Abstract Number: 015-0927

‘Balancing the ‘Know-how’ and ‘Know-why’ of Make-to-Order (MTO) Product Development‘

Iain Reid, University of Liverpool Management School, Chatham Building, Chatham Street, Liverpool, L69 7ZH, UK, Tel: +44 (0)151 7953826, Email: reidi@liv.ac.uk

POMS 21ST Annual Conference

Vancouver, Canada,

May 7 to May 10, 2010

Abstract:

This paper develops an application of knowledge transfer and process assessment within the realms of MTO product development. Prior studies in new product development (NPD) have delivered various tools and techniques in a generic context. A more realistic scenario, however, is to consider the needs of MTO organisations, one of the main problems associated with such organisations which what are sometimes essentially “one-off” projects. By extending the integrated definition for function modelling (IDEF0)-based modelling approach the paper demonstrates how to calculate the ‘process quality’ of the activity output and the robustness of the ‘activity’ within context of MTO. Two longitudinal case studies provided an empirical method of inquiry enabling the researcher to investigate the knowledge transfer within ‘live’ cases using multiple resources of evidence. The results highlight that this is a valuable tool for assessing ‘robustness’ and a mechanism for organisation learning in order to support future MTO projects.

1. Background

It is argued that organisation learning has become an important management strategy (Beer, 2005). However, the majority of make-to-order (MTO) organisations do not employ the tools and techniques to implement such a strategy. This is also more complicated as a majority of MTO manufactures produce bespoke products. Prior studies on the new product development (NPD) problems have delivered various models of the NPD process and a variety of supporting methods, tools and techniques in a generic context. A more realistic scenario however, is to consider the needs of MTOs. The purpose of this paper is to ask the question; Do MTO organisations have the mechanisms in place to learn from past experiences? This paper also highlights the mechanisms required for developing knowledge sharing from such projects, as well as support future NPD activities.

1.1 The growing demands in Make-To-Order (MTO) Manufacturing

Make-to-Order (MTO) manufacturing organisations have continually been asked to respond to shorter product life cycles, greater demands on manufacturing flexibility, and ever increasing intensity of global competition, as well as a turbulent economy. As a consequence of the taxonomy of MTO product development there has been increasing levels of uncertainty within the product development process, as a result may impact on the performance of the project its entirety (Muntslag 1994), therefore a framework is desirable to organise, identify the resources 'uncertainties' or sometimes referred to as 'hotspots' in complex systems or products (Rush, H & Hansen, K (1998). Managing the exchange of knowledge and experience within these processes is one particular issue important to coordinating the management of NPD processes in various ways. (Hicks, 2002), Hicks, McGovern and Earl (2000) identified three reasons why knowledge transfer is important in complex product development. First, effective sharing of knowledge and information requires the use of common systems that support tendering, design, procurement, and project management. This requires records of previous designs, standard components and subsystems together with costing, planning, vendor performance and sourcing information. This knowledge is a key source of competitive advantage for both Make and Engineer-to-Order (MTO/ETO) companies. Second, limiting customisation and standard items provides more flexibility in the timing of procurement decisions, as well as reducing costs and lead-times. This approach also gives higher quality planning data earlier. Third, proactive procurement implies participation in the development of specifications. This requires technical liaison with tendering and design based upon knowledge of potential vendor capabilities and performance. This infrastructure is necessary to make the management of the NPD process more strategic in such MTO/ETO companies. This paper introduces a model that supports such MTO/ETO manufacturing projects in terms of knowledge transfer and management of manufacturing projects, specifically in MTO/ETO manufacturing organisations. The approach focuses on assessing the knowledge transfer, as well as resource capital and therefore provide a knowledge base for embedding, coordinating and disseminating information and personal experience that can be harnessed in order to support future projects, as well as identify the 'Hot Spots' in the project when bringing a complex product or system from tender to a customer sign off.

1.2 The complexities of NPD-Make-to-Order (NPD-MTO)

The management NPD depends on a growing number of technical and social relationships in order to manage the project successfully. For that reason alone managing NPD projects has to adapt knowledge and experiences from previous projects to 'live' projects. The phrase "reinventing the wheel" stands for such tactics, where existing knowledge and experiences cannot be accessed and used, because the information is not easily transferrable, due to its format or accessibility of where it is archived, resulting in very little information available to managers to guide them through the decision-making process in NPD projects, or even assisting them in tackling those NPD uncertainties (Hicks 2000a). Therefore, a structured approach is one way of addressing such risks and uncertainties and furthermore, the NPD activities can be assessed in terms of reliability or uncertainty. Such active approaches to knowledge management require manufacturing companies have to continually challenge, review and revise or renew their routines in response to uncertainty or change (Gunasekaran, A. and Ngai, E. W. T. 2007). Uncertainty exists to both possible outcomes and the likelihood of the occurrence; as a result NPD projects face the challenge of identifying the factors that affect their impact during the development process (Muntslag, 1994).

