TOWARDS A NEW UNDERSTANDING OF THE CONSTRUCTION INDUSTRY AND THE NATURE OF ITS PRODUCTION

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Looking around, there is no doubt that the poor performance of today's construction industry is a global phenomenon. This leads to reflections on the nature of the industry itself and its project performance compared to the situation before World War II. Have the projects and or the industry changed for the worse? And if so, why? And how can it be changed back again – if getting back is desirable?

This paper looks at the industry and the projects from flow and complexity points of view and observes that the whole industry forms one very complex and dynamic network, whose nature and behaviour is poorly understood. It applies two basic rules to the complex network: the economic driver of service industries that demands optimization of resource utilisation, and the fundamental rule of queuing theory that relates waiting time and/or buffers to capacity utilisation rates. Taken together, these rules begin to provide an understanding of this network and its behaviour that offers a reasonable explanation for the industry's performance.

KEY WORDS

Complex networks; Construction management; Flow; Stalemate; Subcontractors; Variability.

INTRODUCTION

The Empire State Building was constructed in eleven months. Why can't you do this today? It took you fifty months to construct each of the World Trade Towers, which were approximately of the same size.

This question – or a similar one – is often asked of the construction industry in general with the undertone implication that management in construction is not as efficient as it should be or once was. But few – if any – seem to have a valid answer to the question. The usual outcome is that construction managers bow their heads and accept the critique. But is it really true that the construction industry is becoming increasingly worse in managing its processes? And if so, why is it that construction all over the world seems to attract the 'Dummies' to its management? The authors, who have spent more than forty and fifteen years respectively as professionals in the construction industry, do not believe this to be the case. Criticising construction is a very easy sport, not least for those standing outside the field and lacking a deep understanding of the nature of neither construction and construction management nor of craft production in general. The Latham (1994) and Egan (1998) reports are just two such critiques, and unfortunately their opinions are among the most widespread.

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But similar white papers may be found in almost any country. Denmark has several reports of the same kind (Erhvervsfremmmestyrelsen, 1993, Byggepolitisk Task Force, 2000, Dræby, 2000)[3] as does Australia (Building Our Future in Australia , CRC, 2006) just to mention some examples, and we are getting more white papers all the time on how we should bring our show back on the road.

The motivation behind this paper is that we may need to answer back. Not by simple arguments, but by explaining the true nature of the construction industry and its processes, and by doing so on a scientific basis. Based upon their background in practice and research, the authors believe that the work of the IGLC community has established, or is in the process of establishing, such a basis, and that in the end we may show that our critics may be as responsible as ourselves for our industry's poor performance.

This paper argues – as a hypothesis without any detailed analyses at this point in time – that the general understanding of the construction process within the industry and on the part of public administrators is too simple, as it sees the process from a transformation perspective only, entirely leaving out the important flow perspective. Also, the construction process is seen as a basically ordered system where order should be improved as much as possible and where unforeseen events unfortunately happen from time to time, as opposite to understanding construction as a complex and dynamic system where the complexity and its effects should be managed directly. Therefore, a new mental model is needed.

Koskela and Howell (2002) discuss this by demonstrating the weakness of present project management practice, and suggest a much broader management perspective. Bertelsen et al. (2006, 2007) describe and discuss the simplistic mental model underlying most management tools used in practice (figure 1), which is based on the critical path method (CPM). Here, we tie this hypothesis into some of the present lines of thinking in Lean Construction: These include TFV theory (Koskela, 2000), flow and queuing, (Ballard 1999), construction physics (Bertelsen et al, 2006, 2007), and construction as a complex system (Bertelsen, 2003a and b). We argue that these theories, along with perception of construction as a service and a deeper understanding of the economic motivations guiding contracting practice (Sacks 2004, Sacks and Harel 2006), may hold the keys to explaining the construction industry's behaviour and performance. The paper sets out with a brief introduction to Construction Physics. It then proceeds with a discussion of some of the principles at play in project management as well as in trade contractors' business management. Two very different and conflicting sets of objectives are demonstrated as a possible underlying reason for the industry's poor performance.

In conclusion, three issues for research are suggested: understanding the Empire State case in depth in the light of Lean Construction; examining the relationships of different agencies to the construction industry; and looking more closely into complexity and the way our management tools work – or rather do not work – in complex settings.

