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Managing project changes: Case studies on stage iteration and functional interaction

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Abstract

This paper investigates project changes and their relationships with stage iteration and multi-functional interaction. Changes often occur in a complex solution-based project, which makes the linear management model limited in its application. Complex project planning is based on assumptions about future events. Assumptions often fail and as a result the plans contain activities that are impossible or unnecessary to execute. The consistency of project planning needs to be restored and maintained by revising or redefining project activities.

Case studies were used to collect data from international solution-based companies based in the UK. Two solution centres and four projects were examined. Major findings suggest four perspectives for stakeholders to understand and manage changes in the development of complex bespoke system. Mechanisms such as tension management, specification management and organisational learning exist to enable project planning and (re)defining at multiple levels.

Keywords: Complex projects; Project changes; Stage iteration; Multi-functional interaction

1. Introduction

A project is commonly featured as a multi-stage process and a multi-functional effort. Our understanding on project stage iteration and stakeholders' interaction, and their links to project changes, however, has been limited. This is particularly true with large complex development projects (Browning, 2010; Danilovic and Browning, 2007; Nightingale, 2000) where thousands of activities that are connected to hundreds of people post uncertainties in planning and control of project stages, resources and dependencies, and thus create many sources for project changes (Killen et al., 2012).

Project changes have been conventionally treated as having heavy or negative impacts on project completion and, in theory, they should not happen if project activities have been perfectly planned and scheduled. Managers thus strive to avoid variations or to rectify discrepancies by using methods such as project crash-down (Kezsbom and Edward, 2001) or trade-offs. Management thus aims at compressing activities and stages, maximising resources and functional inputs, and reducing time-to-market. The link between project changes and stage iteration and functional interaction has been largely overlooked.

The use of projects as a way to innovation, however, challenges these and other related assumptions about project changes. Klein and Willian (1958) questioned whether theories and tools developed for operational decisions could be effectively applied to developmental decisions. For example, unlike in routine operations' decision taking, the uncertainty in the development process is an unknown factor (Söderlund, 2002; Williams, 1999). Recent studies (Browning, 2010; Danilovic and Browning, 2007; Davies et al., 2006; Gottfridsson, 2012; Hobday and Rush, 1999; Hobday et al., 2000; Lampel, 2011) into the development of complex products and systems argued that Research and Development (R&D) strategies for mass-produced products are essentially inappropriate for one-off, business-to-business, high technology and capital intensive projects, such as the design and delivery of offshore oil platforms and nuclear power plants. The

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discussions on complex development projects indicate a need to understand organisational and managerial approaches to project changes (Nightingale, 2000; Zhang et al., 2011). In particular, the researcher asks how to manage project stage iterations and functional interactions in a complex project, where changes are taken as unavoidable and unpredictable (Tukiainen et al., 2010).

This paper explores how project stages are iterated and how (mainly internal) stakeholders interact in a constantly changing business and operations environment. The literature review will discuss the nature of complex projects and project changes; stage models for project planning and control; and multi-functional approaches in balancing between innovation and optimization (Klein and Willian, 1958). A preliminary conceptual framework was then proposed to guide the research design which involved two case study companies, their planning and control centres (i.e. solution centres) and four projects (i.e. two projects from each company) that were examined in an integrated way (Thomas, 2011). The Results and Discussions sections will report and address four main issues (or perspectives): defining project interrelated activities; challenges to the iterations of project management functions; formation and behaviours of project organisations; and patterns of decision-making in dealing with conflicts across functions. The paper intends to demonstrate that departmental formation and co-ordination are institutionally fundamental (Lampel, 2011) for project stage iteration and change control. Finally, the paper will conclude by summarizing the main findings and drawing attention to further research opportunities.

2. Literature review

2.1. Project changes in complex projects

The author wishes to distinguish between projects that are funded and implemented for organisational change (Gemünden et al., 2005; Paton and McCalman, 2000; Vuori et al., 2012) and process re-engineering (Hvam and Have, 1998), and project changes (Bailetti et al., 1998; Bozdogan et al., 1998; Tukiainen et al., 2010) emerging from intermediate results or unexpected events with new features in system codification and new activities in project definition/programming. The latter is typical in complex projects developed and implemented to provide unique and bespoke solutions (Davies, 2003). Complex solutions cannot be fully detailed in product catalogues. This is in contrast to the case of mass customisation (New and Skipworth, 2000) and mass-produced new product development (Liker et al., 1996) where approaches such as prototyping and 'point-based' are widely applied and largely successful.

A complex project is delivered not to articulated requirements but to an 'open' conformity which is constantly shaped by the project stakeholders and/or the intermediate results. Unlike mass-produced new product development, complex bespoke systems are sold before they are developed. During the development and implementation of these contracted solutions, there is often an aspect of novelty in terms of technology, application environment and establishing a supply base (Iansiti, 1998; Patterson and Dawes, 1999), and project stakeholders will experience many 'first time' events leading to new activities, new partners, or new materials and supplies to be located and emerged (de Graaf and Kornelius, 1996; Hobday and Rush, 1999). This indicates that the innovation process in complex development projects cannot be technically separated from the operations process (Zhang et al., 2011). Because of this, the cost and other investment in R&D for complex projects have to be justified and recouped. Common or good practices such as 'Design for Manufacturing' and 'Modularity for Supply Chain Integration' obliquely depict these two related but different stages (i.e. development and production).

The situation of 'make-to-concept' as opposed to 'build-to-print' is likely to occur in complex projects where there is a degree of openness in contracted specifications; and project changes are thus deemed unavoidable during the development and implementation of complex systems. The use of 'make-to-concept' arguably implies the difference between a solution-based production system and a 'purely' goods- or services-based one (Zhang et al., 2011). Open system specifications thus provide a mechanism when the customer's need is to be further clarified during the project life cycle. Technology integration and system (re)configuration (Davies, 2003; Killen et al., 2012) present other challenges for managing project changes. For these and other contextual reasons, emergent issues and information resulting from project interactions and changes create a situation where new activities can and need to be defined and planned for the next stage — resulting in the emergence of a solution. As the status of system specifications varies from 'open' to 'as built' (Segerstedt and Olofsson, 2010), a multi-functional decision-making process needs to be in place to provide opportunities for project stakeholders to interact, innovate and move forward.

