THE INTERACTION OF CONTRACTOR'S COST FLOW WITH OPERATIONAL PRACTICE: A SIMULATION STUDY

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ABSTRACT

The construction companies are struggling for cost control in construction projects. This is often based on cost estimation of scheduled activities. A project may fail due to lack of cash even if it is profitable. The cash flow presents dynamic characteristic which is changing with time progress and it is influenced by the uncertainty project environment, such as supply chain variation, equipment failure and the deviation of working efficiency.

At the same time, the increasing market competition forces these companies to transfer from the traditional practice to more advanced and efficient practices, such as lean or flexible production. However, to use lean or flexible production might not prove successful unless the practices are introduced in the right environment. The resources are used in a very efficient way concerning lean, but the practice demand a high degree of predictability. The opposite is true for a flexible production. The resources are not used as efficient but can then on the other hand handle variation better than lean.

The research is based on the question: How does managerial operational practices and variation in production influence the cash flow? A model is proposed to simulate and forecast the cash flow considering the uncertainty project environment and selected operational practice. A case study including six scenarios (high and low variation, three operation practices) is used to illustrate the proposed model. A conclusion is that it is important to consider both managerial aspects as well as operational aspects in order to avoid sub-optimization in production. From the cash flow management perspective, the proposed model can assist the contractor to forecast the cash flow and synchronize the operational practices with project environment.

Keywords: process, behavior, modeling, simulation, uncertainty

1. INTRODUCTION

Nothing is as hard to predict as the future. Generally the further in to the future one try to predict the less accuracy. The weather forecast tends to do better with a two day forecast than a two week forecast. This is also valid for a construction project. Karlsson (2009) could not find a correlation between well-planned projects and the outcome of the project. The unplanned events during the project life had a major influence of the outcome.

The repercussions for unplanned events can be minor and hardly noticed, but the repercussions can be quite severe and not only affect one project. In one of the initial interviews for this study, an onsite manager had recently experienced a ten week delay of the most crucial material in a refurbishment project. The delay affected not only just the time schedule for the individual project but it also affected other projects. The supplier did not share any information regarding the delivery date until the material was more or less leaving the factory.

2. LITERATURE REVIEW

2.1 Theoretical Background

Essentially, the problems that face the project planner are similar to the newsboy problem, a mathematical model used to determine inventory levels. Significant for the problem is fixed prices and a perishable product. A newsboy has a demand that is volatile. To be on the safe side the newsboy order, buy and sell newspaper equal to the mean demand or lower. However, to be on the safe side means lost opportunity and a lost profit. To be really "brave" results in a loss since unsold paper can only be returned to the supplier for a lower price than the price the newsboy paid for the newspaper. The question to answer is how to balance the buffer size to minimise the cost. Quite similar to a buffer for a construction project, if one regards time as perishable. A lost production opportunity will never come back.

However, the buffer in a project is more complicated than to get a few extra newspapers. Lee et al. (2006) discuss the arbitrary use of buffers in construction as they have been used as contingency with a certain percentage of the activity durations added. The authors propose a dynamic buffer instead of the standard static percentage buffers. The reliability and stability buffering approach should lessen the influence of uncertainties. Also, the placement of the buffer is of importance. Lee et al. (2006) and Park and Peña-Mora (2004) recommend to place the buffer in the beginning of an uncertain activity while Ballard and Howell (1995) suggest that the buffer should be placed at the end of the activity. Goldratt (1997) doubts the advantage of individual buffers and proposes the use of global buffers.

Still, the use of buffers can be quite invincible since the buffers are often hidden in the total time and not market as a buffer. A reason for that is the lack of directly added value and therefore buffers can be considered waste. In lean and just-in-time, buffers could impede a smooth workflow (Lee et al., 2006). Walker and Shen (2002) define leanness as: "reducing nonvalue-adding processes and activities in the supply and production chain. It implies striving to use less of everything in a way that squeezes out waste and non-value activities or processes". Browning and Heath (2008) discuss the problems with value and its emerging quality that in practice provide problems when dealing with a complex production situation. Furthermore, Brown (2003) (from Lee et al., 2006) emphasises the need of redundancy in order to avoid a worse situation. The cost of redundancy is less the cost for a disaster. Both Browning and Heath (2008) and Walker and Shen (2002) propose the use of a flexible (agile) elements in a production.

