APPLICATION OF LEAN CONSTRUCTION PRINCIPLES IN PRODUCT DEVELOPMENT PROCESS MODELLING

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ABSTRACT

Several studies have pointed out the importance of the product development process in terms of improving the performance of the construction industry. Product development management is difficult because it involves thousands of decisions with numerous interdependencies, under a highly uncertain environment. This has led to the development of a number of initiatives in research and practice aiming at improving the product development process. Process models have been devised, which are useful in understanding how the process develops and suggesting ways of controlling it. Unfortunately, the implementation of these models and methodologies in practice is very slow and until now there are no major improvements resulting from these solutions. One of the reasons for this is the lack of understanding that any new product development process needs to be managed as part of a change programme within companies.

The aim of this article is to present an analysis on the application of lean construction principles to product development modelling in real life settings. This discussion is based on empirical data collected in one case study that focused on the importance of integrating any new product development process within a change management framework. The case study involved the assessment of the development and implementation of a product development process model within a construction company from different perspectives, including the utilisation of information technology.

KEY WORDS

Product development, process modelling, lean principles

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INTRODUCTION

Product development has been an explicit topic of study primarily within industrial or manufacture engineering, with occasional forays into construction (e.g. Koskela, 2000). Most studies examine the management of new products, as well as the project processes used for developing and an idea or need into a finished product, with the associated support and services (Kagioglou, 1999).

It has been well acknowledged that the product development process (PDP) is important to most companies in terms of maintaining and improving their competitiveness (Clark and Fujimoto, 1991; Jensen and Harmsen, 2001). Product development, however, is a complex, unpredictable and variable process (Reinertsen, 1997), involving a number of decisions, which are often based on partial information. Due to its importance, a number of researchers have undertaken studies on effective and efficient product development projects in various industries.

Empirical research on product development has focused mainly on managerial approaches and performance measures, and different improvement concepts, principles and methodologies have been proposed. Attention has been placed in integrating and optimising PDP within the development of managerial approaches such as Just-In-Time (JIT); Total Quality Management (TQM); Business Process Re-engineering (BPR); Concurrent Engineering (CE); and Lean Production.

Different but yet interrelated improvement principles and concepts can be found within each of these approaches. Furthermore, all approaches have focused in a lesser or greater extent to understand and model the work and information flows (Austin et al., 1996) within product development. Regrettably, despite the research effort in devising models for product development, it seems that only a few companies have implemented those models successfully.

Most of the ideas described in the improvement approaches aforementioned are not new, but they are being integrated into a model of emergent 'good practice', described in the lean improvement principles and concepts. Those improvement concepts have been presented within the Transformation, Flow and Value Generation (TFV) theory, proposed by Koskela (2000). Table 1 presents a set of lean principles, and proposed ways to apply them.

Through the analysis of the literature on product development, it can be argued that recommendations for better performance are well articulated, and this is especially true when observing the fact that most studies point to fairly consistent features for process models. However, there is less systematic understanding concerning the application of process models in practice. Furthermore, the potential benefits of applying lean concepts not only within process models, but also during the modelling exercise, have not yet been addressed. The aim of this paper is to address the application of lean principles in process modelling based on the analysis of one case study. Also, the paper describes the main barriers identified in the implementation of process models, addressing the importance of integrating the new product development model within a change management framework.