2.2. Project stage iteration

Davies (1997) described two different phases in complex products and systems: architectural development and system implementation. He discussed these phases in the context of an industrial and historical point of view as clearly representing part of a general process of *technology evolution*, noting that the fluidity of bespoke systems requires an understanding of how the interconnections of changes affect the progress of project operations.

The concept of a complex project and its stage iteration was further developed by Paton and McCalman (2000) in their study of *organisational change*, where objectives are unclear and technologies are ill-defined. In their view, companies must learn from the execution of complex projects and determine appropriate behaviour as a complex project that consists of both technological (system-oriented) learning and organisational (people-based) learning.

The idea of seeing a complex project process as organisational change is strongly supported by previous research into organisational learning. For example, Argyris (1999), Hatch (1997) and Heracleous (1998) identified two learning mechanisms in organisations: 'single-loop' and 'double-loop', observing that complex learning occurs when solutions to emerging problems are not only discovered but are also generated. Flood and Romm (1996) go even further to claim 'triple-loop learning' for organisations and individuals to manage the increasing number of models, methodologies and theories being applied during complex projects.

Complex learning implies the development of management's capacity (Killen et al., 2012) to adjust governing variables and resolve incompatible or conflicting requirements. Complex organisational change and learning needs 'total project management' which is primarily an iterative and system-based planning technique that aims to integrate 'soft' management philosophies and techniques into a traditional project management process.

The soft holistic system approach recommended by Paton and McCalman (2000) involves three phases: *definition* of the project's scope in terms of its primary mission and associated objectives, constraints and performance measures; a *planning* phase consisting of a project review, network development, integration of component networks and performance indicator identification; and *implementation*, consisting primarily of the 'mechanisms' necessary to present the plan to relevant parties, and the installation of required monitoring and correction systems. These phases allow the project team to forecast and deal with difficulties arising during the project life cycle. It remains unclear how a factor neglected in one phase would be incorporated into the next, or whether there is any process that facilitates the overlapping and iteration of phases and/or activities.

Turner and Keegan (2000) suggested that the number of stages or activities involved in the process is not important; the key issue is how these activities overlap and are iterated. For large projects with markets characterised by few customers, the command and control system tends to vary along the process of order fulfilment. Close working relationships are encouraged, to enable internal personnel to interface with external stakeholders to solve complex project problems.

In the case of small projects with markets characterised by numerous customers, companies tend to use project champions to co-ordinate human resources across projects and to reduce one-to-one relationships (that is, the number of interfaces). The use of tactical approaches may vary during the project life cycle, and is at the discretion of the project teams and, more particularly, the managers.

Turner and Keegan (2000) argued that a complex project should be looked at from a *business and operations process* point of view, and that in complex project-based organisations jobs are typically ill-defined and poorly designed; command and control systems are not stable; and the focus is not on increasing efficiency. However, Turner and Keegan's research fails to address the fluidity of complex systems and the interaction between customers and suppliers (Tidd et al., 2001).

2.3. Functional interaction in complex projects

Bailetti et al. (1998) recommended that when organisational co-ordination is applied to developing complex products it should be based on the interdependence of responsibilities rather than on tasks. Despite the possibilities of stage-iterations and overlapping stages being ignored in Bailetti et al.'s research, it implies that both project-based and functionally oriented companies can survive and thrive if they adopt the principle of interdependence of responsibilities. Their research identified four co-ordination modules (operational stages): communication of information; integration of changes over time; cognitive mapping; and management tools. It can be inferred that specification development based on the project changes serves as an intermediating process.

This joint development approach (Gottfridsson, 2012) is endorsed by other researchers, such as Caron and Fiore (1995), who explored the working relationships within the engineering-to-order (ETO) industry and concluded that companies should avoid conventional sequential innovation processes, which cause both project lead times and costs to increase. A new project management model should be introduced, which integrates repetitive activities aimed at *production efficiency*, and 'pulse' activities oriented towards *innovation effectiveness*.

Similarly, Bozarth and Chapman (1996) claimed that the main issue for ETO companies is to find a balance between *the objectives of two conflicting operations*: productivity and responsiveness. These authors suggested the relevance of a specification process for joint project management. By focusing on constraints and opportunities, and involving customers in the development of bespoke systems, specification management can help to solve project problems and create new business, and allows overall project co-ordination.

Specification management plays a key role in bridging project communications and facilitating co-ordination between multiple players, from top management to brand marketing, and from product development (Nellore et al., 1999) to service offering (Gottfridsson, 2012). The first phase of specification management can be prolonged and complicated, as it can involve both intra- and inter-company stakeholders in various activities concerning data acquisition and translation, and the generation of requirements (Cooper and Wootton, 1998).

In the second stage of specification development, solutions are generated: this involves both internal and external stakeholders in the process of strategically engineering and managing customer requirements (Lampel, 2011). Carr (2000) discussed supplier requirements in detail. The third and final stage is the process of validating sub-systems and components both internally and externally.

The three-stage model is not linear; system specifications change over time and are created through the joint efforts of various people. In large complex engine projects (Nightingale, 2000), specifications flow not only down through the design hierarchy, but also upwards and across. Because of this, much reworking of both design and operations is required, and sometimes the impact of such changes is not predictable in terms of timing and effect. This underlines the importance of project change control and close working relationships between project stakeholders.

A similar three-stage model was identified by Hicks et al. (2000) in their empirical studies into *supply chain integration* in ETO companies, which are typically involved in the design, manufacture and construction of capital equipment. The level of detail in product specifications in their view becomes a key issue in determining the effectiveness of the procurement function, which in turn affects operations planning and control.

Applying modular design principles (to increase design standardisation and reduce costs) is difficult, if not impossible, since, in ETO operations, customer requirements are inherently diverse and the tendency for designers to produce creative solutions is very strong. These two features typify the situation of 'make-to-concept' (Zhang et al., 2011).

