Applicability of the capability maturity model for engineer-to-order firms

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Abstract: Most of the well-known management and improvement systems and techniques, such as Lean Production (e.g. Just-In-Time (JIT) pull production, one piece flow) and Six Sigma (reduction in variation) were developed in high volume industries. In order to measure the progress of the implementation of such systems, companies and consultants use reference frameworks, which contain descriptions of best practice processes. The core principles of these systems are applicable in any type of industry or service (e.g. focus on reliability and minimisation of waste). However, the best practice references and other implementation tools are dependent on the context in which the principles are applied. For the Engineer-to-Order (ETO) industry, many of the traditional practices (e.g. JIT logistics or line balancing) are not applicable. In this paper, it is demonstrated that the Capability Maturity Model Integrated (CMMI), a best practice reference framework widely used in the software industry, contains practices which are also widely applicable in ETO companies, but that the original model needs to be enhanced. CMMI provides a philosophy, as well as a set of hands-on guidelines and measurable stages for process improvement. CMMI may provide practical techniques to ETO companies which other companies acquire from systems such as Lean Production and Six Sigma.

Keywords: ETO; engineer-to-order; CMMI; capability maturity model integrated; lean production; process management; construction.

Reference to this paper should be made as follows: Veldman, J. and Klingenberg, W. (2009) 'Applicability of the capability maturity model for engineer-to-order firms', *Int. J. Technology Management*, Vol. 48, No. 2, pp.219–239.

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1 Introduction

Many publications report on the success of management systems such as Lean Production and Six Sigma. Lean Production has evolved into a widely accepted system or philosophy, for the management and improvement of production systems (Holweg, 2007). The overlap or relation between Lean Production and other systems, such as Agile manufacturing (Narasimhan et al., 2006) and Six Sigma (Linderman et al., 2003; Sulek et al., 2006) is also well described. Some authors (e.g. Shah and Ward, 2003) emphasise the individual tools and techniques normally regarded as elements of Lean Production. In particular Just-In-Time (JIT)/continuous flow production, lot size reduction, pull systems/kanban and quick changeover techniques are frequently reported as key elements (Shah and Ward, 2003). Other authors emphasise that Lean Production should be seen more as a holistic philosophy, a set of values and that many of the tools and techniques are interdependent (Herron and Braiden, 2006a,b).

In nearly all publications relating to Lean Production, examples from high volume industries are used. Indeed, most of the tools and techniques (continuous flow, lot size reductions, JIT/pull/kanban) are mostly applicable for high volume production. To date, surprisingly, little research is available on the possibilities for implementing Lean Production and other systems in Engineer-To-Order (ETO) industries.

In principle, the best practices of Lean Production are so well described that they can be used by companies as a practical reference. Many companies and consultants use these descriptions, sometimes described in progressing stages, in order to aid improvement (Herron and Braiden, 2006a,b). It follows that for companies which are not in the typical high-volume production industries in which the best practices were developed, alternatives or amendments to the reference frameworks are required. This is the case for the ETO industry.

ETO companies have an order penetration point that is situated before the start of the engineering process (Olhager, 2003). Work activities in this type of firm are often so untypical that the existing tools for preserving and improving processes do not work very well. Many ETO organisations often spend a great deal of effort implementing currently popular concepts and programmes, without obtaining the desired results. The main contribution of this paper to the existing literature is twofold:

1 it provides an overview of the factors that obstruct the effective use of process management tools in ETO firms

2 it presents a concept that could deal with some of these factors – the idea of process maturity as a roadmap towards a state of continuous measurement and improvement.

An important framework for the stepwise improvement of ETO processes is the Capability Maturity Model (CMM), developed by Carnegie Mellon University's Software Engineering Institute in the late 1980s (e.g. see Humphrey, 1988). Although this framework[1] was originally created for the software engineering industry, efforts have been made to generalise it to areas such as new product development (Dooley et al., 2001) and construction (Sarshar et al., 2000). Although a more generic method was introduced in 2002 (the Capability Maturity Model Integrated (CMMI), the central idea of a maturity model as a basis for process capability improvement beyond software engineering has not been widespread since. In this paper, we will describe some typical obstacles for ETO firms in introducing and effectively using process improvement concepts and postulate what could be done to overcome these problems using the concept of process maturity. We furthermore map CMMI onto typical ETO processes to identify the areas in which ETO firms can apply CMMI readily, and the areas within CMMI that need extensions.