In order to find appropriate buffers or to reduce the uncertainty the drivers of uncertainty must be identified. Thomas and Završki (1999) discuss the complexity of the project and the variability. Poorer performing projects had much higher variability than better performing projects. Howell et al. (2004) established that a reduction of variation will improve the reliability of the planning. Wambeke et al. (2011) examined the factors that influence variation. Among those factors were; senior management coordination, material management, prerequisites and constructability, crew management.

The choice of production methods, supplier, buffers etc. should not be done in isolation. Somehow these decisions should reflect a purpose. Tangen (2004) establishes that progress has been made on establishing performance management systems that have a number of measures and not just a single focus on profitability. Tangen (2004) continues with the importance of the clear link between performance measures at the different hierarchical levels in a company, in order for every department to strive towards the same goals. Kagiogliou et al. (2001) addresses the problem of standard financial measures and it's lagging qualities. It is afterwards the result becomes clear not during a project. Therefore it is necessary with additional measures of a construction project.

Cross and Lynch (1988) presented the Performance Pyramid as a link between strategies and operations. The model translates the strategic objectives top down, based on customer priorities, and the measures from the bottom up. The pyramid's four levels of objectives address both external and internal measures, see figure 1. An alternative to the performance pyramid is balanced scorecards. Kagiogliou et al. (2001) the advantages as: "it rationalizes the relationships between performance measures and goals derived from strategy, so the impact of those measures on an organization's performance can be examined and analysed to indicate potential areas for improvement".

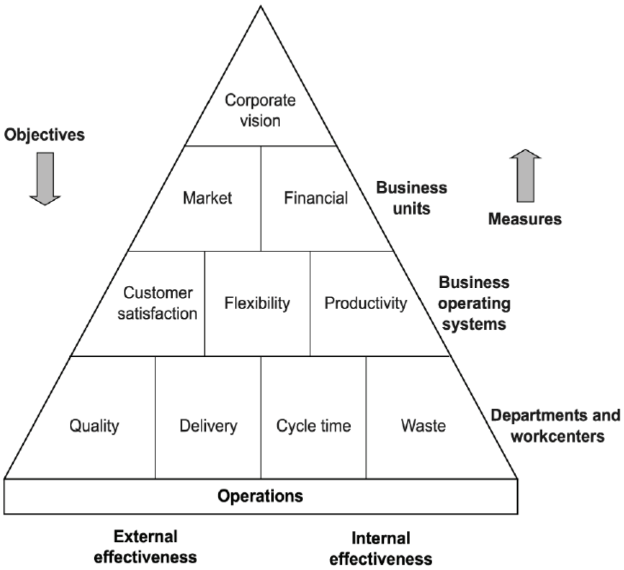


Figure 1: The performance pyramid (adopted from Tangen 2004)

2.2 The Concept Model

A concept model regarding the production, planning and result has been developed. The model is based on a model from Browning and Heath (2008). Depending on what type and degree of uncertainty, different production methods might be suitable. With a high uncertainty, a flexible production might be the best choice because the possibility of detail planning in advance is limited. A very low degree of uncertainty makes resource effective but sensitive methods a valid option. This is not question of chose one or the other for a project. It is a question of finding the right method for a certain activity based on the uncertainty factors.

There are four drivers of production uncertainty that has to be taken in account when the project is planned and/or in production. Demand is the client dimension. If the client has a clear understanding of their vision of the project, the uncertainty will be less compared with a client that is running late with every decision or constantly changing the specifications. According to Karlsson (2009) these types of changes lead to a project with large discrepancies between planning and result. Supply uncertainty will increase both time and cost results. The cost of the logistic can be up to 60 % of the price for a material (Wegelius-Lehtonen and Pahkala, 1998). It might even have a negative external influence like the example in the introduction. Complexity depends on for example number of subcontractors, used technique, scale of the project. Novelty is the use of new techniques, new organisations etc.