Under ideal conditions, the scope of the project would be able to identify all unknowns and implement a plan of action to systematically address them. In reality, MTO/ETO projects have limited resources, so must therefore decide which uncertainties to explore and reduce. Both the acquisition of outside knowledge (e.g. through searches and consultants) and the development of internal knowledge (e.g. through tests and experiments) are critical to resolving such uncertainties effectively.

A key question therefore is; by what means are these ‘uncertainties’ managed and by what processes can new the learning experience or new knowledge be captured, managed, embedded and disseminated to support future projects? Within such MTO/ETO manufacturers common questions that are asked include: whether the performance, quality, variety, schedule and specification of products meet the demand of customers, whether the products have competitive advantage, whether the new business opportunity is recognized by the market, and whether the newly developed market opportunity is easily lost to the competitor. Repeat business is a strategic factor for MTO/ETO company’s survival and is therefore an important strategic choice, this learning from experience is a key source of competitive advantage for MTO/ETO firms.

The process of NPD-MTO may be mapped in a serial fashion, but they have connections with other processes forming a multi-layered structure. For example, MTO/ETO companies have processes associated with tendering, product design, manufacturing, installation, and commissioning. However, decisions made within a process are strongly influenced by the availability and the quality of knowledge and information obtained from other processes. Furthermore, early stage decisions have an impact on subsequent processes, their solution space and constraints. These interactions between knowledge, decisions and multilevel process significantly increase the complexity of knowledge management activities. Hicks (2000b, 2002) acknowledged that knowledge management has a promising set of methods and tools that could help knowledge workers in performing their job better and that will probably be used in many different occupations in the future.

2 Knowledge Transfer across NPD-MTO Projects

Knowledge Management is a field dominated by a lot of hype and a mixture of theory and technology from different research fields. It can be difficult to understand the different knowledge management initiatives particularly within the manufacturing sector. A number of studies (e.g. Petrash, 1996; Gupta ands Govindarajan, 2000; Olivera, 2000; to name a few) indicate that practicing knowledge sharing (KS) results in improved organizational effectiveness. Moreover, Knapp (1998) proposes that knowledge assets concern all sectors of the economy. However manufacturing organisations are failing to exploit some of the knowledge management initiatives (Gunasekaran, A. and Ngai, E. W. T. 2007).

In order to obtain best performance MTO manufacturers, the efficient and effective management of the NPD is vital. However, project non-conformances are substantial and the cost of rework can be large, and this makes successful NPD of 'one-off' projects rather a complicated task to be exercised with caution (Reid et al, 2004) and (Hicks 2002).

2.1 Is 'Project-Based Learning' the way forward for Knowledge Transfer?

After seeing some characteristics to some of the common problems associated with manufacturers developing one-off projects, why would we suggest project-based learning as a concept? Let us first discuss why this approach is relevant for such MTO/ETO manufacturers, and why it is interesting as a research topic for NPD.

Our main argument is that project-based learning is an ideal approach in coordinating complex product development as is focused around the success of the project management process Howick et al 2007. Managing such projects is a knowledge-intensive activity and the project managers are key enablers in exchange of individuals or groups knowledge and experience. We claim that NPD in MTO/ETO manufacturing environments is complex knowledge-intensive and is central to the organisation's learning capability because:

1) Projects require broad and in depth technical knowledge in domains such as quality, design, procurement and manufacturing, including problems and remedies.
2) The required knowledge is changing because of technological changes, and because customer's demand new solutions. So, it requires knowledge both to do an efficient & effective job, and also to cope with rapid changes both in terms of competition, legislation, technology and the specific order requirements.
3) Knowledge intensive-work can be improved by managing knowledge better, because:
    i. Work that requires knowledge can be done better if you 'know how' and 'know what' that the knowledge is relevant and up to date, which requires learning.
    ii. To ensure that you learn relevant knowledge, it is best to learn from your own environment, the 'know-why', which is the essence of knowledge management. This also means that you "try to make the best out of the resources you have available already".
    iii. To improve knowledge work, we need a holistic approach with both technical and organisational aspects. People learn better when they are motivated to do so.
    iv. Focusing on managing knowledge will activate local knowledge that exists in a company.

What activities can an organisation perform to promote 'know-how'? If we turn to Kolb, we should try to make room for reflection on experience in order to improve learning processes in a company; and understand that different people have different learning modes that they prefer. No learning recipe will suit all people. If we turn to Nonaka and Takeuchi (1995), codifying (externalising) tacit knowledge and writing it down can be one activity, having a group of people to combine explicit knowledge a second, and finally making such externalised knowledge available for people to learn from. As an example of a knowledge management process, we will now describe varieties of processes for “externalising” tacit knowledge, and making it explicit, what we can call “know how” and “know why”.