Table 1: Lean construction principles, adapted from Koskela (2000)

	Principle	Proposed ways of application
t	*Hierarchical decomposition; control of decomposed activities*	Work Breakdown Structure; Critical path method; Organisational responsibility chart
flow	*Reduce share of non value adding activities* (waste); *Shortening of design times*; *Reduction of uncertainty*	Reduce waiting, transferring info., inspection, and rework due to errors, omissions,…
		Reduce waiting for info. by decomposing design activities (e.g. design structure matrix - DSM), planning and transferring information is small batches
		Reduce unnecessary work by clearly specifying the suppliers work in relation to its internal client
	Reduce rework (caused by variability and uncertainty)	clearly define int. & ext. client needs; carefully define project scope, reducing changes; consider all life cycle simultaneously to reduce iterations; order design activities; use prototyping to reduce uncertainty; freeze design decisions
	Reduce *effort to transfer information*:	teamwork, informal communications, empowerment of the team, rearranging order of design tasks
	Use technological solutions	for collaboration, databases, extranets,…
value	*Elimination of value loss* (gap between achieved and best possible value*)*	Rigorous requirements analysis; systematized management of flow-down requirements;
	Remove *obstacles to creativity*	insufficient time, evaluation pressures, reluctance to change,…
	Improve requirements capture and avoid loss of requirements	to avoid missing requirements and to identify the requirements throughout the process, through Quality Function Deployment or value engineering, for instance
	Increase *optimisation*	teamwork, commonly held goals, complete visibility; mutual consideration of all decisions, collaboration to resolve conflicts and equality between discipline specialists

PDP MODELLING AND CHANGE MANAGEMENT

Modelling the product development process and decomposing it into workflow activities is necessary to organise the work of the product development team and direct its efforts (Prasad et al., 1997). Smith and Morrow (1999) point out that developing models of product development is useful for both learning about this process and suggesting ways to control it. The goal of modelling the PDP is the creation of one (or more) predictive model that improves managerial decision-making (Smith and Morrow, 1999) and optimises process predictability. As a result, much effort has been spent in devising models for the PDP, and the scope, objective, and conceptual basis of those models vary widely.

Two types of process maps can be found in the literature, i.e. true maps of what happens ('as-is' models), and protocols of what ought to happen ('to-be' models). 'As-is' models simply try to depict the process, some focusing on the PDP as a whole, while others describe parts of the process. 'To-be' models attempt to provide protocols and tools to support improved product development management. Usually, they are supposed to be used as templates containing a generic model and a set of tools. Such models can be used as checklists of the key steps in a development activity, and also as a way to improve the process by introducing good practices, such as the stage-gate approach (Cooper, 1994).

A number of different approaches to process mapping can be found. IDEF0 is a modelling technique developed in Information Technology (IT) systems which focuses on

defining information flows, usually in a very fine level of detail. The very detailed level of the information represented makes it very difficult for companies to understand and manage those process models (Kagioglou et al., 1998). However, IDEF0 is very useful for defining IT systems.

Another approach adopted is the business approach, which focuses upon flows of information within an organisation and between different actors, but in a broader perspective. In this approach, typically a two dimensional map is developed. Usually those maps describe a dimension of sequence, of stages in one axis, and actors or functions responsible for each sub-process on the other axis. Also, sub-processes are usually described through different levels of detail.

In the construction industry, there has been considerable interest in developing generic process models (e.g. Kagioglou et al., 1998). The insight that construction is a process is not new, but a wider and more integrative process perspective is gaining ground. Process mapping is becoming widely recognised and its use in construction is growing rapidly (Winch and Carr, 2001). This has been happening because of the recognition in both industry and academia that even though the supply constantly changes and relationships are dynamic in a project environment, the underlying generic processes remains broadly consistent (Mill and Ion, 1994; Kagioglou, 1999).

ORGANISATIONAL CHANGE AND BARRIERS TO IMPLEMENTATION

Organisational change is approached in this research as the conceptual lenses through which the implementation process could be understood and made more effective. BPR is an approach to organisational change that focuses on process development and implementation. Hammer & Champy (1995) describe it as the fundamental rethinking and radical redesign of business processes to bring about improvements in measures of performance, such as cost, quality, service and speed. The underlying principle within its philosophy is that organisations should structure themselves around processes, rather than functions.