2 Process management literature

A process can be defined as a "time-dependent sequence of events governed by a process framework" (Mackenzie, 2000, p.110). Process management, then, can be described as follows: "process management, based on a view of an organisation as a system of interlinked processes, involves concerted efforts to map, improve, and adhere to organisational processes" (Benner and Tushman, 2003, p.238). Process management practices have become core elements of well-known programmes and concepts such as the International Organization for Standardization's Series 9000 programme, Total Quality Management, Business Process Reengineering, Six Sigma (Benner and Tushman, 2003), Lean and Agile manufacturing (Narasimhan et al., 2006). Differences between these programmes and concepts exist, but it is still unclear where these differences lie exactly and at what level. In an attempt to conceptualise Lean Production, Shah and Ward (2003) distinguished four 'bundles of practices': JIT manufacturing, Total Quality Management, Total Productive Maintenance and human resource management. While this study might suggest a hierarchical structure (in which Total Quality Management is a branch of Lean Production), Andersson et al. (2006) placed the concepts at the same level having comparable origins, methodologies, tools and effects. In another study, Narasimhan et al. (2006) attempted to disentangle Lean and Agile manufacturing, stating that the pursuit of agility might presume leanness. One of the best-known dimensions from which process management concepts and programmes can be compared is the one between stepwise and radical improvement. Whereas Business Process Reengineering is often positioned on the radical side of the continuum, the others lie more in the middle and towards the stepwise side. In summary, we can argue that although these concepts and programmes seem to be beneficial to organisations, clear distinctions between them are hard to make. They can, however, be compared by means of various dimensions (i.e. use of practices, hierarchical structures, sequence of implementation and degree of scope change).

Besides comparing these concepts and programmes, it is useful to identify the underlying assumptions. First of all, they all focus upon processes. Second, they all serve multiple purposes such as increasing customer value and reducing cost, waste and cumulative lead time. They all have rationalisation and the elimination of variance as a common feature and require that an organisation be aware of the state and outcome of the process (Benner and Tushman, 2003). For such concepts or programmes to work, a certain degree of repeatability and stability is required. If one's aim is to measure and improve a process, one has to be able to predict (that is, at least to a reasonable extent) the behaviour and interrelationships of that process. For the ETO industry, we will demonstrate this is a great challenge.

Clear descriptions of ETO organisations and processes can be found in Hicks et al. (2000a,b) and Cameron and Braiden (2004). In Hicks et al. (2000a,b), a distinction is made between physical, non-physical and support processes. Examples of ETO companies are manufacturers of gas production plants, oil platforms and lithography systems. In addition, many construction projects can be labelled ETO. Common ETO company characteristics that can be found in these publications are:

- output is highly customised to meet individual requirements
- output is low in volume and consists of a wide range of technologies that are often very advanced and at the boundary of knowledge
- processes are highly complex and dynamic
- organisation is often project-orientated
- supply networks are very much integrated and suppliers are powerful.

Today it is clear that existing concepts and programmes should be assessed carefully to understand the usefulness for the various types of firms. Mukherjee et al. (1998), for example, challenged the assumption made by many researchers that process improvement practices are universally valid. Many publications can be found that underline the poor applicability of the traditional process management tools for ETO companies. Shah and Ward (2003) demonstrated that JIT/continuous flow, lot size reduction, pull systems/kanban and Cellular Manufacturing are techniques that most authors see as typical elements of Lean Production, while, for example, management of product information across its life cycle is not listed. Other examples:

- Cameron and Braiden (2004) identified several elements that prohibit companies in the ETO sector from successfully adopting Business Process Reengineering. One of these elements is poor control over the supply chain network outside the organisation. Since ETO work is hardly ever a stand-alone activity, suppliers and partners play important roles. Control over these suppliers and partners, however, turns out to be often so limited that Business Process Engineering can only be applied to particular processes at the business-unit level, while a successful Business Process Reengineering project would require radical change in the entire supply chain.
- Wortmann (1995) indicated that although the timing and quantity of demand in ETO work may be estimated to some extent, the precise nature of the product and its routing through the organisation cannot. For organisations, this means that no consensus can exist on what constitutes the process. Traditional concepts and programmes, however, are modelled after the high volume production control model of traditional mass industries, such as the automotive industry (Winch, 2003). They all assume a medium to high level of predictability in the flow and rhythm of the production process, so that processes can be tightly coupled using coordination mechanisms such as standardisation of output and work. One major alternative proposed is that of ‘Lean Construction’. Lean Construction (e.g. see Koskela and Ballard, 2006; Salem et al., 2006; Serpell and Alarcón, 1998) was developed in the early 1990s as an alternative to the traditional ‘conversion’ types of process views (i.e. relatively simple input–output schemes). Being unsatisfied with the efficacy of production control and improvement principles (originally designed for mass industries), the Lean Construction initiative developed guidelines which described construction projects as value networks with a flow of activities.