2.2 Managing the NPD-MTO Knowledge Transfer

Knowledge management is the process through which firms create and use their institutional or collective knowledge (Civi 2000). Civi (2000) also lists five steps that are needed to be successful in the knowledge management processes: (1) identify the business problems and develop a clear set of goals and objectives for knowledge activities, (2) create a knowledge crew, (3) adapt all level managers to the process, (4) help the companies to change their organizational culture to implement knowledge activities, and (5) provide access to knowledge using various networks and technologies. This approach will be adapted to MTO/ETO-NPD.

2.3 Mapping the process

Business processes in companies thus lie on a continuum from those that are fully mapped and supported throughout the organisation, to those created on ad hoc basis. Most business processes may be mapped in a serial fashion, but they have connections with other processes forming a multi-layered structure, however, decisions made within a process are strongly influenced by the availability and quality of information and knowledge expertise obtained from other preceding processes. Furthermore, early stage decisions have an impact on subsequent processes, their solution space and constraints. These interactions between knowledge, decisions and multilevel process significantly increase the level of complexity as the project evolves.

The Integrated Computer Aided Definition (IDEF) is one particular method supported by (Braiden, et al 1996) in the mapping of MTO/ETO processes. IDEF is a process mapping or modelling technique developed to facilitate process understanding, analysis, improvement, or reengineering processes (Hunt 1996, Winch & Carr, 2003), as seen Figure 1 below.