According to Stickland (1998), BPR is a planned nomothetic organisational change methodology. A nomothetic methodology is based on the identification of similarities and patterns within a system; once they are identified, they become the basis for generating change options and alternatives, from which a 'best fit' decision can be made (Stickland, 1998). As a result, it is believed that there is an optimal or correct change action to pursue.

Therefore, a number of prescriptive models have been devised describing the main steps for successful implementation of new or redesigned processes. Usually those steps go through a PDCA (plan, do, check, act) cycle, which includes: (a) planning the initiative; (b) understanding and redesigning processes; (c) implementing and; (d) evaluating the process (see, for instance, Yung, 1997; Zinser, 1998; Vakola, et al., 2000; Tissari and Heikkila, 2001; Alarcon and Seguel, 2002).

Even in the cases where such implementation steps were applied, a number of problems have been described in terms of implementation. Hammer and Champy (1993) stated that implementation of new or redesigned processes fail in between 50 to 70% in BPR initiatives. One of the reasons commonly described for that relates to the narrow focus of reengineering, with inadequate attention to human issues (Marjanovic, 2000; Cao et al., 2001), which leads to major resistance to change. The failure to integrate the approach throughout the

organisation frequently results in improvements in individual processes but fails to produce organisation wide results (Cao et al., 2001).

Other barriers to the successful implementation of process models have been described in the literature. Karlsson and Ahlstrom (1996) identified barriers to implementing lean product development by observing a company going through this transition. Winch and Carr (2001) described problems on process mapping with one retail client. Cooper (1999) put forward a list of eight critical success factors and seven blockers in process implementation. The author stated that as a result of the blockers, the success factors may become 'invisible', and the expected improvements cannot be achieved. Furthermore, Szulanski (1999) described factors that affect the opportunity to transfer knowledge. Considering implementation as the transfer and application of the knowledge embedded in a model, these factors can be approached as implementation barriers. The main barriers, adapted from the aforementioned authors, are described in Table 2.

Table 2: Implementation barriers identified in the literature

Barriers	Karlsson & Ahlstrom (1996)	Winch & Carr (2001)	Szulanski (1999)	Cooper (1999)
Difficulties in achieving cross-functional integration and the early involvement of suppliers	x			
Co-ordination effort is time consuming	x			
There is high variability in the processes even for similar projects		x		
Design freeze is difficult to achieve due to client initiated changes; those were often beyond the ability of the client to control directly		x		
The strategic importance of programme in the project mission encouraged trade-offs that generated cost increases				
People underestimate what is involved in key tasks				x
Faulty or misapplied new product development process				x
People believe that they already know the answers				x
Lack of discipline: no leadership				x
Big hurry and cut corners				x
Too many projects and not enough resources				x
The transfer of the model content require adaptation			x	
Degree of conjecture on the utility of the process model			x	
Developers or users lack motivation			x	
Developers of the model not perceived as reliable			x	
Ability of the users to identify, value and apply the new model			x	
Barren organisational context			x	
Ease of communication between model's developers and users				

It can be argued that chances of implementation success would improve if management paid proper attention to the implementation barriers previously described. Therefore, gains could be achieved by integrating the management of a new product development process as part of a change programme within companies.

RESEARCH METHOD

The hermeneutic learning spiral (Odman 1995) is the research philosophy applied in this study, in which a pre-understanding and understanding of research issues are developed through cycles. To address the research questions, the control and temporal dimensions of the research, a case study strategy was adopted.

One exploratory and explanatory case study was conduced to gather information on process model development and implementation. Different research techniques have been used, which included: (a) semi-structured interviews; (b) direct observations; and (c) content analysis. The selection of the company to involved in the study (Company A) was mainly due to the fact that, at the beginning of the case study period, the company was developing a product development process model, which was soon to be implemented in a pilot study, and then ramp-out to manage all company's projects.