[3] Bertelsen and Nielsen (1999) present a more comprehensive overview

CONSTRUCTION PHYSISCS

BACKGROUND

'Construction Physics' was first suggested by Bertelsen et al (2006) as a flow based understanding of the construction process and its management. There were several sources which inspired this thinking. Among them were firstly Koskela's seminal work on a Construction Theory and not least the flow aspect of this theory (Koskela 2000; Koskela and Kagioglou 2005 and 2006); secondly Hopp and Spearman's work on factory physics; and thirdly, Goldratt's ideas on flow and the Critical Chain (Goldratt, 1997) along with Ballard's work on flow management (Ballard 1999, 2000). The work conducted within the International Group for Lean Construction in general since its inception in 1993 was also part of the inspiration. Finally, the first author's work in practice using the flow understanding as a basis for new management principles played a role (Bertelsen and Koskela, 2002). Behind all this sits the important work by Shigeo Shingo (1988) which is probably the root of all the new understandings of the concept of (mass) production.

The present state of this work is presented in Koskela et al (2007); Rooke et al (2007) and Bertelsen et al (2007), all contributions to the proceedings of the IGLC 15 conference.

A SIMPLE ORGANISATIONAL MODEL OF CONSTRUCTION

Project management commonly sees construction as the isolated production of an independent one-of-a-kind project by a temporary production systems established for the single case.

However, in practice there exist at any given time a number of such projects being undertaken more or less in parallel (Sacks 2004). The construction industry must therefore be seen as an industry conducting an eternal chain of interwoven projects as any participant is involved in more than one project at the same time. The aspect distinguishing the construction industry from mass or customised production is thus not the individuality of the product per se but the fact that the huge variation in project outcomes makes it necessary for the industry to set up a new production process – and therefore a new production system – for each project, and then to dismantle the same production system while the project is still in progress.

The assembly and dismantling of the production system is manifested by the widespread use of sub contractors[4], who arrive at the site and leave it in overlapping succession. As these contractors are independent enterprises or agents, we have a system where any project shares its production system components – the subcontractors – with all of the other projects in which they are involved, and this highly influences the flow in the project process.

This organisation of the production system, where almost nobody besides material suppliers has a product but offers their services only, is highly flexible and therefore supports the desired individuality of the outcome.[5] But on the other hand, it also

[4] These are often trade contractors, but more and more being organised just as sub contractors at several levels.

[5] This is again opposite to most manufacturing where the product design often includes products from other suppliers, which leads to a more stable production system. In the selection of suppliers,

forces all agents to compete on price alone instead of price and quality, as is the practice in most manufacturing industries. The effect of this will be discussed later.

FLOW IN THE CONSTRUCTION PROCESS

Koskela (2000) establishes a model for the understanding of the construction process. This Transformation-Flow-Value (TFV) model offers a lot of inspiration for the understanding of the nature of the aspects of the construction project, not least the flow. While Value – at least for the time being – is an issue being discussed in different settings (Green 1996, Emmit et al 2004) and may thus be put aside in the present discussion, the aspects of Flow and Transformation still remain to be discussed in detail.[6]

In this paper we start from the flow perspective. Bertelsen et al (2007) challenge the classical mental model which sees construction as a chain of tasks as expressed by CPM, PERT or similar systems, which often also expresses the project management point of view where performing the tasks is the primary issue (as shown in figure 1). Instead, Bertelsen et al. (2007) suggest that the construction process should rather be understood as a true process – like a fire or a chemical process: as a phenomenon producing the desired outcome being fed by a number of flows (see figure 2). Of all the flows only one is the critical flow at any given time, and it is that flow that determines the intensity, or rate, of the overall process.

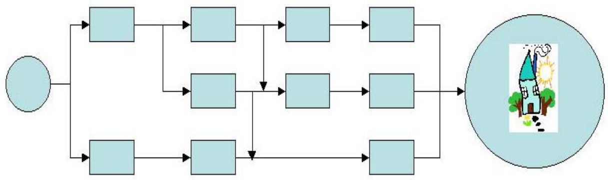

Figure 1: The CPM Mental Model

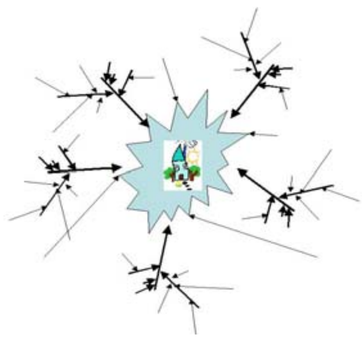

Figure 2: The Process Mental Model

This leads to two important observations: The critical flow is not necessarily the flow of previous work as such but the flow of one of the prerequisites feeding the process; and the important issue for the project management is therefore not as much to manage the process itself but any of the feeding flows that may be critical. (Bertelsen et al, 2007).