2.4. The preliminary conceptual model

The main findings suggest that, first, project changes are inherently related to the nature and dynamics of complex projects. The business and operations processes proposed for developing complex bespoke systems are dramatically different from those that are used for mass-production and mass-customisation. With the contracted offering being sold before it has been developed, the scopes of complex project are likely to be fluid throughout the system development process. Open system specifications lead to varying and often conflicting interpretations, thus project changes, experienced by project stakeholders.

Second, the number of system development stages functional interactions varies in complex project, depending on the size of projects and other contextual situations. Partly because of this, the research reviewed offers different perspectives, considers different influences and produces different results, complicating a general understanding of the planning and control of projects. Approaches to organisational change management and organisational learning emphasise various intervention and learning mechanisms and are therefore worthy of further investigation.

Third, complex projects often start with open system specifications or open project scopes. However, it is not clear how system specifications are further developed and eventually closed and how project activities are further divided or merged. The process of re-defining and re-planning business and operations activities involves changes by both internal and external stakeholders in the project. Changes create opportunities; they also introduce risk. The relationship between the development of specifications and the progress of the project life cycle is an area to which previous studies have contributed little.

Fourth, previous research has failed to make it clear that a project operations process is different from a project management process. The former is consisted of operational activities that are physically delivered such as tendering, award of contract, purchasing, design, on-site construction, etc. The concept of stage iteration hardly applies to these irreversible processes. A project management process refers to the definition and execution of operational activities. Information that are generated from operations activities and stakeholders interactions will provide indicators at multiple levels for management decisions-making that are to be iterated and overlapped — in order for the project to be progressed and solution to be developed. The accessibility, quality and understanding of project information are therefore crucial to the successful completion of complex projects.

3. Research design

To find out how stage iteration and functional interaction contribute to the change and development of a complex bespoke system, an in-depth case study with qualitative data analysis was used. An in-depth approach helps to enrich information and paint a holistic picture of the issues being investigated. It is most appropriate and practical where: a) the research topic and scope are evolving; and b) there is a need to take into account different perspectives and/or data need to be analysed at different levels (Yin, 1994). These and other features (such as a flexible approach to the research subject and triangulation of sources of data and perspectives) would justify the design of the current research, which is largely explorative and designed to assemble the building blocks of a theory of managing changes in complex projects, rather than to systematically test hypotheses.

Discussions were held with a number of companies listed in the British Industrial Index (2001–2002), from which two firms (i.e. solution centres) and four projects were selected through purposeful sampling and for multiple embedded case analysis (Yin, 1994). The companies and the projects (see the details below) were selected on the basis that they are solution-oriented, delivering one-off or very small batch product and that the project planning and implementing involves high uncertainty and complexity owing to the variety of changes.

Case 1. SAIC (System Automation and Information Corp, a pseudonym)

SAIC employs around 6000 staff and is located in central England. SAIC specialises in providing system development and implementation services for industrial companies operating in the food, beverage, automotive, chemicals, railways, air transportation and metals sectors. Supported and coordinated by its parent company SAIC delivers its automation business via five specialist centres. These centres undertake innovation-based activities; and have close links with manufacturing, procurement and consultancy, which provide activities that are organised as a routine business. ESS (the company's Engineered System and Services centre), which has around 60 staff, annually completes 150 to 200 projects characterised as "from idea to production". Seventy percent of contracted projects are developed off-site as bespoke applications; the remainder consist of various on-site services. Pooling ideas and parts/devices from around the world and via its parent company, SAIC focuses its business on local, mainly UK-based, clients. SAIC agreed to participate in the research on the basis that it will help to better understand the innovation process of solution-oriented business.

Case 2. PPL (Power & Plant Limited, a pseudonym)

PPL is based in the south of England and employs approximately 3000 people. It specialises in the development of power plants for new build projects and sub-system projects and upgrading of existing energy equipment. SEC (the company's System Engineering Centre) currently employed around 300 full-time staff at the time of the investigation. The company has three business/operations divisions, each specialising in technology development, key parts manufacturing, and system engineering (i.e. SEC). These units work closely on the design and development of complex bespoke boilers and their interface systems — their core products. Externally PPL forms a variety of project-based consortia with other key stakeholders, such as steam turbine providers and generator providers, in delivering a "total energy solution". For new build projects designed for Asian countries, up to 80% of contracted operations are outsourced worldwide; some of these services are contracted back to PPL's clients and their suppliers. The value of project contracts ranges from £10 million to £300 million. Most projects are tailored to the customers' requirements and application environment. Like SAIC, PPL was chosen for its full acknowledgement of project stage iteration and functional interaction to the change and development of complex bespoke systems.

3.1. Data collection and analysis

The participating companies were willing to provide office facilities for the research for a period of six months, enabling project and branch meetings to be observed on, as well as allowing time for searching, selecting and studying company documents in the time between interviews, which had to be held to fit in with the interviewees' working patterns. Anecdotal events, emerging issues and comments were gathered, by use of fieldwork diaries, and analysed, focusing on activities such as critical point review, risk assessment, change control, project review and specification processes regarding user requirement specification, functional design specification, test specification, and system specification "as built". A number of questions were tailored to reflect the interviewees' background. The interview protocol adopted and questions posted (see Appendix 1 for further details) were used to collect data from key and experienced project stakeholders. These included business managers, system or service managers, project managers/directors, functional managers, (leader) engineers, project administrators and programmers. 17 interviews were conducted with SAIC and 16 with PPL. Interviews were tape-recorded and subsequently transcribed. Like other data sources the interview data were collected and condensed by using a similar strategy to that suggested by Miles and Huberman (1994). A method called 'template analysis' (TA) (King, 2004) was used to code thematic issues. TA is plausible for this study because it fits between content analysis, where codes are all predetermined and their distribution is analysed statistically, and grounded theory, where there is no a priori definition of codes. Towards the end of analysis each company was provided with a comprehensive report about its operations practices, for ethical, factual and content approval, before conclusive discussions were drawn.