A protocol was used to support the case study development. Six interviews have been transcribed, and reports on a number of meetings that happened over a period of eight months were developed. Detailed reports describing issues on process modelling and implementation were developed based on the analysis of the transcriptions, company documentation and observation of meetings. Data analysis focused on the identification of lean construction principles embedded into process modelling. Also, the barriers on the application of the resultant process model in practice were identified.

CASE STUDY FINDINGS

Company A is a major civil engineering contractor in the UK, and its primary markets include public health, road, rail, energy and infrastructure projects. An improvement initiative was being developed by the time the case study was conducted. Implementing Best Practice (IBP) aimed at improving the performance of all company's projects, and to achieve consistency throughout project processes. It involved a comprehensive development of both company and project knowledge through a high-level process model, together with a review and development of the IT infrastructure necessary to support business processes.

The company invested in this programme as a result from a change in the company's business model, in which an increased number of design and build projects were identified, as well as the need to adapt to market changes and to access external IT resources. Internal and external evidence of performance problems were also the catalyst for the improvement need. The realisation of delays in project's delivery and losses from unsuccessful projects as well as internal audits further confirmed the need for improvement.

AIMS OF THE MODEL AND REASONS FOR IMPLEMENTATION

The aim of developing a process model in the company was to introduce lean concepts by 'a system that could ensure proactive control of all aspects of the PDP that delivers compliance and enables construction to be achieved within specific cost, time & quality limits'. Their main objectives were to (a) avoid jobs that turn out as losses; (b) define a minimum standard for all projects, improving performance; (c) achieve a better design management; and (d) improve risk management. Reduction of costs and time, and improvement of quality overall are the aims of applying lean principles.

PEOPLE INVOLVED

Different people from diverse managerial levels were involved in IBP. Concerning the process model development, three main actors were involved: (a) the improvement initiative manager, responsible for the model analysis; (b) a senior design manager, responsible for designing the process model; (c) a design manager, who was responsible for the pilot implementation of the model, and got partially involved in its analysis.

CHANGE LEVEL PROPOSED AND CHANGE PROCESS

The changes proposed within IBP focused on introducing a new process throughout the whole organisation. Change was to be introduced structurally in the company through the establishment of the new communication systems (company portal), as well as through the new workflows described in the model. It was also to be introduced by influencing peoples' behaviour through changing work tasks, specifically by redesigning the role of design managers and coordinators. The company's change process is described in table 3. It is similar to the PDCA type of models proposed in the literature (see section 2).

Table 3: Change process in company A

Planning the initiative	× Identification of the need to change processes and IT systems; × Strategy definition: formation of a team, identification of the processes to be redesigned, and data collection on processes;
Understanding and redesigning processes	× Initial process development (through consultancy) × Redesign of the process (internally) × IT systems development
Implementing	× Pilot implementation – control and evaluation of the process model (unsuccessful) × Ramp up of the IT systems
Evaluation	× Which was not done

The main problems identified by the researcher and discussed within the company in relation to the proposed change process, prior to the pilot implementation of the model, were:

- There was no clear implementation strategy, teams or training strategy defined;
- The improvement targets of IPB were too generic and therefore not measurable; also, there were no measures included in the process model;
- Problems in the preliminary versions of the model were identified in an *ad-hoc* manner, and specific performance gaps have not been described;
- Many of the changes included in the process redesign were due to IT needs, while the aim was to adjust IT to the process needs.
- The need of acceptance of the model from its future users was not considered; also, the company had ten design managers, from which only one was partially involved with the modelling exercise;

MODELLING METHODOLOGY APPLIED

The high-level generic process was initially developed through a consultancy work. This model was part of the quality management documentation of the company for more than two years, but it has never been properly implemented due to: (a) lack on a pre-determined implementation programme; (b) the initial model was not a compulsory document; (c) there was no consensus regarding the model structure and contents; and (d) there was a lack of top management support for its implementation. Therefore, the initial model was re-designed as part of the improvement initiative. Although this model was never tested, it was used as a preliminary source to generate the new process model. The RIBA plan of work (1980) has also been used as an information source to devise the new model.