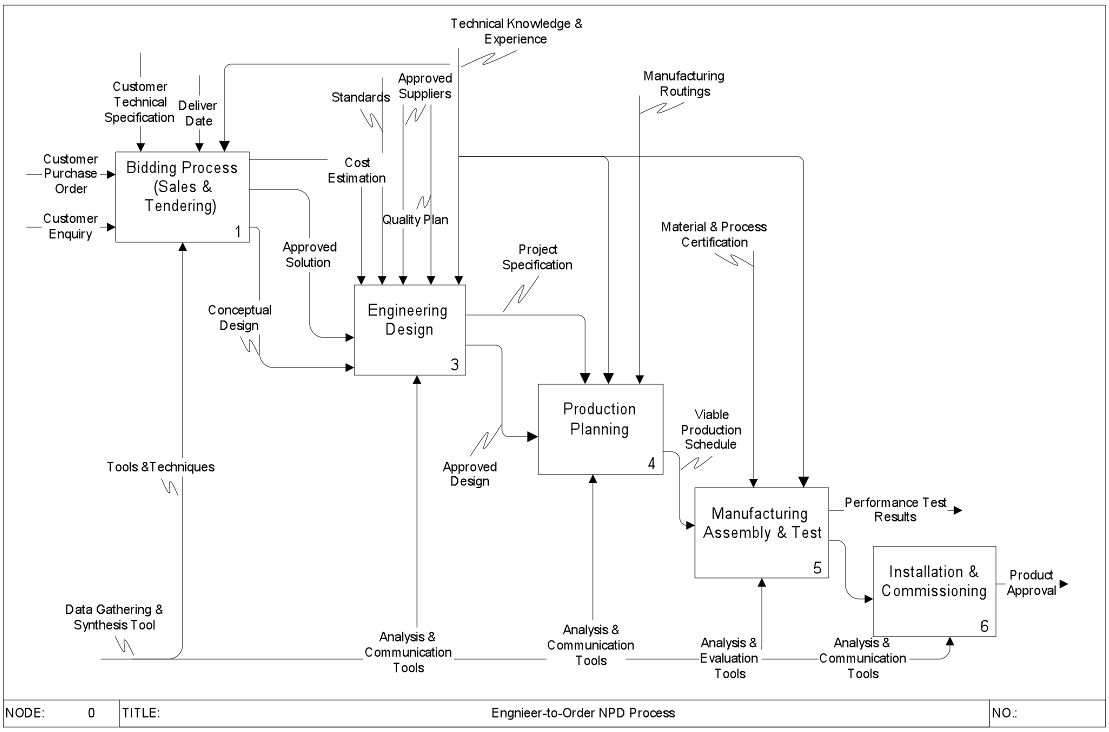

Figure 1 A Generic IDEF(0) Model for the NPD-MTO

From the point of view of assessment, systems analysis and modelling techniques which are commonly used by engineers seeking to understand complex systems. These methods are reviewed by Bravoco and Yadav (1985). The investigation was designed to identify the loop-holes within the process by using IDEF technique. IDEF is a standard modelling method used to establish function models, which has already been accepted by most experts and end-users in this field. Diagrams are formed based on the Inputs-Controls-Outputs-Mechanisms (ICOM) Code and there are strict syntax and semantic rules, which ensure that the model is described precisely. Because of its rigor, it can be integrated seamlessly with other types of models such as IDEF1X (Cheng, 2000). However a common limitation of this technique is that it neglects the significance of tacit knowledge, information systems and personal routines and knowledge workers. There is also limited amount of research data that exists in particularly within MTO/ETO manufacturers from both a practical and theoretical sense about managing the knowledge transfer across projects in terms of project-based learning. In order to assess the robustness of the MTO/ETO-NPD process, as well as the opportunities for knowledge transfer & project-based learning, we argue that capturing the process reliability provokes the need for an analytical model throughout decision-making process in a more structured process manner. By extending the integrated definition for function modelling (IDEF0)-based modelling approach the paper demonstrates how to calculate the quality of the resource output and the robustness of the 'know-how' and 'know why' within such MTO/ETO manufacturing projects. This assessment must address all MTO/ETO product development issues, such as uncertainty and risk, as well as the opportunity for knowledge transfer.

The next section will show how the description of the events as they happen, as well as the assessment of the process. This assessed will be shared within the management of such MTO/ETO manufacturing projects, as well as providing analytical measure supporting the reliability in order to support future projects.

3 Research Methodology

The researcher adopted an action research approach interacting with 'live' or on-going issues that allowed a focus on different aspects of the manufacturing process. First, the process of MTO/ETO-NPD was examined by using IDEF methodologies. Second, project uncertainties when managing new manufacturing projects are examined. There is a limit amount of research data that exists about the NPD-MTO from both a practical and theoretical sense, therefore two longitudinal case studies provided an empirical method of inquiry which enabled the researcher to investigate sharing knowledge within a real life context using multiple resources of evidence. This paper presents the findings of these two case studies. Within the two case study companies a number of 'live' projects were examined allowing the researcher to focus on different aspects on the NPD-MTO process e.g. quotation, order entry, engineering, manufacturing, testing, despatch & other (project management). Between 30 and 40 interviews were conducted for data gathering and process mapping purposes. In addition project related documentation was made available to the researcher. The investigation was designed to identify the loop-holes within the NPD-MTO processes and particular attention was given to the critical decision making points and mechanisms of transferring the business processes.

The industrial survey instrument attempted to establish the structure, issues and problems across the two MTO manufacturing organisations with particular focus on the use of knowledge transfer opportunities, thus the researcher defined the needs and requirements for the successful NPD process in order to develop the conceptual framework for analysing the 'robustness' of such MTO/ETO manufacturing projects.

4 The Case Studies

The two companies where UK based, with Company X is crane manufacture that has produced material handling equipment for over 125 years. Company Y is the principle plant for the groups' core pump systems product range. The company is a market leader, has an excellent reputation, and can be considered to be successful when compared to its sister companies and competitors. One of the companies strengths is its readiness to review its' operations and receive external inputs, hence its' involvement with this research. Table 1 provides a summary of the findings. These factors have increased the need to review the NPD-MTO process in order maximise competitiveness, and improve the organisation's sustainability within the marketplace.

4.1 The Approach

The model provides both theoretical and managerial insights into the 'Knowledge Transfer' between process flexibility and process capability. Finally, the implications of a specific MTO/ETO manufacturing projects will be explored. The investigation was designed to identify the existing process characteristics. The action research approach also provided a unique perspective into all functions of company including sales and design prior to manufacturing process.

Table 1 A summary of findings in Companies X & Y

	Company X	Company Y
NPD-MTO characteristics	Design, Development and Manufacture of gantry cranes & material handling equipment	Design, Development and Manufacture of Engineered Pumps for the oil & gas industries
People Employed	100	150
Ave Project Value (£)	£450K	£750K
Number of Project Milestones	15	28
MTO Lead times	12-20 weeks	28-40 weeks
NPD-MTO Critical Activities		
Requirement Identification and Management	Requirements Capture at Bid stage Customer Feedback loops and User involvement Changes in Scope and new requirements from customer Negotiation Skills Product Standardisation	Requirements Capture at Bid stage Learning from Customers Changes in Scope and new requirements from customer Staffing pressures at Bid Stage Poor Risk assessment Issue Product Standardisation Negotiation Skills
Coordination of Information	Task Definition Project Feedback Loops Bid and Project Team continuity Technical Uncertainty and Difficulty	Technical uncertainties and Difficulties Project Structure Supplier Management Negotiation Skills Bid and Project Team continuity Technical uncertainties and Difficulties
Process Issues	Inattention to procedure Staffing Levels Supplier Management Organisation Structure	Project Structure Organisation Structure Compatibility between new product and previous generations of technology Technical Uncertainty and Difficulty Management of suppliers

4.2 Model Proposal: Process Assessment Matrix

The first step in process modelling is thus concerned with establishing the objectives of the process from which a context and viewpoint can be understood. Moreover, this is a top-down method which starts from general process activities and moves on to more specific issues, from a single page that represents an entire system to more detailed pages that explain how the subsections of how the system work (Goulden & Rawlins 1995). For this example these activities determine the general structure of the process, such as the managing the product development process. The research proposal was to identify and analyse the process 'know-how and the 'know-why', as well as the reliability of the outputs, in terms of the inputs and resources in order to ensure the consecutive outputs were reliable and in accordance with the desired objectives of the project.