The fact that every ETO project is relatively unique does not necessarily imply that learning is impossible. As demonstrated by Brady and Davies (2004) and Engwall (2003), most projects start off from some level of experience obtained in comparable projects. Furthermore, a current trend in ETO industry is the life cycle view of processes. In many cases, ETO processes are considered as part of a life cycle, with a high degree of integration between up- and downstream processes such as design, maintenance and operations. In this view, decisions are made in a multidisciplinary way, covering all parts of the life cycle, whereas in the traditional approach design decisions did not take the latter phases into account. Learning in ETO companies thus involves the identification and application of knowledge and experience obtained in similar settings as well as learning across the process boundaries. In the first case, project closeouts could be used as a reference manual for future projects, whereas in the second case cross-boundary learning is the translation of downstream data and information into knowledge upstream or vice-versa. Such learning processes are found to contribute positively to process capability (Ravichandran and Rai, 2003). A major trend in ETO industry is the integration of design and production work with maintenance activities. Maintenance data could thus be used to improve designs and the way the product is built. Today many advanced maintenance techniques such as condition-based maintenance provide the organisation with this input. Translating this input into action, however, is still a big challenge for many ETO companies.

3 An example of industrial process management questions

In order to clarify some of the statements made above we will consider the case of Stork GLT, an ETO firm that engineers, constructs and maintains gas production plants for a major oil and gas production company. The first author had the unique opportunity of conducting in-depth case research at the organisation.

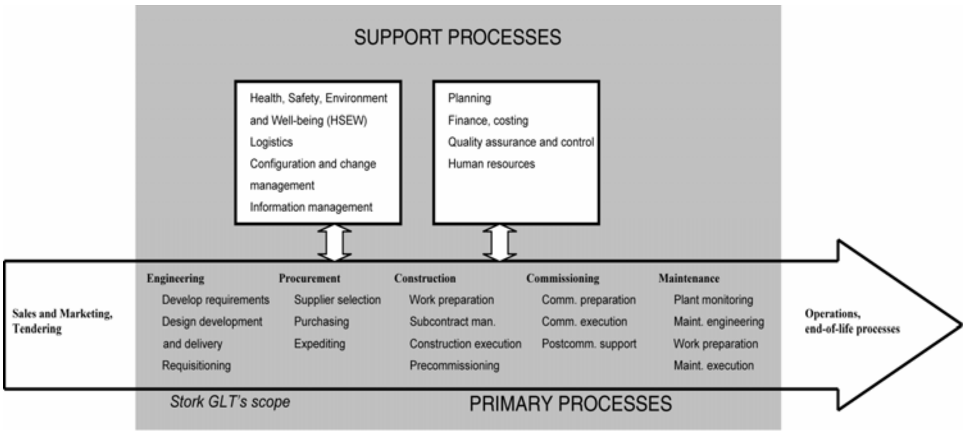
Stork GLT is a joint venture with five partners (engineering, construction and maintenance, instrumentation, compression and electric motors for compressors). It has been awarded a long life contract for the renovation and maintenance of 22 gas production plants for a large gas field in The Netherlands. The renovation part is executed in batches of two to four production locations. Activities include basic design, detail design, procurement, construction and subsequently maintenance. After handover of the plant to the customer, the expected time the plant will be operated is approximately 25 years. When the gas reservoir is depleted, plants will enter end of life processes which include the decommissioning of the plant. Early design decisions will take the operations and end-of-life phases into account.

The largest part of the project's characteristics is typical for ETO firms. Output is delivered in very small quantities and every subproject has some unique and some common properties. Processes are therefore dynamic and complex. Stork GLT's project organisation is deeply integrated with the customer. This leads to efficient and effective communication structures and decision-making processes.

The degree of partnering and subcontracting is very large. The gas plant is a configuration of many technologically advanced components. Design, manufacturing and assembly of the advanced automation and instrumentation technology are done by one of the partners. The 23 megawatt compressor and the electric motor are also designed, manufactured and assembled by partners in the joint venture. These technologies can clearly be considered as key technologies in the renovation project. Production of other 'package goods', as these large technologies are called within the project, is also outsourced for a large part. Furthermore, long-term relationships with suppliers are a major aspect of procurement strategy. Much of the construction work is subcontracted. For this reason, subcontract management becomes a vital coordination activity.

Engineering changes and modifications are major sources of process disturbance during engineering, construction and maintenance/operations phases. The sources of these changes can arise from: suppliers, customers, lessons learned from earlier engineering, construction, maintenance and operations work. Design challenges might also be detected in a later stage, which then need to be corrected. Due to the repeatability within the project, routines and formalisation are major aspects of the work. Engineering changes and modifications are a major source of variation within nearly every process within the project organisation. They therefore disturb the regular 'process flow' within the organisation. Company processes are shown in Figure 1. The figure includes the parts of the process that are within the project organisation's control and the parts that are not (operations and decommissioning). Marketing and sales and tendering are depicted because these processes are important in every project. At the case study company, these processes are inactive since the contract covers a long period and no new sales have to be made.

Figure 1 Case company primary and support processes



During the case studies, some process improvement challenges were identified. These challenges were related to the nature of the ETO firm. In particular, the day-to-day measurement of performance and process improvement opportunities (Kaizen) appeared to be difficult. Several questions arose:

- How can the core capabilities of the company be measured and improved?
- To what extent does Lean Production apply to this organisation?
- A lot of data, information and knowledge are available in the organisation.

How can we capture this, make it explicit and reintegrate this into our processes and designs? Should our aim be to standardise our processes and plants or should we aim to continuously improve them?