Data analysis/presentation was focused on two levels: (1) solution centres, and (2) projects. Both companies had developed solution centres (i.e. ESS in SAIC and TSC in PPL) to tender and secure projects, co-ordinate programmes and sourcing and mobilisation of resources. Issues included mobilising engineering resources, project portfolio, bidding and negotiating, business consultancy, and vendor financing and asset management. This social matrix process (Hallen et al., 1991) favours the in-depth case study which combines contextual, time-dimensional and multiple-level analysis. Discussion were made with the two centres on how to develop new complex systems (a road map for business/operations) and the dynamics of project interaction in change control and solution development. These led four key themes to be emerged from the analysis: 1) (re)defining project at multiple levels, 2) challenges to project planning, 3) project formation and behaviour, and 4) decision-making pattern (see Table 1 for further details). A final analysis at this level draws an interrelated link between these themes and the change and development of the system specifications.

At the project level, two complex development projects were chosen from each company to undertake "nested and contrasting" analysis, integrated "as part of the wider case" (Thomas, 2011: 152-5). At SAIC the projects selected being undertaken were in the "Personal Care" and "Safety System" areas, having values of £200,000 and £300,000 respectively. For PPL the two projects studied were 'Tai Chang' and 'Shan Dao' valued at £200 million and £300 million, respectively. At this level, three sub-processes were investigated within SAIC: business order winning process, project execution process and engineering resource process. These three functions were co-ordinated by the System Manager alongside the development of contracted complex offerings. In PPL, because of the complexity and sheer size of the projects granted, all the project functions were integrated into six sub-processes: capture and execution, deliverable-based planning, process and key part design, materials and services, commercial management, and document and control. The Capture and Execution department which served as a co-ordinating function was sit in by the Chief Operations Officer. He was supported by the Project Directors and other functional directors such as the Technology Director.

Key issues which were related to system changes, and which were common across the projects were coded and condensed into the four thematic areas that were mentioned above and summarised in Table 1. At the time of the study the SAIC projects were near their closing stage. In contrast the PPL projects had completed the detailed design stage and (key parts) sourcing and the project team scaled down from approximately 200 to 300 staff at the peak time to around 30 now.

4. Results

The empirical data (as summarised in Table 1) is presented in the following sequence: 1. How project activities were defined to accommodate potential and unexpected changes; 2. What were the challenges to project planning and programming, and why; 3. How a project organisation was formed and behaved to cope with project development and changes; 4. How project participants interacted in the decision-making process.

4.1. Defining project activities at multiple levels

Complex projects were defined and planned at different levels and stages. At SAIC, the definition and planning of a

Table 1
Perspectives in managing stage iteration and multi-functional interaction.

Company and the centre studied	System and Service Engineering (SSE), System Automation and Information Corp (SAIC)		System Engineering Centre (SEC), Power and Plant Limited (PPL)	
Project and the stage at the time of the study	Personal Care, £200,000, fully implemented, on-site testing stage.	Safety System, £300,000, system installation stage.	Tai-Chang, £200 million, detailed design, key part sourcing. On-site construction.	Shan-Dao, £300 million, detailed design, sourcing, infrastructure completed.
Theme One: Defining project at multiple levels? Yes.	One of the four sub-systems co-ordinated by the manufacturing client from the UK. 100% design and build in house by integrated by the client.	Developed for an existing traffic system to be expanded in a European country. 97% of the project value outsourced. System integrated by the third party.	Turn-key power station project, dominated by the advising body. All parts global sourced outside Mainland China. 70% sub-contracted.	Turn-key plant consortia project, client is also key supplier. Infrastructure sub-contractors operated in China. 75% sub-contracted.
	Definitions and interpretations come from multiple levels from contractual, commercial, technical, to day-to-day operational.			
Theme Two: Challenges to the dynamic planning of project activities	Manufacturing jobs seemingly repeated despite huge subtle differences from previous projects. Cost increases by 40% (Sales inc by 11%) as the project(s) evolve, mistakes occur and new solutions emerge.	Using third party scheme to gain capability and/or networking for the new market. Cost doubles in terms of man-hours in design due to the client and sub-contractor using 'different languages'.	'Mis-interpreting' client's specs. Or suppliers specs. Cost implications. Programming (e.g. WBS) with many "holes" (i.e. 30% information is not available; correctly reflect the change and emerge of project activities and system specs). Changes and innovations impacting the project definition at contractual, technical and procurement and operational level and need to bring under the control by using Orange Books.	
Theme Three: Organising project activities and resources	The project manager works on several other projects as well as engineers. Other functions such as manufacturing and purchasing are shared.	The manager works to represent the client and co-ordinate a team from the sub-contractor.	Functional and high standard professional staff from Design, Purchase and Quality work fulltime within the project. Offices in China, Taiwan, India and UK to co-ordinate local and shared resources. Design centre, tech centre and manufacturing centre based in the UK.	
Theme Four: Decision-making in dealing with changes	Business Manager brings in the offering; Project Manager deliver them; Team Leader sources the expertise and engineers; System Manager supervise and co-ordinate internally.	Business Manager works with the third party to bring in the offering; Project Manager co-ordinate the manufacturing activities and the delivery of the system developed by the third party.	Chief Operations Officer, Project Director head the 'Capture and Execution' department which co-ordinate other five departments within the project such as 'Process & Key Parts Design', 'Deliverables-based Planning', 'Commercial Management', 'Materials and Services', and 'Document and Control'. 'Project Financing' and 'Supply Risk & Quality Management also work within the project organisation.	

project/order was initially made by the business development manager and co-ordinated through the system manager. The most important task was to develop the user requirement specification (URS) and the related proposal. In the proposal, the functional design specification (FDS) was blue-printed to some degree but not to a great level of detail. In developing a URS, SAIC completed a bid/no bid decision-making process, involving assessment and trade-off decisions such as acceptance criteria, project responsibility, experience and availability, profitability and pricing risks. In the latter area, SAIC aimed to go for — projects that allowed control of the required deliverables, and to reach minimum defined standards in terms of time and materials pricing.