The result is the outcome of the production with chosen measures against uncertainty. The results can be measured in different ways. In this paper time and costs are measured. The different dimension can be linked to the performance pyramid for additional measures that can be used in the production phase. Also the concept model is an indication of the benefits of simulation. A project with a high uncertainty in a non-quantifiable dimension like novelty is an indication of additional methods to evaluate the project.

The simulation is based on two quite general expressions linked to the concept model. The general expressions are:

Minimise $\sum$ (production costs)

Subject to

(1) Project time $\leqslant$ Specified date

(2) Cash flow $\geqslant$ Specified lowest figure (this is a continuous requirement throughout the whole project)

Maximise $\sum$ (Project revenues - production costs = Profit)

Subject to
(1) Project time ≤ Specified date
(2) Cash flow ≥ Specified lowest figure (this is a continuous requirement throughout the whole project, not just one point in time)

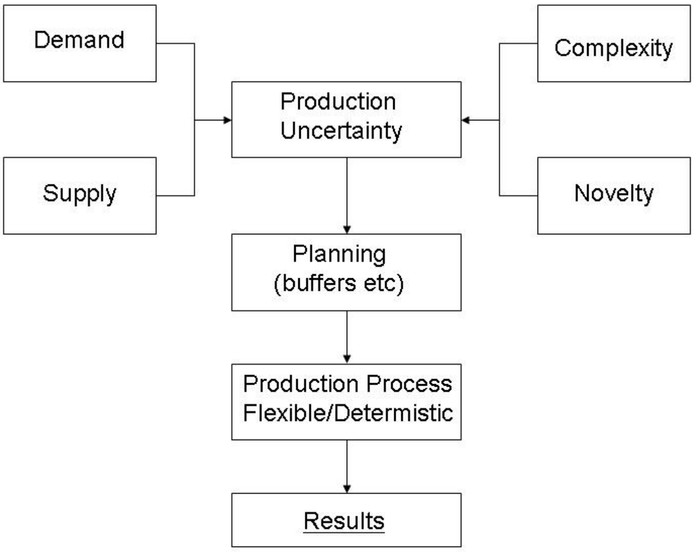


Figure 2: The concept model

2.3 Discrete Event Simulation (DES) in construction

Discrete Event Simulation (DES) has been proven to be an effective technique in predicting productivity and evaluating the behaviours of system (Banks, Carson, Nelson, & Nicol, 2000). It has been used in construction research field since the development of CYCLic Operations Network (CYCLONE) (Halpin & Riggs, 1992). The CYCLONE framework provided the foundation for construction simulation researchers to develop a number of construction simulation tools, such as UM CYCLONE (Ioannou, 1989), STROBOSCOPE (Martinez & Ioannou, 1994), ABC (Shi, 1999), Simphony.net (Hajjar & AbouRizk, 2002), RiSim (Chua & Li, 2002) and SDESA (Lu, 2003). Construction simulation is the science of developing and experimenting with computer-based modelling of construction systems to analyse their underlying behaviours (AbouRizk, 2010). It is a quantitative analysis methodology that the behaviours of system can be quantitatively evaluated and re-designed until it has achieved expected performance.