4 Process maturity

4.1 Process maturity models

Inspired by the problems and challenges illustrated above, a research project is currently being undertaken at the University of Groningen on process management for ETO companies. One of the aims within the research project is to identify (and, if necessary, modify) process improvement models and frameworks that fit the needs and characteristics of ETO firms.

One of the preliminary outcomes of the research project is the identification of the concept of process maturity (e.g. the CMMI (The Software Engineering Institute, 2002)) as one of the possible key elements of ETO process management. In this section, we will explain what process maturity means and we will discuss CMMI. In the subsequent sections, we will discuss a particular application of the maturity concept.

Process maturity is the extent to which a certain process is able to meet its targeted goals. The best-known framework for the achievement of process maturity is CMM. CMM was developed by the Software Engineering Institute at Carnegie Mellon University in the late 1980s. One of its original aims was to create a way of evaluating the software capability of US federal governments. In 2002, the Software Engineering Institute introduced a revised version of CMM, called CMMI. CMMI is the result of the integration of three models (Ahern et al., 2004): the CMM for software, a framework for systems engineering, and a maturity framework for integrated product and process development. The framework has been claimed to be capable of guiding process improvement for projects other than software engineering. In the following sections, we will discuss CMMI.

The basic structure of CMMI is as follows: in the framework, 25 *process areas* can be distinguished. Each process area is attached to one of the four maturity levels (i.e. level two to level five; the first level contains no process areas). Process areas are defined as follows: "A process area is a cluster of related practices in an area that, when performed collectively, satisfy a set of goals considered important for making significant improvement in that area" (Software Engineering Institute, 2002, p.17). Maturity levels are called (in order of maturity): initial, managed, defined, quantitatively managed and optimising.[2] Process maturity, therefore, can be defined as the degree to which a process is explicitly managed, defined, quantitatively managed and optimised (see also Dooley et al., 2001; Fallah, 1997). Figure 2 shows a graphical overview. Short descriptions of maturity levels are:[3]

1 At Level 1, the initial level, the focus is on competent people and 'heroics', meaning that success within projects is dependent on the efforts of talented or risk-taking individuals. Processes are difficult to predict, poorly controlled and reactive.

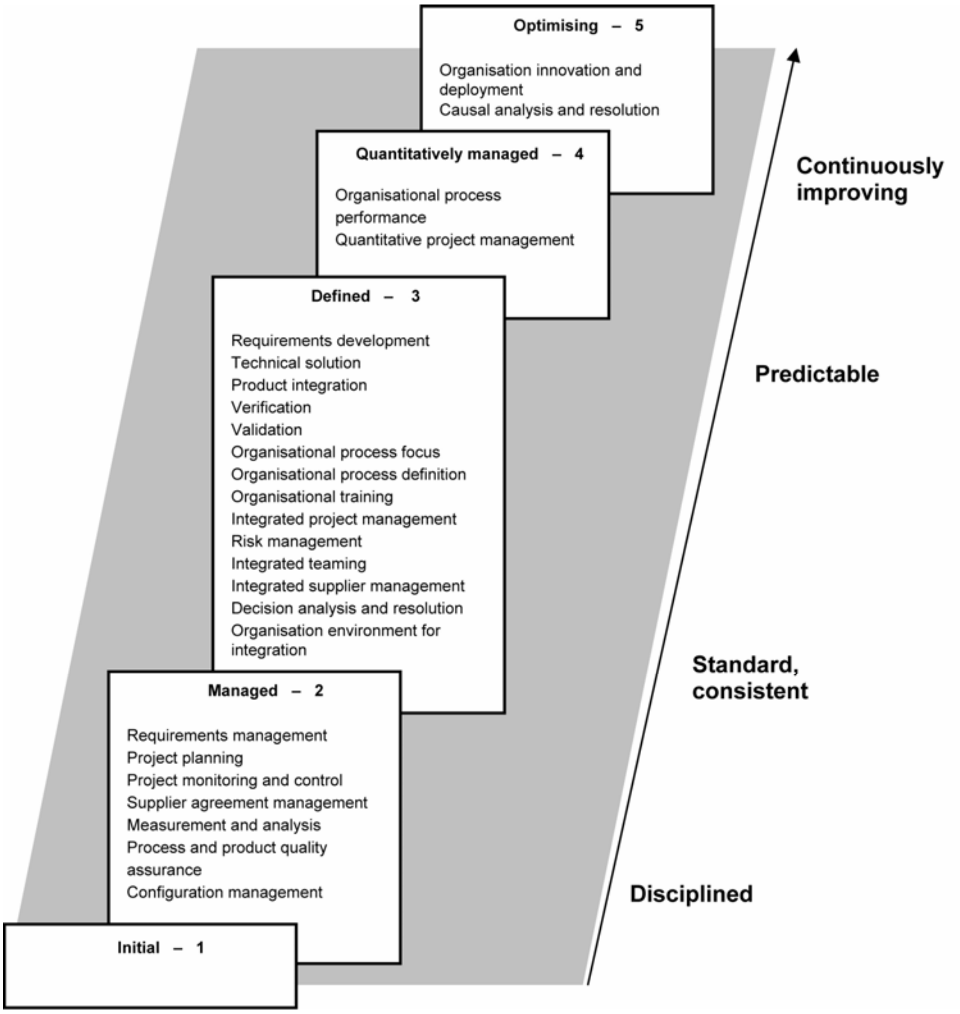
2 At Level 2, the managed level, project management is the most important set of process areas that need to be established. Processes are characterised for projects and are often reactive.