The definition of projects was undertaken further by the project team during the FDS stage and thereafter. One design-build project (i.e. Personal Care as indicated in Table 1) saw changes at all levels, and these included new elements in software engineering that were not initially stated in the FDS: the customer "later changed his mind" and approached SAIC to renegotiate the URS (i.e. the contract). This resulted in a newly developed network system that yielded a feasible way to ensure the fulfilment of performance that the customer really expected. Revision of the URS resulted in nearly 50% of project activities being redefined and/or rescheduled. In "Safety System" project, the on-site revisits to the client by lead engineers from the third party generated a better, mutual understanding which led to the whole project being rescheduled, with many project activities redefined, split or merged. All changes and project redefining were regarded as 'common practice' in the system automation industry.

Similar to SAIC, the interaction between project management and business management was evident throughout the whole of the PPL projects examined. The first level of project definition, planning and implementation was undertaken in accordance with the customer requirement specification (CRS). The second level of management functions was carried out in line with the supply requirement documentation. The third level, covering management/project functions, was managed in relation to the DDS (design deliverables specification). There was rotation of these management functions within each level as well as iterations of them across specification levels. PPL used WBS (work break-down structure) and CPA (critical path analysis) to decompose project activities and deliverables and assign these to groups of individuals. But they seldom went into detail, such as the level of 'work packages'. Instead, they categorised their technological and management expertise and disciplines. They then dynamically allocated their resources into groups of activities and used (weekly or monthly) project meetings to identify the development of 'deliverables' and the tasks for the next stage. The expertise and resources were then borrowed and rented, in terms of man-hours, between groups. Using this mechanism, PPL fine-tuned adjustments at the lower level and identified and corrected mismatches at the higher level.

4.2. Challenges to the iteration of project management functions

The engineering and design activities in SAIC and PPL created detailed information about the goals of the project, and thus provided crucial information for the creation of the manufacturing, assembly and installation plans. Since it was known that this kind of operational information would be further generated during the execution of the plan, project planning was organised in a manner that enabled these kinds of environmental, technological and organisational innovations (or changes) to be taken into account. As one of the Planning Managers from PPL reported: "Programming a project is not finished one day. I am doing it every day throughout years".

As a result of the challenges explained above, project plans were represented at multiple levels in both SAIC and PPL. A plan was represented not as a single point in the solution space but as a subset of the solution space. According to the interviewees, those parts of the solution space that did not lead to the goal were ruled out and the remaining parts then represented the plan. Here the task of project management was to minimise the levels of assumption making, and hence reduce conflict during project execution. The project management also facilitated the multi-agent planning process (e.g. in the case of PPL where three operations offices were set up — in Taiwan, India and the UK). Once these kinds of multiple level plan representations were properly committed, problems due to diverging planning goals and artificial conflicts (i.e. unnecessarily strict representation formats) between agents would be solved or avoided.

As experienced by the case study companies, plans were developed in advance of execution, thus planning decisions were based on assumptions (i.e. the expectations from suppliers and customers) about future events. Assumptions often failed and as a result the plans contained activities that were impossible or unnecessary to execute. In other words, the initial plan became obsolete during the project. Learning to deal with changes and learning for changes were fundamental to the case study companies. Interviewees from PPL reported in common that they made mistakes in planning activities and in understanding the intermediate outcomes. A small survey of project experiences from SAIC shows that project team members learnt a lot from working on the project, regardless of whether the project was repeated or novel. The Orange Book in PPL and road mapping in SAIC are good practices in building up new experiences collectively and making implicit knowledge explicit.

4.3. Organising project resources and activities

According to the interviewees, only around 50% of the orders contracted to SAIC were delivered in the full format of project organisation. The remainder of the orders were delivered along functional lines and were supervised or expedited by the department's co-ordinators. This kind of 'semi-project and flexible organisation' appeared in the projects examined, each took different formats. For example and in "Personal Care", only one (software) engineer was involved in the entire project process and had responsibility for 'pulse activities' (i.e. responsive and interactive design and test activities). Four other people including the Project Manager and hardware engineers were each working on several other contracted orders. "Safety System" that was contracted to SAIC was to develop and implement an industrial safety system. Since they are not specialists in this area, SAIC committed few internal resources; therefore, 97% of the work was outsourced. The third party (i.e. the system sub-contractor) assumed the integrating role as well as the development one. However, the client allowed SAIC to act as the first-tier contractor, foreseeing the role of SAIC in upgrading the whole operations systems in the future. They perceived that they greatly benefited from SAIC's strong service capabilities in clarifying customer requirements, project management, broad industrial networking and a series of foresights on the future of manufacturing automation. By representing its customer and supervising project activities, SAIC established, broadened and maintained business networks and experiences, thus gaining social influence and legitimate power in the future decision-making process, which is largely collective and interactive.

The specification practice of the quality support system (QSS) in PPL echoes the illustration of how project and functional activities are knitted together and embedded in a hybrid and dynamic project organisation. The QSS department provided routine functional services in the areas of quality assurance and supplier 'surveillance' (i.e. on-site monitoring). During the execution of "Tai-Chang" project, an engineer from QSS was sent to work full-time on the project. This individual worked to provide a focal point for project communication and co-ordination between the UK project centre, the client and their representative, the Taiwan operations offices and the Indian operations centre. At the same time, the QSS department also maintained direct contact with the client and their representative. It was PPL's convention not to subordinate one person to two bosses and to maintain dual relationships between three communication centres. However, PPL's specification practice required QSS to act from a different functional perspective so that emergent issues and potential risks for the on-going project were foreseen, identified and mitigated. By participating in the process of specification development, QSS gained short-term ownership of and influence over contracted projects as well as their functional legitimacy in the long run.