However, the really interesting issue here is that the flow of prerequisites – or the operations, to use Shingo's term – ties any project into any other ongoing project in the region by the shared production system. The new process model presented in figure 2 is thus far too simple, as any project is part of a global, unknown network, which highly influences a project's performance (figure 3).

quality – along with other parameters – are set in relation to price instead of just costs as is done in construction procurement where it is assumed that any carpenter is just as good as the next.

[6] The above three contributions to IGLC 15 do that from different perspectives but a complete and stable model has not been reached at this stage.

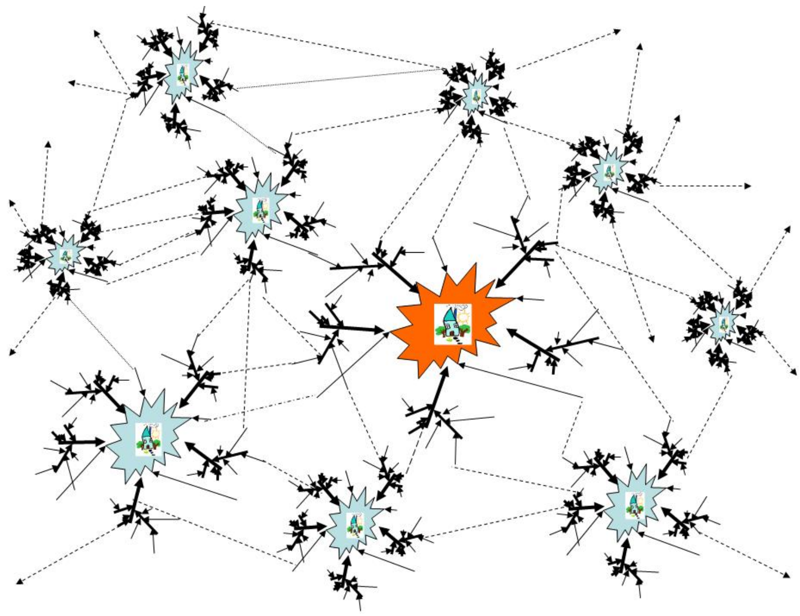

Figure 3: The Real World

It is this complex flow situation and the management conflicts it imposes that is the basis for an explanation of the often very poor performance of the construction industry.

MANAGEMENT IN CONSTRUCTION

Management in the construction industry is most often seen as either management of projects or as management of companies. However, when understood from the above flow model, these two kinds of management operate simultaneously and will most often be in conflict.

MANAGING PROJECTS

The aim of the project management is to deliver the project in the desired quality on budget and time with an adequate profit, which is the contracted price minus the total cots.

These criteria for success are most often met by procurement of operations – work, materials, equipment etc – through competitive bidding in order to secure the lowest prices and then after contract awards, keeping a keen eye on claims from the subcontractors. The time criteria are met through a project schedule managed as tightly as possible, and often associated with milestone penalties. Quality is met by supervision along with quality assurance systems.

MANAGING OPERATIONS

The operations are studied much less in construction than are the flows of work they are feeding. However, any operation may be seen as a flow as well – shorter or longer depending on its nature. For example, in the case of crews, the flow includes getting them released from other projects, bringing them to the site, feeding them instructions and supplying them with equipment and materials, etc. (Shingo, 1989; Rooke et al, 2007; Bertelsen et al, 2007). These flows may easily tie in with other flows. The crew may not be able to be released from its previous job; the flow of information is similarly constrained by the designers having other tasks, and therefore delaying the flow of drawings; there may be lead time on equipment or materials, etc. From the point of view of any individual project, as the number of uncertainties in all of the flows grows, so grows the variability of the execution of the whole project.

THE NATURE OF FLOWS IN CONSTRUCTION

Considering the process model shown in Figure 2 as a starting point, we recognise that there are a multitude of flows feeding any single step (activity) in a project and that all of these have variability. The fact that the flows are not independent and not static, e.g. the flow of information feeds the flow of materials, etc., makes the system complex and thus nearly impossible to comprehend or even map completely.