The process model was developed through steps, which included:

1. **Definition**: establishment of the process model aims and who would devise it;
2. **Revision of existing documentation:** included the analysis of the initial model and the search for other information sources.
3. **Draft development**: based on that information, a linear flow chart describing the main PDP management activities was devised.
4. **Definition of the structure and form of presentation:** involved the establishment of the need for a standard format to represent all processes within the firm, as well as a standard to present them in the company portal (navigation page in the intranet).
5. **Process map production**: later versions of the process map were devised through an iterative process (see Figure 1) including loops of development and analysis. The feedback was provided in an unstructured form, i.e. based only on the perceptions of the programme manager, which was not experienced in managing the PDP. The development of the process map took ten months and was described as laborious.
6. **Development of documentation:** this included guidance notes, tools and checklists. The tools development occurred in parallel with the process map production.
7. **Skills, training and communication**: a great focus was put on the definition of the design manager skills. The need to train people on the model characteristics was determined from the beginning of IBP, but no action followed this decision.

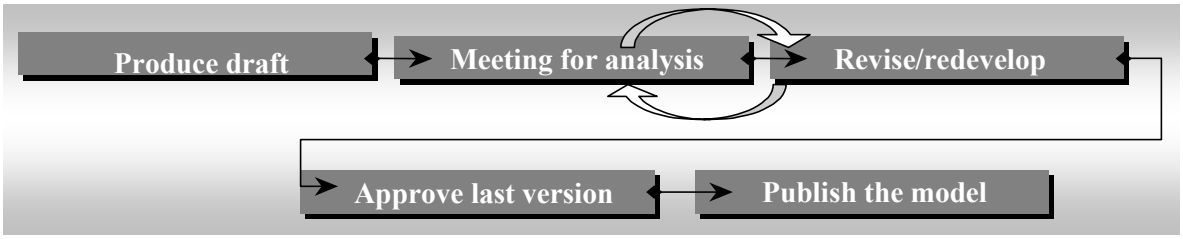

Figure 1: Model development loops

The model analysed is a 'to-be' model, presenting on its higher level the main process stages (i.e. get opportunity; work up BID; win and start up; do work; handover and close; and review). Those stages are then further detailed into: (a) preparing to design; (b) managing design; (c) mobilisation, production information and inspection of construction works, and (d) handover and close. Each of these stages are detailed through flowcharts that present inputs, process (i.e. flow of the activities contained in the specific stage), outputs and customers. For some of the activities described in the flowcharts, there are detailed procedures, tools (e.g. spreadsheets), or guidance notes.

LEAN PRINCIPLES IN THE MODELLING EXERCISE:

Lean principles were applied to introduce improvements in the process model. Those principles could also be applied to the modelling exercise, in order to help organising and introducing improvements in this activity. The lean principles identified in the modelling exercise are described as follows:

- **Control of activities - reduction of the model development time**: control was based on the revisions of the different versions of the model. Since there was no detailed plan for the model development, and no measures for the attainment of objectives, the whole process extended the predicted period for its realisation.
- **Reduce the effort to transfer information**: informal communications through telephone and e-mails happened throughout the model development. Nonetheless, it could be observed that many problems happened due to lack of knowledge of the overall model by the responsible for the improvement initiative.
- **Reduction of rework**: apart from the normal loops due to definition of the model content, a number of loops happened during the model development due to rework. This rework happened due to different reasons, mainly: (a) the lack of a definition of the IT framework in which the model was to be presented from the beginning of the modelling activity; therefore, the model needed to be re-designed completely after its first draft was ready; (b) lack of criteria to evaluate the model content; it was common for the programme manager to introduce changes to issues that have already been analysed and agreed; (c) lack of teamwork; the responsible for the model development needed to include in the model activities from different processes, and he did not had enough knowledge about them. Since there was no team providing him with the necessary support, he would devise the model, and then changes would need to be introduced.
- **Use of technological solutions:** technological solutions were not used as a means to improve the model development. As stated previously, the need to publicise the model in the extranet provided extra problems during its development;
- **The value of the process model content:** the requirements of the model users were not defined, consider nor analysed during the model development. The best possible value to be achieved by the model was also not determined. Due to this factor, users could not perceive benefits in applying it. Furthermore, obstacles to

creativity, as evaluation pressures and insufficient time, happened during the model development.