3 At Level 3, the defined level, processes are standardised based on several process management process areas. Advanced engineering process areas are implemented to ensure high quality output that meets customer needs. Processes are shared at the organisation level and are proactive. Substantial process improvements can be made.

4 At Level 4, the quantitatively managed level, quantitative measures of processes are available and processes are proactively controlled.

5 At Level 5, the optimising level, substantial process improvements can be made based on a deep understanding of the behaviour of processes.

Figure 2 CMMI process maturity framework



Source: Partly based on Paulk et al. (1993).

Two conditions need to be met in order for an organisation to be at Level 2 or higher. First of all, as discussed earlier, the *specific* goals attached to each *process area* need to be achieved. For example, one of the specific goals of the Level 3 process area ‘requirements development’ is “stakeholder needs, expectations, constraints and interfaces are collected and translated into customer requirements” (Software Engineering Institute, 2002, p.209).

Second of all, generic goals are attached to each maturity level to guide the institutionalisation process of a particular process area from one maturity level to the other.[4] Institutionalisation is "the ingrained way of doing business that an organisation follows routinely as part of its corporate culture" (Ahern et al., 2004, p.62). For example, the generic goal of the Level 2 process areas is to 'institutionalise a managed process'. The achievement of generic goals is guided by generic process descriptions or practices. These practices are organised around the basic components of an entire implementation process:

- commitment to perform
- ability to perform
- directing implementation
- verifying implementation.

Appendix gives an overview of maturity levels, process areas and specific practices. For more detailed information, full framework descriptions can be downloaded from the Software Engineering Institute website.[5]

The mechanisms within the framework and the performance effects can be explained in different ways. The basic idea behind the maturity levels is that when processes become standardised, they can be controlled because variation is recognised. The higher the maturity level, the better it is understood and the more the measurements of process behaviour make sense. Significant improvement of processes can only be achieved if processes are measured quantitatively.

The significant benefits of process maturity models have been described in several publications. Generally, process maturity models lead to increased quality, shorter development cycles, increased efficiency and flexibility (e.g. Dooley et al., 2001; Harter et al., 2000; Jiang et al., 2004; Krishnan et al., 2000). Several other fields have adopted the maturity approach to guide the road to improvement, such as in the field of project management (Grant and Pennypacker, 2006).

4.2 Process maturity models for ETO firms

CMMI is one of the few frameworks that are able to deal well with the specific nature of ETO projects. As mentioned above, CMM was able to guide software engineering firms into a state of continuous improvement, in which high quality products were delivered at low cost and on time. CMMI usage was promoted several years ago (e.g. see Nambisan and Wilemon, 2000). Aside from some applications of CMMI in new product development and the use of the maturity concept in construction, however, few applications outside the software engineering arena are known. A process maturity framework such as CMMI, however, could be very beneficial for ETO organisations for a number of reasons:

- Maturity frameworks reduce task uncertainty and help manage complex interactions among actors, tasks and processes. We mentioned that these complex interactions are a central element in ETO work. Through the structuring of functional and cross-functional processes, interfaces are known to major actors such as engineers, buyers, work-package coordinators and construction workers. This eventually leads to a reduction in defects and rework.

- Maturity frameworks provide substantial guidance for the integration of process and product experience back into design and processes. In particular, the process management process areas offer support for this. Knowledge reuse is important in this industry and the more explicit reuse practices of CMMI can complement the softer and more intangible practice of social-knowledge networks, as is common in the architecture, engineering and construction industry (Demian and Fruchter, 2006).
- Supplier integration can be enhanced by the process areas of supplier agreement management (Level 2) and integrated supplier management (Level 3). These process areas stress formal relationships, yet relationships for the long-term based on negotiation and coordination of mutual concern.

Besides these specific reasons, some generic reasons for using maturity frameworks could be cited as well. CMMI provides the organisation with an auditable process (Falah, 1997). Furthermore, we believe that these maturity stages can be viewed as parts of an implementation ladder. The staged approach therefore facilitates a relatively easy transition from chaos to structure. It makes sense to define a process at a project level, then carry it to the organisation level, measure it and improve it accordingly. It also makes less sense to do it the other way around.