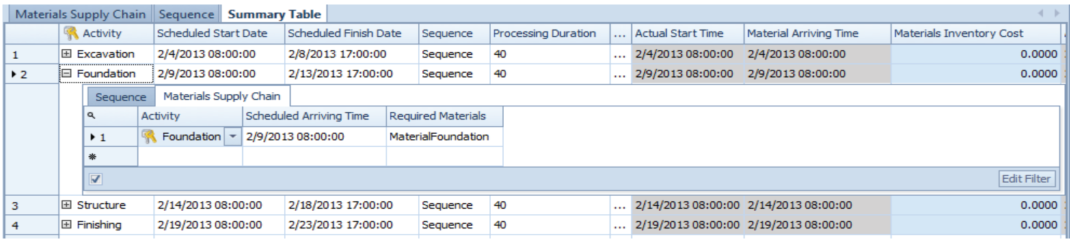
With the advancements in DES, key areas of developments include visual interactive modelling, simulation optimization, virtual reality, integration with other software and theory, etc. (Robinson, 2005). Vitascope (Kamat, 2003), which integrates DES with 3D visualization enable the modeller to visualize simulated processes in smooth, continuous, 3D virtual worlds. Such 3D visualization provides valuable and accurate insight into the DES model and facilitates simulation model verification and validation. For instance, a system of tower crane operations integrating 3D visualization with DES was built to effectively communicate and understand simulated construction operations, thus improve the credibility and accessibility of simulation model (Al-Hussein, Athar Niaz, Yu, & Kim, 2006). Additionally, DES is also integrated with other tools and theory in construction simulation. DES is integrated with project scheduling to feed optimal resource allocation into a project schedule, and executes stochastic simulation-based scheduling (Lee, Yi, Lim, & Arditi, 2010). The relationships and framework for integrating lean theory and simulation methodologies has also discussed in construction simulation (Agbulos, Mohamed, Al-Hussein, AbouRizk, & Roesch, 2006; Lu, Olofsson, & Segerstedt, 2010). In general, lean thinking provides a structured format in which processes can be re-designed (Halpin D. W. & Kueckmann, 2002), and DES offers a methodology to re-engineer the construction operation under lean theory (Al-Sudairi, 2007). The information from the simulation model can be used to compare the performance of the lean system to that of the existing system (Detty and Yingling, 2000). The integration of lean and DES provides convincing arguments for the adoption of lean (Fawaz A et al., 2007).

3. SIMULATION STUDY

3.1 Simulation input

In the study, the simulations have been carried out with Simio^{TM}, a simulation modelling framework based on intelligent objects which fully supports both discrete and continuous systems, along with large scale applications based on agent-based modelling (Sturrock and Pegden, 2011). The input information for scenario 1 is as shown in Fig 3, in which there are no variation on the production system.

In many cases, materials are stored dispersedly, in temporary warehouses or in open spaces everywhere on the construction site. It is both labor-intensive and error-prone to record all management data in a notebook on site and then transfer the information into an existing information system on computers after returning to the office. In addition, the comparison between the relevant bills and the actual quantities also needs to be conducted in the office after the execution of on-site processes, causing extra cost of problem handling. In order to solve the problems, QR code and mobile terminals are applied together, where the former is used to identify materials quickly and the latter is used to save the manual input of such information as the type of material or its code by scanning the QR code and to get necessary information on site from the information system.



	Activity	Scheduled Start Date	Scheduled Finish Date	Sequence	Processing Duration	...	Actual Start Time	Material Arriving Time	Materials Inventory Cost
1	⊞ Excavation	2/4/2013 08:00:00	2/8/2013 17:00:00	Sequence	40	...	2/4/2013 08:00:00	2/4/2013 08:00:00	0.0000
▸ 2	⊟ Foundation	2/9/2013 08:00:00	2/13/2013 17:00:00	Sequence	40	...	2/9/2013 08:00:00	2/9/2013 08:00:00	0.0000
3	⊞ Structure	2/14/2013 08:00:00	2/18/2013 17:00:00	Sequence	40	...	2/14/2013 08:00:00	2/14/2013 08:00:00	0.0000
4	⊞ Finishing	2/19/2013 08:00:00	2/23/2013 17:00:00	Sequence	40	...	2/19/2013 08:00:00	2/19/2013 08:00:00	0.0000

	Activity	Scheduled Arriving Time	Required Materials
▸ 1	Foundation	2/9/2013 08:00:00	MaterialFoundation
*			

Figure 3: Input information for the simulation model

The simulation model is as shown in Figure 4, in which the entities move through the links and nodes of the network as well as in and out of exaction, foundation, structure and finishing. The entity is intelligent as it reads information from the input table, and sends out the requests on resources, such as workers, machine A, machine B, machine C and machine D. The objects in the simulation model present different status in the running of model:

Idle: in this case, worker and machine incur working and machine waiting cost.
Allocated: The object’s capacity has been allocated and seized by entity.
Off-shift: The object’s capacity has a Value of '0' based on resource schedule.
Waiting for Material: The object is waiting for arriving of materials to execute the process.