- **Optimisation**: The developers and future users of the model did not commonly hold the goals of the modelling exercise. Also, decisions made during the model development were only based on the views of the two persons involved.

PILOT IMPLEMENTATION OF THE PROCESS MODEL: MAIN BARRIERS IDENTIFIED AND IMPLEMENTATION OUTCOMES

As soon as the model development was concluded, the model should have been implemented in a pilot study. A PFI (Public Private Finance) project was selected to allow pilot implementation. The project involved the development of an extension of a Hospital in central London.

The initial idea was that the model would be implemented in this project by means of adapting it to define specific activities needed in the PFI stage of the project. From that, a plan for product development would be defined, and all the project information would be stored in the company extranet.

As stated previously, the model was not successfully implemented in this project. Many reasons for that were pointed out by the design manager: (a) lack of time to adapt the model to the project in hand; (b) political problems within the company, i.e. some people could not see any benefits in implementing the process model; (c) lack of an overall strategy in relation to product development within the company; (d) the model was approached by the design manager as 'a way of monitoring other people's, what they should and what they should not be doing', which caused a negative concern on its implementation; (e) the process model content was not considered to be satisfactory. It is believed that if more consideration were given to the application of lean principles during the modelling exercise, most of these problems could have been avoided.

The main barriers identified in relation to the process model adoption were:

- **Failure to integrate the process model throughout the organisation**: people from the different regional areas have not been involved with the initiative, and different approaches were identified, i.e. some managers considered it important, while others considered it not relevant;

- **Inadequate attention to human issues and lack of motivation:** the design manager did not have the necessary motivation to change the way he was managing product development, due to the effort needed to implement the model, the lack of confidence in its content, and no support from senior management. It is believed that if more attention was put on the value of the process model content, i.e. identifying the model user's requirements, this problem could have been diminished;

- **Problems in the process content**: there was a high level of conjecture on the utility of the knowledge embedded in the process model; this happened due to lack of confidence on the source of information used to devise the model, lack of confidence on the person that was devising the model, as well as due to lack of

involvement with its development. Also, the complexity of the model content requires an adaptation prior to its use, which did not happen; once again, a better consideration of the requirements of the model users, coupled with a better control of the activities developed during modelling could have reduced the occurrence of this problem.

- **Lack of leadership** on the implementation process;
- **Barren organisational context**: represented by the lack on an agreement on a strategy for product development, on the lack of definition of the role of the design manager, and of the different viewpoints in different regions with regards to the need for a process model.

CONCLUSIONS

This paper has presented an analysis on the application of lean principles to process modelling. Potential improvements that could be gained by applying lean principles to the modelling exercise and by integrating new processes in a change management framework have been described. The main findings regarding modelling and implementation can be summarised:

- The triggers for process modelling in company A are similar to those described in the literature;
- Lean principles were partially applied to modelling; that partial application had a negative effect over the success of the outcomes;
- The modelling methodology to be used was not well established in the beginning of the improvement initiative, which caused rework and time delays. Also, the steps to implement the processes were not well established;
- The transfer of the principles described in the model to the project level required an adaptation that did not occur mainly due to lack of motivation, lack of confidence on the model contents, and lack of confidence in the source of the knowledge embedded in the model;
- The lack of a well established definition of the role of the design manager played an important part on the lack of use of the process model;
- The implementation was not considered as part of a change framework, and this is one of the reasons why it was not successful;

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