For example, by drawing upon their rich experience and credibility in the area of quality management, carefully reading contractual specification documents related to the project and interacting with the client and other project stakeholders, QSS identified that, although a standard company quality programme was submitted as part of the contract tender, there was no agreed submission date for the quality plan. In addition, there was a list of inspection points of suppliers and equipment specified and suggested by the client, but the extent of inspection and test plans to be submitted were apparently unclear. These undetermined quality activities held up the routine functional process of supplier selection and evaluation and gradually became highly critical to the delivery of the whole project on time. Personnel from the UK, Taiwan and India were mobilised to clarify all inspection points that the client specified and to obtain quality plans from suppliers. A back-up strategy was also suggested in case suppliers failed to submit their quality plans within six weeks of order placement (i.e. equipment orders).

In the case of boiler manufacturing, QSS identified that different understandings between PPL and the client could result in serious risk problems. In "Shan-Dao" project, there were references in the contract specification to code certification by an independent recognised inspection agency. While PPL had committed to appointing an inspection agency, no clarification had been sought from the client as to their definition of the term "code certification". Since different materials were used in the process of system integration due to different industrial and national standards and supplier surveillance strategies, the assumption of using one group of materials as opposed to another needed to be agreed by the client at an early stage so that the extent of third party activities could be interpreted correctly and arranged in a timely manner. The above examples illustrate how stakeholders interacted to inform the iteration of definition, planning and implementation of the project.

4.4. Patterns of organising decision-making activities

The in-depth case studies with SAIC and PPL also led to the identification of two empirical patterns of internal decision-making processes. The patterns act independently or in concert according to different situations, as they are the result of both planned and emergent efforts and decisions. The SAIC pattern saw layers of the close working relationship between the System Development Team, Programme Management, Infrastructure and Key Outsiders. Core members of the System Development Team included Business Owners, Project Managers, the Team Leader, and above them, the System Manager, who works to ensure that authorities and powers are properly allocated among these key project players.

Business Owners play a key role in generating business opportunities. They work to gain a clear understanding of application environments and to creatively clarify the customer's enquiries or requirements to allow early formation of the project. Project Managers interact with infrastructure personnel and other key project stakeholders during the project's life cycle. Their main task is to identify constraints and co-ordinate activities that are required to accomplish the project and to satisfy customers. The Team Leader commits to the project from its early formation and conceptualisation through to the stages of design, installation and operations on site. His/her job is to ensure that the variety of engineering expertise and resources are mobilised and allocated in the right place and at the right time.

These three core members of the solution club act together, forming and closing up the feedback loop of decision-making and action-taking. Co-ordinated directly by the System Manager and supported by other team members (e.g. Lead Engineers) and other routine functions such as Procurement and Manufacturing, they determine the best solution development strategy (i.e. coalition and execution of projects) in terms of resources, activities, issues and relationships. Therefore, they serve as the main on-going interface points of complex projects, each of them with different focuses and priorities.

PPL's pattern has evolved as the result of years of on-going 'project process re-engineering' activities. Based on the experiences of large-scale complex projects, it consists of six sub-processes: capture and execution, deliverable-based planning, process and key parts design, materials and services, commercial management, and document and change control. These six sub-processes are each made up of many project activities that are more controllable and measurable. For example, the function of deliverable-based planning is fulfilled by conducting planning activities at contract level, project level and operational level. These day-to-day activities need to be co-ordinated within the project planning function. Project planners also need to talk to other 'project departments' in order to validate or modify project scheduling and resource allocation. The analysis of PPL's pattern indicates that the definition, planning and control of complex projects are the responsibility of a variety of project participants who bring their ideas, understanding and interpretation of the project into play, at various levels.

The centre of 'capture and execution' is headed by the Chief Operations Officer and is made up of key members from other sub-processes. They maintain close contact with the client to ensure that contractual specifications and project scopes are properly interpreted or clearly understood, major risks are promptly identified and mitigated, and solutions are cost-effective and satisfactory to the customer. They also expend time co-ordinating issues and relationships between project sub-processes and the company's infrastructure, such as the marketing and business development departments in Taiwan (i.e. Tai-Chang project) and China (Shan-Dao project), and technology and manufacturing centres based in the north of the UK. Actions are also taken to solve activities that are interlinked in the project and responsibilities that are interdependent with one another. The core members like Project Directors remained committed to the project throughout, to co-ordinate changes in other sub-processes, changes in the consortium, change of vendors and change of ownership of firms in India, China and Taiwan.

5. Discussions

The Results of the empirical study (i.e. themes as summarised in Table 1) indicate that there need four perspectives to understand and manage stage iteration and multi-functional interaction in complex projects. Stakeholders need these 'process views' (Browning, 2010) to co-manage the evolution of complex systems and other related changes. These four perspectives are further discussed below.

5.1. Defining project activities at multiple levels

The results of case studies show that there are many 'holes' in implementing conventional planning and control because of the openness of contracted specifications (Danilovic and Browning, 2007; Gottfridsson, 2012; Segerstedt and Olofsson, 2010; Zhang et al., 2011). The common practice in SAIC project management is that managers and engineers update their estimates of project completion once a month. Detailed contract cost reports are restructured accordingly in line with financial and programme management. The implication for the management of complex projects is that planning and control systems and tools such as WBS and CPA need to be kept open to the development of specifications and project changes. There needs to be chorological WBS and CPA. Namely, at the beginning and during a complex project, some work can be identified and split at the bottom level where all elements are well-defined in detail and, therefore, buildable by individuals or a small group of engineers. For other work, an astute management will wait until the development of specifications yields further information with enough accuracy and stability to allow action.

The interviews with the case study companies' employees suggest that there tend to exist four interlinked sub-processes in delivering complex systems: an operations process, a design-development process, a management process and a specification process. The operations process involves the mobilisation and best use of resources. The design and development process focuses on technology integration and system configuration. This is where product and process innovations emerge. The management process specialises in planning and control in order to co-ordinate conflicting objectives. The specification process is oriented more towards information, knowledge, networking and communication (Bocewicz et al., 2009; Gottfridsson, 2012; Segerstedt and Olofsson, 2010). This is the area that most previous studies tend to overlook. This study shows that project management functions are in close relationship with the status and development of system specifications. At the level/stage of the URS, the business team needs to define, plan and control the project (i.e. the order) largely for the sake of creating a solution space and opportunities. At the level of FDS and beyond, the project team pursues management functions in order to explore this solution space and to improve the accuracy of the project estimates. So the function of management (i.e. defining, planning, control and implementation) iterates at these different levels of the specification process. Based on the development and sharing of specifications, the function of project definition, planning and control is iterated effectively and efficiently — to minimise unnecessary rework or to turn project conflicts into new business opportunities.