The upper part of the simulation model is the materials supply chain which delivery the materials according to the delivery plan specified in the input table. There are two possible states: materials arriving time is ahead of the actual start time of activity, in this case, it incurs material inventory cost.

On the other hand, if materials arriving time is later than the actual start time of activity, it incurs working and machine waiting cost.

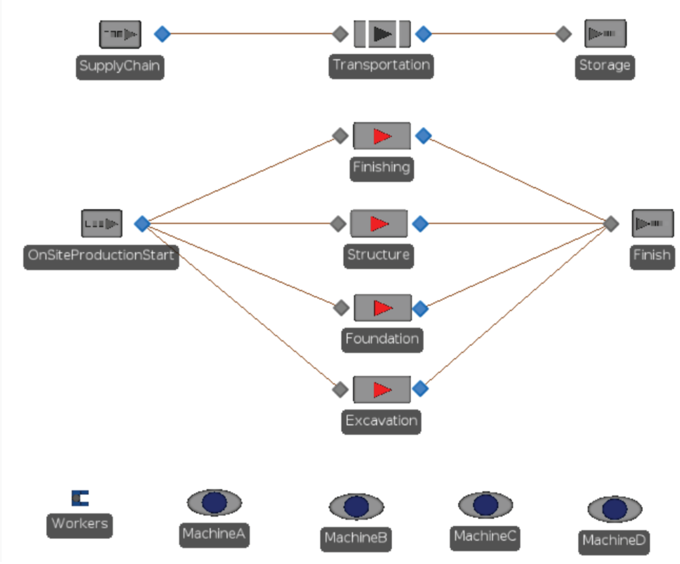


Figure 4: Simulation model

3.2 Simulation Output and Analysis

Scenario 1: 5 working days for each activity, no buffer in the planning.
Scenario 2: 5 working days for each activity, 4 hours buffer for each activity in the planning.
Scenario 3: 5 working days for each activity, 8 hours buffer for each activity in the planning.

For each scenario, there are two types' variations: materials arriving time deviation and processing time deviation. Each type has three level variations: low (L), medium (M) and high (H).

The effects of variation on three scenarios are compared in Fig1. The low materials arriving time deviation defines as Discrete distribution (-4, 0.35, 0, 0.6, 4, 1) hours, medium materials arriving time deviation defines as Discrete distribution (-1, 0.35, 0, 0.6, 1, 1) day and high materials arriving time deviation defines as Discrete distribution (-2, 0.35, 0, 0.6, 2, 1) day. The low processing time deviation defines as Triangular distribution (36,40,44) hour, medium processing time deviation defines as Triangular distribution (32,40,48) hour and high processing time deviation defines as Triangular distribution (28,40,52) hour. There are four combinations of variations for each scenario:

0&0: no materials arriving time deviation and no processing time deviation
L&L: low materials arriving time deviation and low processing time deviation.
M&M: medium materials arriving time deviation and medium processing time deviation.
H&H: high materials arriving time deviation and high processing time deviation.

As shown in Fig 5, under L&L environment, scenario 1 performs the best in the three scenarios. With the variation increased from L&L to M&M and H&H, scenario 2 and 3 present better cost performance than scenario 1. For L&L, scenario 3 with its large buffers is the worst alternative because of the buffer size is to large compared with the variation of the scenario. For M&M, scenario 1 with no buffers is the worst alternative because lack of buffers that can absorb the variation. For H&H, scenario 1 with no buffers is the worst while scenario 2 with medium size buffer is a better alternative compared to scenario 1. With buffers in a high variation environment the cost performance will be improved due to the fact that the buffers will lessen the impact of the variation, which is even more obvious when scenario 1 is compared with scenario 3 that has the largest buffer size.

In all scenarios, with the increasing of variation, the project duration is increased, as shown in Fig 6 (note that the duration of the project includes the on-shift and off-shift working hours). This observation is consistent with Parade game. However, scenario 2 and 3 need more time to deliver the project than scenario 1 under the same variation. But if the planning is considered, scenario 2 and scenario 3 have less deviation compared to the initial planning of the project's duration. Scenario 1 has the highest percentage deviation from the initial planning even when the L&L variation considered. This might result in financial penalties that might be higher for scenario 1 since it has the largest deviation from the initial schedule.