As mentioned already in section 2.3 the decomposition of the IDEF0 technique was used. However, the approach expanded upon in order to assess and quantify the level of uncertainty at each stage of the process. By capturing & representing the process characteristics allows the individuals to assess the 'robustness' of the project. The application of the IDEF Assessment Matrix requires a detailed analysis of the output quality of the NPD activities. This necessitates the use of formal systematic methodology, and probing approach for capturing the characteristics of the activity throughout the NPD process. This allows for continuous updating of the process quality as project evolves through the NPD-MTO process, providing the platform for Knowledge Transfer. The flowcharted activities were categorised as the following:

- **Process Robustness**: The technique is a valuable tool to assess the robustness and sensitivity of the process to changes in the quality of inputs, controls and tools. The developed model can be used as an assessment tool to calculate vulnerability whereby various scenarios are tested and the severity and impact of each on the success of the process is evaluated. Preventative action can then be identified and implemented.

- **Process Quality** The technique can also be used to monitor and control the process. Frequent evaluation of the process model throughout the project life can be carried out using current data to assess whether the quality of the outputs are achievable or not. Remedial actions can be identified and implemented. This avoids the ad hoc approach to process improvement when the numbers of factors to consider make it difficult to understand their interdependency.

Figure 2 below illustrates in a single IDEF activity box, the transformation of input to output is carried out by the attribute(s), which are also referred to as resources, following certain instructions or operating within certain conditions and monitors referred to as “Controls”. The Activity Assessment Matrix is also presented in Figure 2 below. The calculation is based on the ‘High, ‘Medium’ or ‘Low’ ranking which is a methodology for analysing potential reliability within the process. The quality of each output is derived from the following criteria:

a. Explicit Knowledge – Relates to the completeness of the data and information received in order to fulfill the output requirements for the individual activity. These are typically based on data and supporting information available within and outside the company.
b. Tool Quality– Related to the quality and effectiveness of the tool/resources in order to cope with the turbulent activities defined with each individual activity.
c. Tacit Knowledge– Represents the skill of the human resource in supporting each individual activity. These are typically based on knowledge, experience, ‘know-how’, available within the process or function.
d. Output Quality Score – Is the result of the resource assessment (Explicit Knowledge, Tool Effectiveness and Tacit Knowledge of Individual or Team) with the combined resource characteristics (inputs, methods and controls) in each individual process activity).
e. Reliability Score – Is the result of the resource assessment of the combined Knowledge, Tool Effectiveness and Tacit Knowledge across the resource characteristics (inputs, methods and controls) in each individual activity).

The proposed technique was developed from the initial survey findings from of the case study companies. To illustrate and validate the approach, it is applied to two of the ETO manufactures in order to identify the knowledge gaps with the NPD process. Two longitudinal case studies provided an empirical method of inquiry enabling the researcher to investigate sharing knowledge within a real life context using multiple resources of evidence.

		Assessment Criteria			
	Activity A2	Explicit Knowledge	Tool Quality	Tacit Knowledge of Individual /Team	**Output Quality**
Attributes	Input 3				
	Method 1				
	Method 2	'H'	'M'	'L'	=HML = 9x3x1
	Control 3				
	Control 3	'H'	'H'	'M'	=HHM =9x9x3
	Reliability	18	12	3	270