In this situation the project management tries to reduce the variability in the flows feeding its own project process, which often occurs by the use of buffering. Buffers of workers, equipment, materials and information are established in order to make sure the progress is as secure as possible. In this thinking the project management does not speculate very much on the management implications of buffers for the subcontractors providing the operations – and not at all on the effects of this strategy on other, parallel projects. However, the outcome is a tremendous amount of work in progress, often without having the work packages sound when needed anyway.[7]

The subcontractors, on the other hand, have to perform their business by managing the flow of operations, but within multiple projects. This takes their attention away from any particular project – '*I have a business to look after here, and as long as we fulfil the contract, everything must be OK?*' But indeed, that is not the case. This thinking leads the subcontractor to optimize his or her own operations across the projects the company is involved in, which repeatedly creates bottlenecks for other subcontractors' operations and thus for all the projects in progress.

A LOOK AT THE GUIDING RULES

There may be several principles guiding the behaviour of this system (Sacks and Harel 2006) but two seem to be central in this context.

The First principle: Protect your earnings

This simple business objective leads to the recognition that in any service based enterprise the ground rule for financial success is to keep the product of the markup ratio (F = reimbursed price per hour / labour cost per hour) multiplied by the exploitation ratio (R = hours actually billed / hours available) above a certain break even level – the Target, T.[8] [9] [10]

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[7] A 'sound' activity is a work package with all its prerequisites ready.

[8] If the paid wage is $20 and the reimbursed price is $40 then F = 2. If there are 1,000 hours available in a month and 750 are sold, R = 0.75 and the outcome is thus 1.50. Whether this is good or bad is dependent on the nature of the industry and is not the issue of this paper, but the principle applies for any service-providing business.

[9] Protect your earnings applies of course to any industry in a commercial market. However, quite a few industries obtain their earnings from many other sources, such as trading products, patents (Galaxy, Novo), other intellectual property (Harley Davidson, Microsoft, Google), brand name (Coca Cola, Nike), or just an original concept (Starbuck).

Thus:

$$F \times R \geq T$$

Procuring of contracts most often takes place at lowest price. But what is procured is basically craft, which means the capacity of labour. Let us assume that we have a labour market where the hourly wage is the same all around[11], then the trade contractor has only one primary route to protect his business – that of increasing its capacity utilisation.

Even though there seem to be four parameters to control, two of them are often not in play in the project's short perspective. Within *F*, the reimbursed price cannot be changed because the contract unit prices are already set; only the labour cost can be manipulated, and then only by reducing middle management overhead costs. Within *R*, any labour directly employed has a fixed number of hours for which the contractor must pay.

As long as the operation is understood as craft, any craftsman should be able to undertake the job and basically he is supposed to be able to do so at the same basic cost. Therefore, the primary parameter for protecting a subcontractor's earning is thus increasing *R* by increasing the number of hours worked – and this is indeed the one most often taken. Higher utilisation of the work force sounds like an increase in productivity as it seems like reducing waste time, and it may indeed look so from the subcontractors' point of view. But it is not necessarily at all an increase of the project performance, and may easily not be that either seen from the subcontractor's point of view in a broader perspective. Why? Because of the second principle.

The Second Principle: Increased load means more waiting

The simple answer is queuing theory. This theory explains waiting in flow systems, e.g. on rush hour freeways. This theory is 100 years old and it explains nicely the problem we are dealing with here. If we load a flow system with an embedded variability over a 'critical' combination of load and variability, the average waiting time will increase steeply, and when the system is fully loaded, the waiting time will approach infinity.

In construction practice we tend to change waiting time to buffers, but the key issue is still the same. In the case of trade contractors, they can generate buffers of work in progress by not providing the resources to the project they should have in accordance with the schedule. (El-Mashaleh, 2001; Sacks 2004; Sacks and Harel 2006a; Harel and Sacks 2006)

[10] The first author's experience with this stems from a long carrier as partner in a consulting engineering firm, where the target was above 1.7 some 25 years ago and has now moved down below 1.4 due to fierce competition.

[11] Or at least that the wage is constant for the same piece of work.

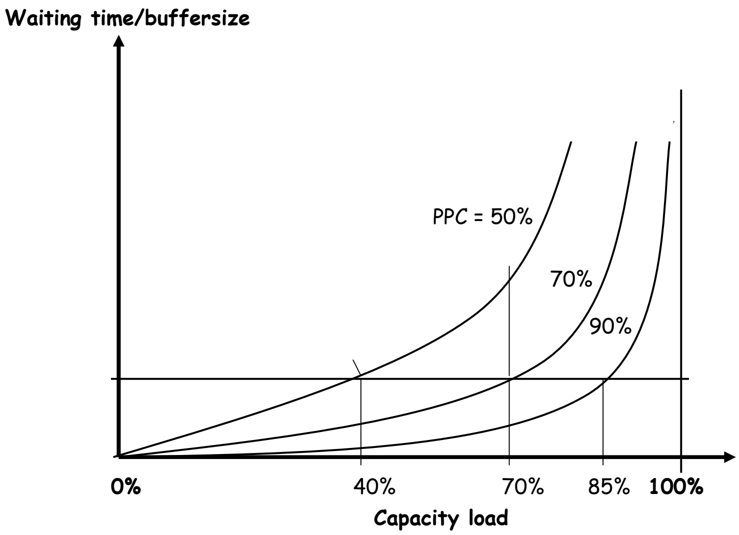

Figure 4: Waiting time/buffer-size versus capacity load (Source: Lecture notes from Professor Glenn Ballard's courses on Lean Construction) [12]