4.3 Mapping CMMI to ETO life cycle processes

Sections 4.1 and 4.2 clearly describe the potential benefits of CMMI for ETO firms. In this section, we describe the details of CMMI to uncover where ETO process management can directly benefit from CMMI and where CMMI needs enhancement. We do so by means of a ‘gap analysis’. This gap analysis is a detailed mapping of company processes with best practice reference frameworks. Any reference framework should essentially cover the whole range of business processes of the firm. For ETO firms these consist of the primary processes engineering, procurement, construction, commissioning and maintenance. Also the support processes Health, Safety, Environment and Well-being (HSEW), planning, logistics, finance, cost and acquisition control, configuration and change management, quality assurance and control, Information Management/Information Technology (IM/IT) and human resources should be taken into account. More detailed process descriptions can be found in Veldman and Klingenberg (2006). The processes shown in that paper share a great deal of overlap with the framework presented by Hicks et al. (2000b). Admittedly, the processes given are a focused on construction and maintenance organisations, in which, for example, HSEW is of greater importance. We also do not include the primary stages (marketing and sales, tendering) in the framework. Furthermore the manufacturing and assembly undertaken by partners are not included, since they are not within the scope of the organisation. We consider that the framework is universal and can be used outside the construction and maintenance setting. In order to avoid an exercise that is too theoretical, Stork GLT (see Section 3) is used as a reference case. The processes were shown earlier in Figure 1.

4.3.1 Mapping principles

The following method was used. Firstly, we obtained detailed descriptions of ETO processes, and verified these with experts from Stork GLT. Then we obtained the specific goals of CMMI. Each ETO process was mapped against CMMI process areas, whereby we scored each ETO process with the following scale:

1 no coverage of the process by CMMI

2 weak coverage

3 moderate coverage

4 good coverage

5 full coverage.

The amount of coverage is related to the extent to which the typical activities within a process are supported by a specific goal CMMI goal. Since specific practices are not described as 'required materials' in the CMMI documentation and for the ease of mapping, we did not focus on specific practices.

4.3.2 Mapping results

The results of the mapping process are given in Table 1. We found that the strongest coverage of CMMI is given for the processes of engineering, procurement, planning and quality assurance and control. This is not surprising since these are the typical processes within software engineering projects. Moderate coverage is provided in the areas of commissioning, finance, cost and acquisition control and configuration and change management. These processes are also very standard in engineering-oriented projects (e.g. product development), but the differences between construction projects and other development projects are more visible. The commissioning process, for example, consists of careful testing of a complex facility prior to and after 'gas in'. These activities contain a high level of plant knowledge, support and material flows. The 'validation' process area of CMMI does include testing of the output in its real-life setting, but the practices given for these activities are simply too general to support typical ETO-processes. Further developments in the process areas scored 'moderate' are thus needed. The CMMI process areas linked to these activities can provide a good starting point for this development.

The processes of construction, maintenance, logistics, IM/IT and HSEW are weakly covered by CMMI. No generic goals of the CMMI process were found to be fundamentally beneficial to these processes. The construction process, for example, is in the ETO/oil and gas setting a complex activity of work package preparation (i.e. obtaining designs, estimating work activities, estimate cost, obtain permits, coordinate subcontractor work, quantity surveying), construction and precommissioning. This process also includes the complex activity of subcontracting and the relationships with (engineering,) manufacturing and assembly processes, that, in the case of Stork GLT, are the responsibilities of the joint venture partners. This is called subcontract management. These typical activities cannot be structured according to the CMMI product integration process area, simply due to the lack of details. The maintenance process, another example of a weakly covered area, is said to be supported by the framework according to CMMI advocates (e.g. Chrissis et al., 2003). Careful analysis of the model leads us to conclude, however, that maintenance is primarily seen as a stakeholder of the other processes (e.g. for engineering), and not as a process that is supported by practices specific for maintenance. It is for exactly that reason that maintenance maturity frameworks for software are currently being developed (see April et al., 2005).

Table 1 Coverage of ETO processes by CMMI process areas

ETO process	*Main activities within process*	*CMMI process area coverage on the ETO activity level*	*Process area specific goal number*[a]	*Score*	*Conclusion (coverage)*
Engineering	Develop requirements	Requirements management	1	5	Strong
		Requirements development	1–3		
	Design development and delivery	Technical solution	1–3	5	
		Product integration	1–2		
		Verification	1–3		
	Requisitioning	Requirements development	2–3	5	
Procurement	Supplier selection	Supplier agreement management	1	5	Strong
		Technical solution	2		
		Integrated supplier management	1		
	Purchasing	Supplier agreement management	2	5	
		Integrated project management	2		
	Expediting	Project monitoring and control	1–2	5	
		Supplier agreement management	2		
		Verification	1,3		
Construction	Work preparation	Project planning	1	2	Weak
	Subcontract management	Project monitoring and control	1	2	
		Supplier agreement management	2		
		Integrated supplier management	2		
	Construction execution	Product integration	1–3	1	
	Precommissioning	Product integration	3	3	
		Verification	1–3		