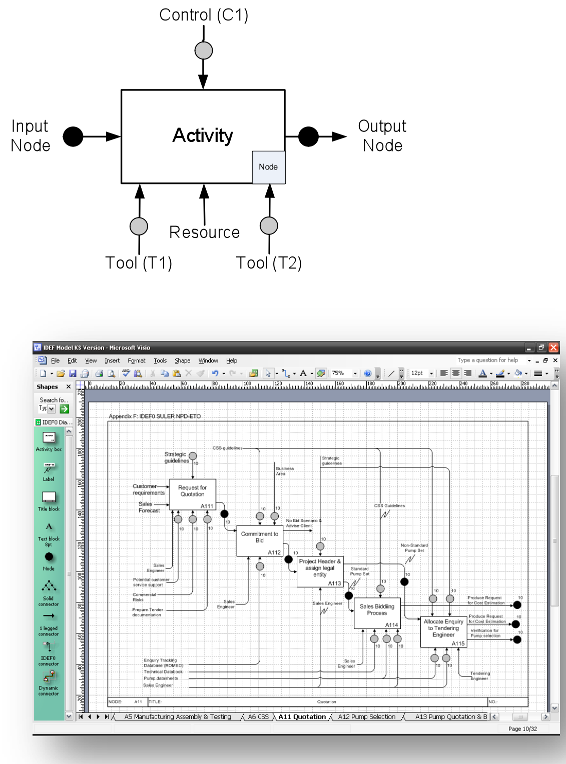

Figure 2; Activity Assessment Matrix & IDEF(0) Assessment in MS Visio

Each activity element was then assessed against the using High (score 9), Medium (score 3) or Low (score 1) rankings and multiplying these ranking scores to calculate the output quality of each activity element (see figure 2 above). This type of analysis provided an assessment of the problems as seen from functional manager's point of view.

4.5 Applying the approach with NPD-MTO

In such MTO/ETO organsations, the sequence of processes and the procedure relations for the various business processes is significant issue, especially with respect to the transfer and reuse of knowledge & experience. The literature on the NPD, includes some of the tools and techniques that may be used to identify the process such as QFD, FMEA, Taguchi, etc (Caffin 1998) and the procedural relationship and group activities together in a systematic way to facilitate integral team building.

The uncertainty factors are concerned primarily with the people (or system) managing and directing the process in terms of tasks and resources, predominately people such as project managers, or other key individuals involved in the NPD process, key departments Process 'A' to Process 'B' such as Tendering, Design, Production etc. There is also the aspect to do with content of transferring knowledge to project-based learning. Here we analyse the performance of the 'Tools' and the level of reliability whether due to poor 'know-how' or 'know-why' (the Tacit Knowledge) through the NPD-MTO process, as seen in Figure 3 below.

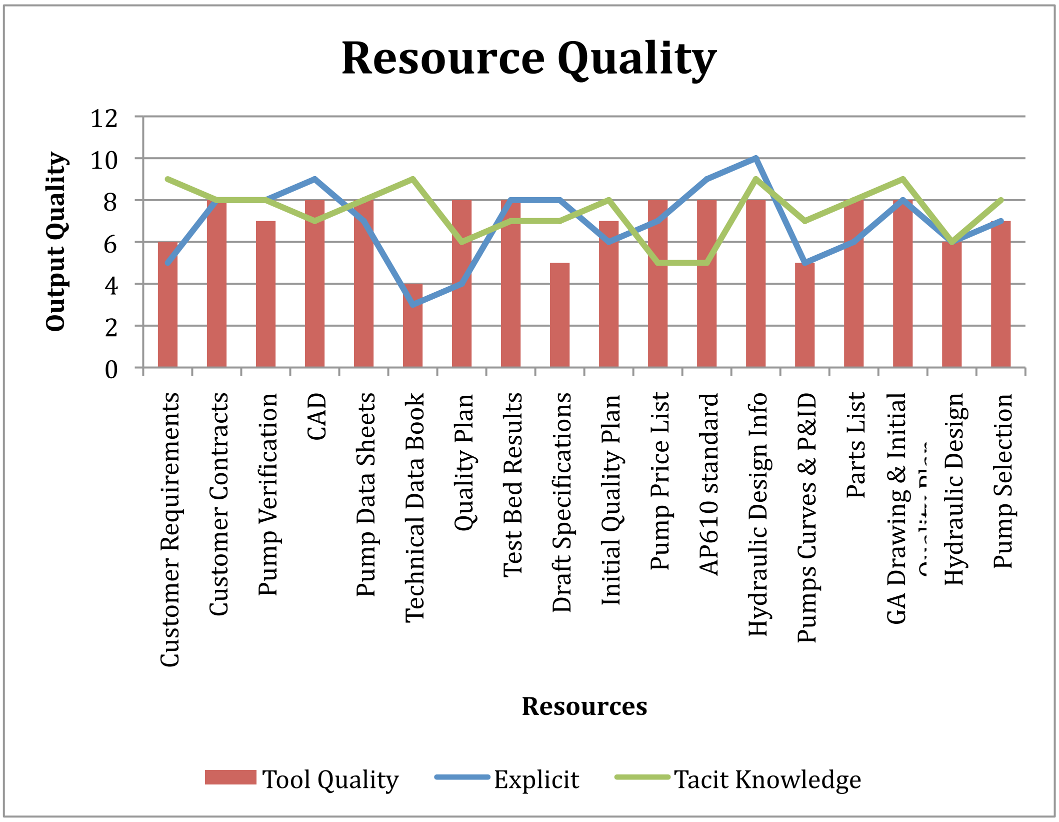

Figure 3: The Tool Quality & Knowledge-Base

To illustrate and validate the proposed approach, it is applied to two case study companies above including the mapping and matrix assessment of the knowledge gaps within their NPD processes. The case studies provided an empirical method of inquiry which enabled the researcher to investigate sharing knowledge within a real life context using multiple resources of evidence. The investigation was designed to identify the loop-holes within the NPD process. Particular attention was given to the critical decision making points and mechanisms for transferring knowledge and personal experience across projects. The above results indentified four general areas (each of which related to 'Hotspots' or "Points of Vulnerability" within the NPD processes) affecting the performance of the project included the following aspects:

- Commercial uncertainty/difficulties and risk
- Organisation and project structure
- Management of requirements capture
- Technical uncertainty/difficulties

5 Balancing the Know-How & Know Why of NPD-MTO: Development of a Project-Based Learning Framework

The study enabled the researcher to gain a much clearer perspective of the proposed methodology, it also allowed the researcher to correct any faults in the initial framework proposition (Reid 2009). Some of these factors tested during this stage included: (a) the clarity of the awareness of management tools in the NPD-MTO process. The above findings indicated that there were four general areas (each of which contribute to a number related to 'Hotspots' which kept coming up within company X & Y include those that relate to:

- Commercial uncertainty/difficulties and risk
- Organisation and project structure
- Management of requirements capture
- Technical uncertainty/difficulties

The interface between senior management and the project team is also very important based on specific case histories of past projects. One of the senior Project Managers expresses

"Management's responsibilities during the life cycle project must be executed in a disciplined, consistent, and focused manner".

These responsibilities include the alignment of projects with the firm's business strategy. The membership of the project team required pertinent functional representation, and disciplined decisions, or 'Stage Gate' reviews. Problems in these areas tended to be more serious, and can be mitigated by a improving the robustness of the MTO-NPD activities.

5.1 Project 'Hotpots'

Previously agreed stage-gates/milestones checklists were of considerable benefit to improving the discipline and consistency of reliability of the process. To avoid such problems as incomplete or insufficient information, the integration of NPD tools, have resulted in companies making new products better and faster. However, there is usually very little information available to managers to guide them through the decision making process, and assist them with uncertainties in the NPD process, this was prominent in the interviewed company. This is largely because of the difficulties associated with knowing what has been sold at the 'front-end' of the process. Figure 4 below shows on going frustrations).

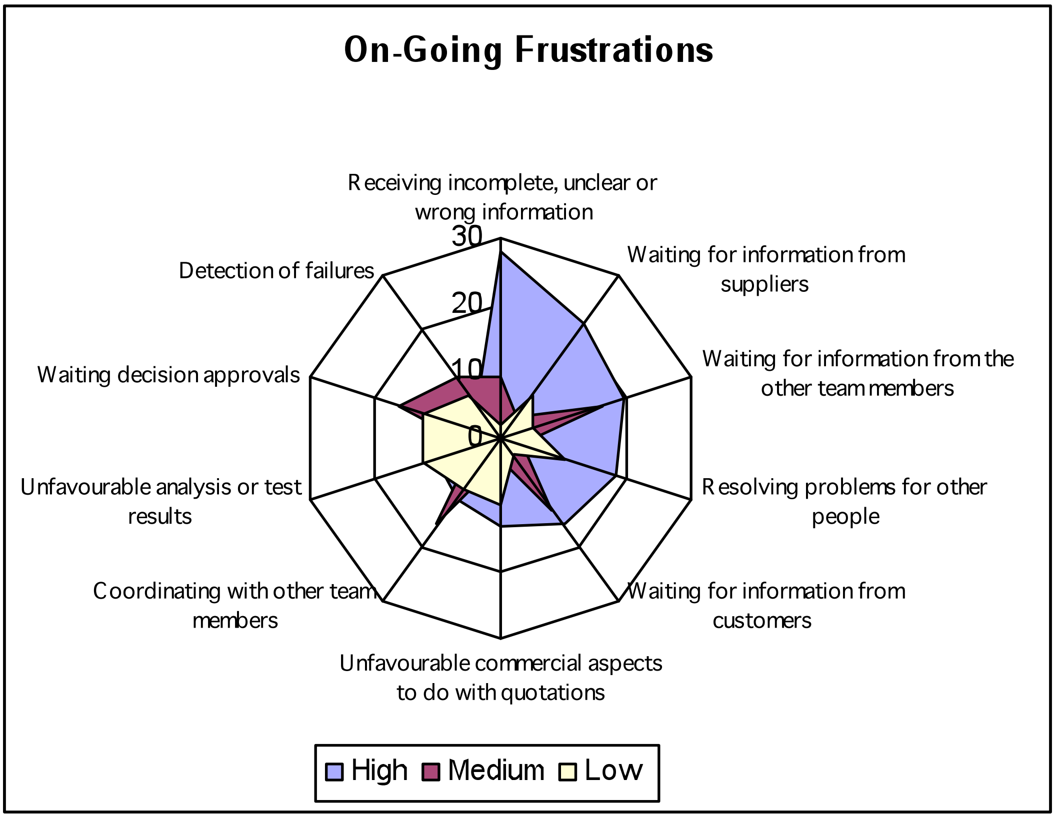

Figure 4: Ongoing Frustrations within Company Y

Figure 5 below highlights the project 'hotspots', based on the Activity Assessment Matrix in figure 2 above, which also highlighted the highest level of uncertainty concentrated pre-manufacturing stages of the project.