Figure 4 shows this dependency between waiting time, as expressed in queuing theory, and system load. The curves express the nature of the system. The higher the capacity load, the more waiting must be expected. The three different curves express the impact of variability on the flow (here expressed by PPC as a simple measure of predictability). As shown by the vertical bars, reducing the variability inherent in a system allows one to increase the capacity utilisation with a given accepted waiting time and/or buffer size. Alternatively, the waiting time and/or buffer needed could be reduced for the same original capacity utilisation.

Indeed, there is a strong relationship between subcontractors' perceptions of plan reliability/variability in a project and their behaviour in providing resources. Sacks and Harel (2006b) explained, using a game theory model, how increasing plan reliability can influence the resource allocation behaviours of project managers and subcontractors. Improved stability leads to stable equilibriums of behaviour that engender cooperative behaviour. Conversely, low PPC leads to stable 'lose-lose' equilibriums where subcontractors achieve highest expected utility by providing fewer resources than demanded.

Tie in

These two simple rules may have a tremendous effect on construction performance. The first principle explains why the trade contractors tend to overload their production systems. Even worse, they tend to overload their middle management, because the cost of management is most often seen as an overhead. Unfortunately, in so doing, middle management is turned into a bottleneck (Kim and Jong, 2006), with strong detrimental effects on the variability within the system.

The second principle shows how this natural behaviour causes increased waiting time and thus increased variability and waste as well, which again influences the trade contractors' behaviour, and we have a vicious circle in play. Looking at the whole

[12] The figure is not exact but it illustrates the phenomenon.

construction landscape, one finds a network with a very large number of such circles in play at any given time.

CONCLUSION

In so far as the whole construction industry in any given market, and all of its ongoing production, should be seen as one integrated, dynamic complex system, no individual person or organization can fully understand or predict how a project may be affected and develop from any given moment forward in time. As such, they can not manage the situation prescriptively and completely. What construction managers tend to do in general in the face of change is stick to their guns – or rather their schedules and contracts – and increase contract penalties while leaving the subcontractors to face the real production issues. Reaching this understanding, the next question is how to achieve better performance.

OPENING UP THE STALEMATE

It seems that the normal accepted contracting practice may be a reason for the stalemate situation. As long as the general contractor does not carry the real costs associated with the production system, trade contractors are pushed towards minimising their costs and risks across their projects. To change this calls for a new project management understanding with a focus on the flows feeding the project process. If the project management carried the liability for the production system's waste (i.e. downtime of crews, equipment etc.) either permanently or for the duration of a project, its incentive to establish a reliable and stable flow would be much higher. At the same time the couplings to other projects would be reduced.

One way of achieving this is to apportion production system related risk in accordance with the ability to control the risk. Some contracts create a 'safety net' for subcontractors by allowing them to make claims for situations in which work does not become available as planned, but this is a retro-active measure. Apportioning risk should not be left to subcontractors' claims for compensation, but built in *a priori* as an inherent part of each price, by splitting unit prices into two components – one to be paid for product, and the other for resource capacity supplied, whether utilized or not.

FUTURE STUDIES

The paper opens several issues to be studied.

The first is the opening statement: How was the Empire State Building erected in 13 months? One of the root causes may have been that the economic crisis of the Great Depression of the 1930's may have freed up resources sufficiently to allow the project to operate in a stable resource allocation environment, relatively independent of the vicious circles described above; but the case should be studied more deeply in the light of our lean construction theories.

The second issue is the validity of our mental models of the construction industry and the relationships and processes with the agencies – customers, authorities, government bureaucracy, trade unions, trade associations etc – that surround it. It is these models that set the framework and mindset in which we have to operate.

The third issue is to look more carefully at the project management tools we are using. A brief investigation indicates that the model underlying them is a simplistic transformation one in most cases. Flow – and thus connection to other projects and their possible impacts – is seldom considered.

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