Table 1 Coverage of ETO processes by CMMI process areas (continued)

ETO process	*Main activities within process*	*CMMI process area coverage on the ETO activity level*	*Process area specific goal number*[a]	*Score*	*Conclusion (coverage)*
Commissioning	Commissioning preparation	Validation	1	3	Moderate
	Commissioning execution	Validation	2	3	
	Postcommissioning support	N/A	N/A	N/A	
Maintenance	Plant monitoring	Measurement and analysis	1–2	1	Weak
	Maintenance engineering	See 'engineering'		5	
	Work preparation	Project planning	1	2	
	Maintenance execution	Product integration	1–3	1	
HSEW	HSEW management system delivery	N/A	N/A	N/A	Weak
	Risk and trend analyses	Project planning	2	2	
		Project monitoring and control	1–2		
		Risk management	1–3		
		Causal analysis and resolution	1–2		
	HSEW site supervision	N/A	N/A	N/A	
Planning	Planning	Project planning	1–3	5	Strong
	Monitoring and control	Project monitoring and control	1–2	5	
		Measurement and analysis	1–2		
Logistics	Warehousing	N/A	N/A	N/A	Weak
	Transportation	Product integration	3	3	
	Spare parts management	N/A	N/A	N/A	

Table 1 Coverage of ETO processes by CMMI process areas (continued)

ETO process	*Main activities within process*	*CMMI process area coverage on the ETO activity level*	*Process area specific goal number*[a]	*Score*	*Conclusion (coverage)*
Finance, cost and acquisition control	Forecasting	Project planning	1,3	3	Moderate
		Project monitoring and control	1–2		
		Measurement and analysis	1–2		
	Billing and close out	N/A	N/A	N/A	
	Scope control	Project planning	1–2	3	
Configuration and change management	Engineering change management	Requirements management	1	3	Moderate
		Configuration management	2		
	Modification control	Requirements management	1	3	
		Configuration management	2		
	Configuration management	Configuration management	1–3	3	
Quality assurance and control	Quality assurance	Measurement and analysis	1–2	5	Strong
		Process and product quality assurance	1–2		
		Organisational process focus	1–2		
		Organisational process definition	1		
		Organisational process performance	1		
		Organisational innovation and deployment	1–2		
	Quality control	Supplier agreement management	2	4	
		Measurement and analysis	1–2		
		Process and product quality assurance	1–2		

Table 1 Coverage of ETO processes by CMMI process areas (continued)

ETO process	*Main activities within process*	*CMMI process area coverage on the ETO activity level*	*Process area specific goal number*[a]	*Score*	*Conclusion (coverage)*
IM/IT	Application and network support	N/A	N/A	N/A	Weak
	Project administration	Project planning	2	2	
		Project monitoring and control	1		
		Measurement and analysis	1–2		
Human Resources	Selection of personnel	Project planning	2	3	Moderate
	Training	Organisational training	1–2	5	
	Employee evaluation	N/A	N/A	N/A	

[a]Most process areas contain more than 1 specific goal. In this column, the applicable specific goals are mentioned with a number. Not every specific goal is automatically applicable. Therefore they are specifically mentioned. Specific goal descriptions can be found in Appendix.

4.4 Final remarks

We end this section with three remarks. Firstly, we should stress that ETO organisations can apply CMMI in addition to their existing concepts and programmes, such as Lean Production and ISO 9000 (Ahern et al., 2004; Ashrafi, 2003), although it might be counter-effective to apply too many process improvement initiatives at the same time. Secondly, one must realise that process capability is not the only capability an organisation can or should be concerned with. Other capabilities requiring dedicated resources and the balancing of these process capabilities are, for example, innovative capability or human resource capability (Grant, 1996). Finally, one major part of the criticism CMMI has received over the years is that it promotes bureaucracy and that it does not fit every organisation's culture (Adler, 2005). According to Ngwenyama and Nielsen (2003), many CMM implementations fail due to the necessity to change underlying cultures. This cultural shift is not explicitly included in the framework. Therefore, it is advisable that maturity framework implementations should be accompanied by an appropriate cultural change project.

5 Conclusions

In this paper, we have shown opportunities for ETO companies in managing and improving their processes. Traditionally, ETO companies can only to a limited extent benefit from best practice descriptions in Lean Production and related literature. For a large part this is due to the specific characteristics of organisation, work and output within these companies: low volume and customised, complexity and dynamicity of processes, project-based organisation of work and high level of integration within the supply chain. Many process improvement philosophies and frameworks assume medium to high level of predictability in the rhythm and flow of processes. Consequently, standard contingency theory proposes the use of the different types of standardisation.