5.2. Challenges to the iteration of the project management functions

The literature (for example, see Turner and Keegan, 2000; Caron and Fiore, 1995; Paton and McCalman, 2000) suggests that the iteration of management functions is necessary. However, too much stage iteration will definitely be harmful. The empirical data suggest that it is very difficult to decide when and where complex system or project activities should be redefined. When a complex project starts, the solution space previously agreed between project stakeholders is open (i.e. is elusive and not fully explored) because of the nature and mechanism of bidding for projects and taking-in orders. Some project activities that are initially proposed, may not take place during the project life cycle, while some other activities may need to be modified in terms of time, budget and personnel. During project development, events and conflicts take place, leading to new activities being identified (Tukiainen et al., 2010). It is critical for project managers to decide the significance of these 'seemingly apparent' activities, and their impacts on other subsets of the solution space, if these new activities are to be planned and implemented.

The format of stage iterations posts another challenge. For example, if project reviews are designed entirely as a formal process, then this will represent a lot of consumption in terms of time, resources and management attention. On the other hand, if too many informal processes are inappropriately introduced, it is likely that the result of project dynamic learning and knowledge freshly obtained may not feedback promptly and properly to the development process (Hällgren and Maaninen-Olsson, 2009). In other words, project stage iterations take place formally and informally and at different levels (e.g. URS, FDS and SAB). In the solution-based companies investigated, a process of exploring solution spaces is primarily partitioned into two interdependent elements of dynamic planning: project planning (i.e. management oriented) and process planning (i.e. technology focused). The former updates project plans in accordance with changing managerial conditions and the operational environment, and establishes management metrics to control progress (e.g. cost growth, schedule slippage, staffing shortages). The latter updates process plans once the technical requirements or development environment change, and establishes technical metrics to control progress (e.g. requirements growth, errors reported, rework accomplished).

The challenge for dynamic project planning (i.e. management stage iteration) also underpins the fact that a complex project delivery company is or has to be a learning organisation — an organisation that learns and encourages learning among its staff. The process of co-specifying complex bespoke systems promotes intensive exchange of information between employees, hence creating a more knowledgeable workforce. This requires a very flexible organisation where people accept and adapt to new ideas and changes through a shared vision, and where people build their knowledge through experiencing hands-on activities and working with codified information. Learning by either individuals or groups expends money and time. However, it is difficult to budget for project learning. Strategies (e.g. team learning, shared visions, post-project reviews, mental models, personal mastering and systems thinking) developed from studies of organisational learning are not planned in terms of project activities (Browning, 2010; Killen et al., 2012). Yet the result of these non-financial performances needs to be incorporated into project achievement in project planning (Davies and Brady, 2000; Koners and Goffin, 2007).

5.3. Organising project resources and activities

The empirical case studies indicated that various attributes of temporary project organisations are formalised through contracts and transactions secured to deliver solution-based activities and deliverables, which are put in place for the project's front-end development. Factors include design and engineering, procurement, scale of the resources involved and risk issues arising. Specific formats of project organisation may vary between these two extremes: functional oriented organisations or project-based ones (Hobday et al., 2000). Furthermore, the empirical study revealed that the organisational arrangement of project activities and relationships are equally determined by the nature and dynamics of specification development that takes place to illuminate and prioritise planned and emergent issues. The formation and behaviour of project organisations examined in the case study companies provide potential explanations for the development of specification processes adopted by complex solution-oriented companies.

In the case of PPL, four full-time employees worked in the observed project, receiving, registering and processing documents. Viewed by the company as one of the six key process drivers, the sub-process assumed the role of managing communications across project departments, the company and firms participating in the project. Information about system specifications and project activities are needed to be passed formally and promptly across the project. Documents that indicate the development of system specifications and project requirements provide a formal structure in PPL, complementing other co-ordination mechanisms such as project meetings and numerous internal forums. The arrangement of such a function suggests that the full articulation of project changes is often ongoing. If any key assumptions are not fulfilled, or if some belief in the concept of the project wavers, the company's processes become dysfunctional. The sub-process facilitates other sub-processes in decision-making and action-taking as risks and uncertainties unfold. It functions from the very beginning of the solution right through to the close of the project.

The empirical study showed that, as the size of project significantly increases, issue raising and risk mitigation become the two main processes of specification management. Within project organisations, specification co-ordination between partners testifies to a broad spectrum of means, from basically informal to highly formal ones. This finer level of analysis enables us to see that the on-going negotiation and enactment of a contracted project and its content or activities are a key co-ordinating mechanism for setting dynamic relations between project stakeholders (Zhang et al., 2011) such as engineering, procurement, quality management, the client and their representatives. It also demonstrates that the organisation of the complex project team, coalition or consortium is largely based on a crafted specification arrangement, which is based on a protocol and consortium contract, rather than being transformed into exhaustive sets of standards, rules and procedures, redefining company, sector and country dynamics.

5.4. Patterns of decision-making

Literature (Nightingale, 2000; Read, 2000; Tukiainen et al., 2010; Zhang et al., 2011) suggests that project changes are sourced from emerging interfaces and diverse objectives. The changes in turn shape and are shaped by the stakeholders and decision makers. Because of the potential conflicting objectives and styles, three key tensions are frequently generated, as identified from the case study companies. In the case of SAIC these are:

- Competitiveness of offering vs. feasibility of project. This conflict needs to be solved mainly between Proposal Owners who bring in orders and sell business and Project Managers who take charge of the fulfilment of the contracted orders;

- Achieving a balance between productivity of operations (as routing activities) and responsiveness to project changes that need to be achieved mainly falls between Project Managers and Team Leader, who work to ensure the supply of a variety of engineering expertise and resources; and
- Long-term vs. short-term strategies of developing solution capabilities. These strategies need to be balanced between Business Development (i.e. the proposal owner) and Engineering Team Building (i.e. the team leader).