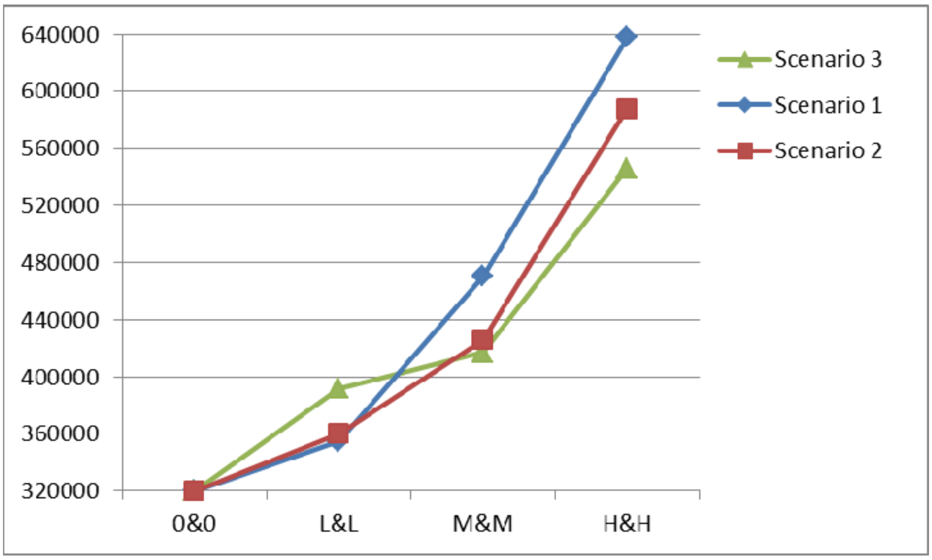


Figure 5: Total project cost (SEK)

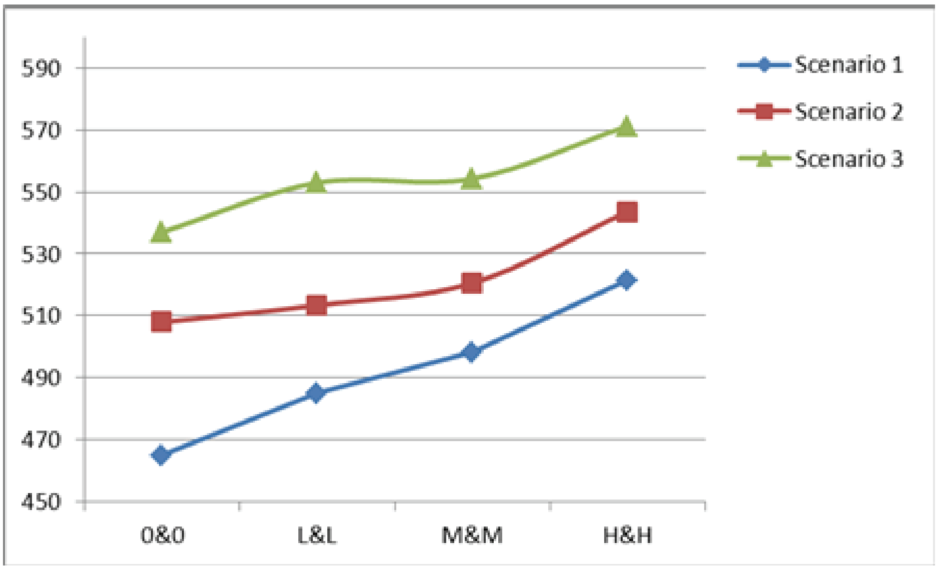


Figure 6: Project duration (Hours)

4. CONCLUSION AND FUTURE WORK

Construction projects do not operate in an isolated environment, thus they need to be synchronized with uncertain and variable environment they are facing, such as capacity of suppliers and productivity of workforce. Adjusting the operating strategy to operation environment seems to be more relevant than adapting lean or flexibility production strategy. The study presents an illustrative case study, only limited factors impacting the production system are considered. Future research will incorporate more complex scenario and adopt simulation-optimization to provide sensitivity analysis.

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