In this paper, it is demonstrated that the CMMI, a best practice reference framework widely used in the software industry, contains practices which are also applicable in ETO companies. CMMI provides a philosophy, as well as a hands-on set of guidelines and measurable stages for progressing organisations towards managed, defined, quantitatively managed and optimised processes. CMMI may provide practical techniques to ETO companies which other companies acquire from systems such as Lean Production and Six Sigma. For ETO companies, CMMI can therefore serve as the much-needed vehicle for structured process assessment and improvement. As with many of such reference frameworks, CMMI has its flaws. Particularly, company downstream processes which become more and more important in the shift towards life cycle management we observe – need better coverage than CMMI provides currently. These areas, which include logistics, construction and maintenance, need to be extended in order for CMMI to act as an effective life cycle process management tool.

Acknowledgements

The authors would like to thank Koen Bogers, Ellen Alssema and Ron Schoemaker of Stork GLT, and Ruurd Hoekstra of NAM for their support for this research. The authors gratefully acknowledge support for this research from the Energy Delta Institute; the International Business School and Research Centre for Natural Gas.

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Notes

[1]One can argue about whether CMM is truly a model or should be considered a framework. When applying strict definitions of a model as being an abstracted or simplified version of reality, and a framework as a set of rules and guidelines that can be applied to reality, CMM is a framework. However, CMM contains several implicit model-like structures. The distinction, therefore, is rather trivial. For this reason we treat 'model' and 'framework' as interchangeable terms.

[2]The Software Engineering Institute has actually developed two representations. In the staged representation, the process areas are organised around maturity levels. An organisation moves to a higher maturity level if *all* of the process areas are meeting its specific and generic goals. In the continuous representation, an organisation is free to choose what process areas to focus on. In this paper we focus solely on the staged version.

[3]The following description is based on Ahern et al. (2004).

[4]As a matter of fact, only Levels 2 and 3 contain generic goals and practices. It is assumed in the framework that institutionalisation of Levels 4 and 5 process areas is guided by the *specific* goals and practices of those process areas.

[5]See http://www.sei.cmu.edu.

Appendix

CMMI process areas

Maturity level	*Category**	*Process area*	*Specific goal(s)*
2	EN	Requirements management	SG 1 – manage requirements
	PM	Project planning	SG 1 – establish estimates
			SG 2 – develop a project plan
			SG 3 – obtain commitment to the plan
	PM	Project monitoring and control	SG 1 – monitor project against plan
			SG 2 – manage corrective action to closure
	PM	Supplier agreement management	SG 1 – establish supplier agreements
			SG 2 – satisfy supplier agreements
	SUP	Measurement and analysis	SG 1 – align measurement and analysis activities
			SG 2 – provide measurement results
	SUP	Process and product quality assurance	SG 1 – objectively evaluate processes and work products
			SG 2 – provide objective insight
	SUP	Configuration management	SG 1 – establish baselines
			SG 2 – track and control changes
			SG 3 – establish integrity
3	EN	Requirements development	SG 1 – develop customer requirements
			SG 2 – develop product requirements
			SG 3 – analyse and validate requirements
	EN	Technical solution	SG 1 – select product-component solutions
			SG 2 – develop the design
			SG 3 – implement the product design
	EN	Product integration	SG 1 – prepare for product integration
			SG 2 – ensure interface compatibility
			SG 3 – assemble product components and deliver the product
	EN	Verification	SG 1 – prepare for verification
			SG 2 – perform peer reviews
			SG 3 – verify selected work products
	EN	Validation	SG 1 – prepare for validation
			SG 2 – validate product or product components
	PSM	Organisational process focus	SG 1 – determine process-improvement opportunities
			SG 2 – plan and implement process-improvement activities

CMMI process areas (continued)

Maturity level	*Category**	*Process area*	*Specific goal(s)*
	PSM	Organisational process definition	SG 1 – establish organisational process assets
	PSM	Organisational training	SG 1 – establish an organisational training capability
			SG 2 – provide necessary training
	PM	Integrated project management for IPPD	SG 1 – use the project's defined process
			SG 2 – coordinate and collaborate with relevant stakeholders
			SG 3 – use the project's shared vision for IPPD
			SG 4 – organise integrated teams for IPPD
	PM	Risk management	SG 1 – prepare for risk management
			SG 2 – identify and analyse risks
			SG 3 – mitigate risks
	PM	Integrated teaming	SG 1 – establish team composition
			SG 2 – govern team operation
	PM	Integrated supplier management	SG 1 – analyse and select sources of products
			SG 2 – coordinate work with suppliers
	SUP	Decision analysis and resolution	SG 1 – evaluate alternatives
	SUP	Organisational environment for integration	SG 1 – provide IPPD infrastructure
			SG 2 – manage people for integration
4	PSM	Organisational process performance	SG 1 – establish performance baselines and models
	PM	Quantitative project management	SG 1 – quantitatively manage the project
			SG 2 – statistically manage subprocess performance
5	PSM	Organisational innovation and deployment	SG 1 – select improvements
			SG 2 – deploy improvements
	SUP	Causal analysis and resolution	SG 1 – determine causes of defects
			SG 2 – address causes of defects

*Process areas can be arranged by categories: EN = engineering, PM = project management, SUP = support, PSM = process management.