Sequencing on Reducing Variability", *Journal of Construction Engineering and Management,* Vol. 145, No. 3, pp. 0401900.

Lindhard, S.M., Neve, H., Kalsaas, B.T., Møller, D.E. & Wandahl, S. (2020): Ranking and comparing key factors causing time-overruns in on-site construction, International Journal of Construction Management, https://doi.org/10.1080/15623599.2020.1820659

Lindhard, S. and Larsen, J.K. (2016), "Identifying the key process factors affecting project performance", *Engineering construction and architectural management,* Vol. 23, No. 5, pp. 657-673.

Lindhard, S. and Wandahl, S. (2014a), "Scheduling of Large, Complex, and Constrained Construction Projects - An Exploration of LPS Application", *International Journal of Project Organisation and Management*, Vol. 6, No. 3, pp. 237-253.

Lindhard, S. and Wandahl, S. (2014b), Exploration of the reasons for delay in construction, *International Journal of Construction Management*, Vol. 14, No. 1, pp. 36-44.

Lindhard, S. and Wandahl, S. (2012), "Improving the Making Ready Process - Exploring the Preconditions to Work Tasks in Construction", "Improving the Making Ready Process - Exploring the Preconditions to Work Tasks in Construction", *International Group of Lean Construction*, IGLC, San Diego, USA, *18-20 July*.

Lo, T.Y., Fung, I.W.H. and Tung, K.C.F. (2006), "Construction Delays in Hong Kong Civil Engineering Projects", *Journal of Construction Engineering and Management*, Vol. 132, No. 6, pp. 636-649.

Love, P.E.D., Tse, R.Y.C. and Edwards, D.J. (2005), "Time–Cost Relationships in Australian Building Construction Projects", *Journal of Construction Engineering and Management*, Vol. 131, No. 2, pp. 187-194.

Mahdi, I. and E. Soliman (2018). "Significant and top ranked delay factors in Arabic Gulf countries." *International Journal of Construction Management*: 1-14.

Malhotra, M. K., and Grover, V. (1998). "An assessment of survey research in POM: from constructs to 439 theory." *Journal of Operations Management*, Vol 16, No. 4, pp. 407-425.

Manfreda, K. L., Bosnjak, M., Berzelak, J., Haas, I., & Vehovar, V. (2008). Web surveysversus other survey modes.*International Journal of Market Research*, Vol 50, No. 1, pp. 79–104.

Mezher, T.M. and Tawil, W. (1998), "Causes of delays in the construction industry in Lebanon", *Engineering construction and architectural management,* Vol. 5, No. 3, pp. 252-260.

Mintzberg, H. (1979), "An Emerging Strategy of "Direct" Research", *Administrative science quarterly,* Vol. 24, No. 4, pp. 58.

Murphy, D.C., Baker, B.N. and Fisher, D. (1974), Determinants of project success *NASA*, Boston, MA.

Lindhard, S.M., Neve, H., Kalsaas, B.T., Møller, D.E. & Wandahl, S. (2020): Ranking and comparing key factors causing time-overruns in on-site construction, International Journal of Construction Management, https://doi.org/10.1080/15623599.2020.1820659

Neve, H.H. and Wandahl, S. (2018), "Towards Identifying Making-Do as Lead Waste in Refurbishment Projects", González, V.A. (Ed.), In: Proc. *26th Annual Conference of the International. Group for Lean Construction* (IGLC), González, V.A. (ed.), Chennai, India, pp. 1354–1364. DOI: doi.org/10.24928/2018/0236. Available at: www.iglc.net

Neve, H. H., Wandahl, S., Lindhard, S., Teizer, J., and Lerche, J. (2020). "Determining the relationship between direct work and construction labor productivity in North America: Four decades of insights", *Journal of Construction Engineering and Management*, vol 149, No 9.

Pheng, L.S., Arain, F., Yu, S.X. (2019), "Factors influencing time duration of high-rise private industrial building projects: some preliminary findings", International Journal of Construction Project Management, Vol. 11, No. 1, pp. 29-38.

Rachid, Z., B. Toufik and B. Mohammed (2019). "Causes of schedule delays in construction projects in Algeria." *International Journal of Construction Management* 19(5): 371-381.

Rooke, J.A., Koskela, L. and Seymour, D. (2007), "Producing things or production flows? Ontological assumptions in the thinking of managers and professionals in construction", *Construction Management & Economics*, Vol. 25, No. 10, pp. 1077-1085.

Sanni-Anibire, M. O., R. Mohamad Zin and S. O. Olatunji (2020). "Causes of delay in the global construction industry: a meta analytical review." *International Journal of Construction Management*: 1-13.

Sinesilassie, E.G., Tabish, S.Z.S. and Jha, K.N. (2017), "Critical factors affecting schedule performance", *Engineering construction and architectural management*, Vol. 24, No. 5, pp. 757-773.

Singh, R. (2010), "Delays and Cost Overruns in Infrastructure Projects: Extent, Causes and Remedies", *Economic and Political Weekly*, Vol. 45, No. 21, pp. 43-54. available at: https://www.jstor.org/stable/27807050.

Shayan, S., Kim, K.P., Tam, V.W.Y. (2019), "Critical Success Factor analysis for effective risk management at the execution stage of a construction project." *International Journal of Construction Management* DOI: 10.1080/15623599.2019.1624678.

Shrivas, A. and H. K. Singla (2020). "Analysis of interaction among the factors affecting delay in construction projects using interpretive structural modelling approach." *International Journal of Construction Management*: 1-9.

Lindhard, S.M., Neve, H., Kalsaas, B.T., Møller, D.E. & Wandahl, S. (2020): Ranking and comparing key factors causing time-overruns in on-site construction, International Journal of Construction Management, https://doi.org/10.1080/15623599.2020.1820659

Sullivan, A. and Harris, F.C. (1986), "Delays on Large Construction Projects", *International journal of operations & production management,* Vol. 6, No. 1, pp. 25-33.

Tommelein, I.D., Riley, D.R. and Howell, G.A. (1999), "Parade Game: Impact of Work Flow Variability on Trade Performance", *Journal of Construction Engineering and Management,* Vol. 125, No. 5, pp. 304-310.

Toor, S.u.R. and Ogunlana, S.O. (2009), "Construction professionals' perception of critical success factors for large-scale construction projects", *Construction innovation,* Vol. 9, No. 2, pp. 149-167.

Visser, Penny S.; Krosnick, Jon A.; Marquette, Jesse; Curtin, Michael (1996), "Mail Surveys for Election Forecasting? An Evaluation of the Colombia Dispatch Poll". *Public Opinion Quarterly*. Vol. 60 No. 2, pp 181–227. doi:10.1086/297748

Wandahl. S. (2014), “Lean Construction with or without Lean – Challenges of Implementing Lean Construction”, in proceedings of *IGLC2014*, Oslo, Norway

Winch, G. (1998), "Zephyrs of creative destruction: understanding the management of innovation in construction", *Building research and information,* Vol. 26, No. 5, pp. 268-279.

Zwikael, O. and Globerson, S. (2006), "From Critical Success Factors to Critical Success Processes", *International journal of production research,* Vol. 44, No. 17, pp. 3433-3449.

Chan, D. W. M., and Kumaraswamy, M.M. (1997). "A comparative study of causes of time overruns in Hong Kong construction projects." *International Journal of Project Management*, 15(1), 55 - 63.