These shared and conflicting objectives need to be fully communicated through internal and external processes. Managed properly, these conflicts and tensions can enhance team productivity, stimulate innovative business thinking, and ensure higher-quality solutions. Through effective interface management and the constructive resolution of conflicts, there is a good chance to gain a broader perspective and understanding of project problems by foreseeing and addressing a wider array of emergent issues. By encouraging rather than suppressing the expression of divergent opinions, managers create a reservoir of alternatives from which a solution may eventually evolve and be refined. In SAIC these varying objectives are supervised by the System Manager who signs contracts and makes sure that orders are delivered. He and the other three managers mentioned above form a decision-making group that deliver application orders.

This empirical pattern of co-ordinating varying and conflicting objectives may apply in the environment, as with SAIC, where a project is relatively small (e.g. between £100 k and £500 k) and most transactions are made inside the (parent) company (i.e. only a small amount of work is outsourced). However, when projects are huge (e.g. more than £200 m, as with PPL) and a lot of design, engineering and manufacturing activities are outsourced (e.g. more than 75% of contracts to PPL are outsourced or subcontracted), the number of decision-making, action-taking and sense-making centres increases. A greater number of possible tensions between varying interests may (need to) be generated. Companies pursuing large-scale complex projects need more functional centres (i.e. sub-processes) to guide the recruitment and utilisation of solution resources, to facilitate the development of system specifications and to co-ordinate project activities, whether planned or emergent. Evidently and very naturally the co-ordination function has extended from a supervisor (System Manager in SAIC) to a supervision group (Capture and Execution department in PPL).

6. Conclusions

Managing a smooth progress and successful completion of complex projects can be very challenging particularly when project stakeholders experience unavoidable and unpredictable changes. This research has explored how solution-oriented companies use stage iteration and functional interaction in the development and implementation of complex bespoke systems. Through the literature review, a conceptual framework has been developed on management approaches to complex projects and project changes. The preliminary model reflects on project stage iteration and stakeholders' interaction, links project changes to the nature and dynamics of complex development projects, and draws differences from those projects that are delivered for mass-production and mass-customisation. The framework has been extended and enriched with four perspectives developed from in-depth case studies of international solution-based companies. Therefore the research has implications for both researchers and practitioners in managing project stage iterations and functional interaction.

The research joins other studies (Nightingale, 2000; Paton and McCalman, 2000; Tukiainen et al., 2010; Zhang et al., 2011) in confirming that unexpected events, emergent issues and waiting for information necessitate interrelated system changes, with the development of system and service specifications being the main source of project changes. The interaction and interplay between project stakeholders engender and reshape these changes which generate project risks for delay or failure as well as opportunities for innovation and evolution.

It can be concluded that, in complex development projects, operations activities are defined and planned at multiple levels and contributed to by internal and external salient stakeholders. Conventional project planning and control systems need to be kept open to the interaction of project stakeholders and, therefore, the development and change of system specifications. A balance has to be found between formal and informal processes of specification communication so that the significance of project activities is properly maintained and agreed. Project learning at multiple levels has to be effectively generated and properly shared so that assumptions about future and unexpected events are promptly updated. A specification process has been found to be embedded in the internal (and external) sub-processes of complex projects, to facilitate communications and interactions. In the final analysis, the researcher claims that management activities (rather than operations stages) in complex projects need to be overlapped and iterated, based on the development of (sub-) systems' specifications and project changes.

Project size, industrial application and the nature and degree of innovation and project learning (i.e. from making mistakes to trying new ideas) affect the number of interfacing points. Patterns of decision-making vary from those in small projects registered in routine functional processes to those with intertwined and concurrently defined functional processes embedded in the capturing and execution of large contracted projects. Tensions between project managers and other functional roles can be dealt with by use of specification management as a functional communication and co-ordination channel. The use of programmes (i.e. System Manager identified in the first case study company and Capture and Execution Department in the second one) will help management to improve planning and control decisions, to co-ordinate project changes in a more responsive and efficient way, to decide which one is to lose money and learn from and which to profit from, and to allocate resources across projects for system evolutions.

Two limitations to this research must be pointed out. One is the internal perspective taken, which was unable to capture customers' and suppliers' accounts of the process. The other is the relatively small number of projects observed and staff interviewed. In addressing these and other limitations future researchers should be able to refine the model of planning and control in complex projects and generalise findings to other industries and economies. Future research will also benefit from in-depth studies of decision-making patterns in which stakeholders encounter system and organisational changes and deal with varying and conflicting interests and objectives.

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Appendix 1. Interview protocol and questions

Data regarding the history and the organisation of the company and especially the project and specification management should be collected prior to each interview.

The interview will proceed in the following steps:

1. The interviewer outlines the purpose of the investigation, and then exchanges business cards with the interviewees;
2. The interviewees are asked to brief the background information of their own, the company, and department and project;
3. The interviewees are asked to describe and comment on their practice (e.g. to give one or two specific examples), in the following areas:
   - Company's business characteristics (product/service range, technology, solution development and implementation, project size, etc.)
   - Business/operations strategies (globalisation, technology integration, supply chain, partnership relationships with customers, etc.);
   - Project features (e.g. open specifications, changes, the combination of operations process with innovation process);
   - Project stage iterations and the link to specification management;
   - Working business relationships and the link to specification management;
   - System development and implementation and the link to specification management.
   - The interviewer requests the access to relevant documents and archival (e.g. contracts, evaluation reports, memorandum) and published papers and anecdotes.

A semi-structured questionnaire will be used during the interviews. The questions to be asked are based on the literature review but have been adapted in order to make the questions more understandable for practitioners and therefore to make it easier to collect data. Answers to the questions will be recorded by filling tables, and taking notes and tape records.

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