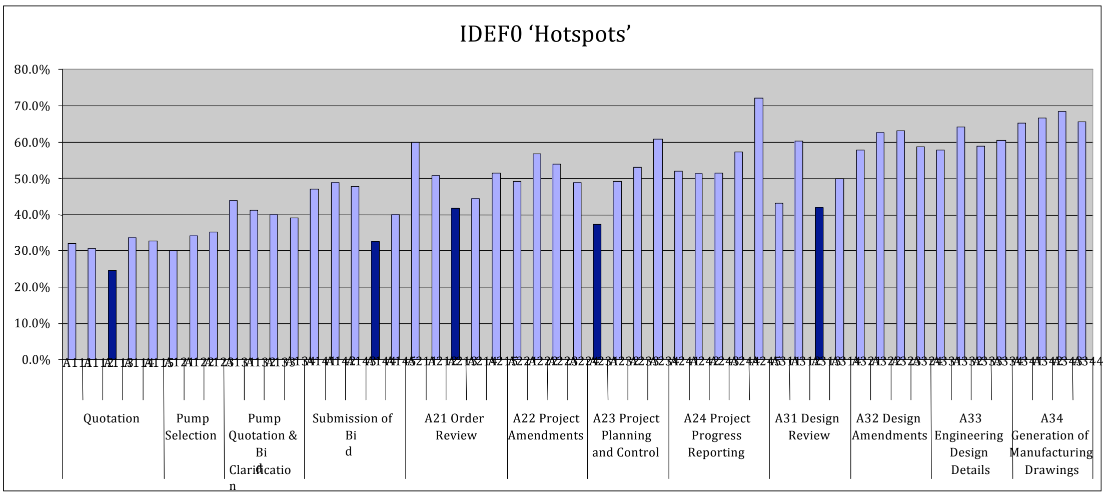

Figure 5: Activity 'Process Quality', including 'Hotspots' of the NPD-MTO process within Company Y.

6 Refinement of the Approach

Analysis of a number of ‘live’ projects identified the broader issues in the relationships with project process, which could be traced to different levels of the organisation, such as key performance indicators. Here we analyse project’s overall performance against previous case histories which assessed the level of reliability whether due to poor ‘information sharing’ or low ‘knowledge transfer. The data gathered through a quantitative analysis of:

- The contributions made by previous projects (i.e. the outputs of the phase)
- The cross impact of ‘live’ projects
- Post mortems of past projects, feedback loops

The assessment also focused on the identification of critical phases with respect to project process in terms of information flow and workflow and resources available. Bottlenecks, project uncertainty can be identified as a gap between ‘as-is’ model and ‘ideal’ model of a particular ‘best practice’ criteria defined by the manufacturing organisation. The assessment must be performed in a number of steps including:

- ‘Knowledge Sharing’ questionnaire
- Process Model (IDEF0 model)
- Process Assessment (IDEF Knowledge Assessment, MS Excel-Visio)
- Project Archive (Access database)

These findings provided the building blocks for a ‘Project-Based Learning’ framework (see figure 6 below) that would enable MTO/ETOs to solve the real problems and provided case-study material for new projects. Within company X the senior management team has since resolved these issues mentioned above. As an example the issue of project ‘hotspots’ highlighted in Figure 5 above. Furthermore, the researcher investigated a variety of tools for supporting Knowledge Transfer to Project-based learning at those ‘Hotspots’ under the following headings:

- Critical Reflection
- Post Project Reviews
- Storytelling
- Information/Knowledge Based/Expert System Tools

By signalling out those problem areas which are experienced time and time again across these projects is not to suggest that they should be ranked as most important to those that appear less frequent. The research is not currently in the position to rank the “hotspots” in descending order of importance. However, some of these identified will have short-term significance, often influencing whether a project is completed on time and within budget; an example might be the difficulties experienced in moving from the bid stage to the development and production. Other will have more significant and long-term impacts on the overall efficiency and productivity of the company, for example the inattention to project management procedures. The above results indicate the importance of managing complex projects at is most critical phases. Monitoring the risk and uncertainty of the process was also a key driver for the creation of a learning organisation. So the modelling methodology should enable analysis of not only process task and process flow but also the critical phases of the project process particularly the robustness of human and resource capital within the organisation.

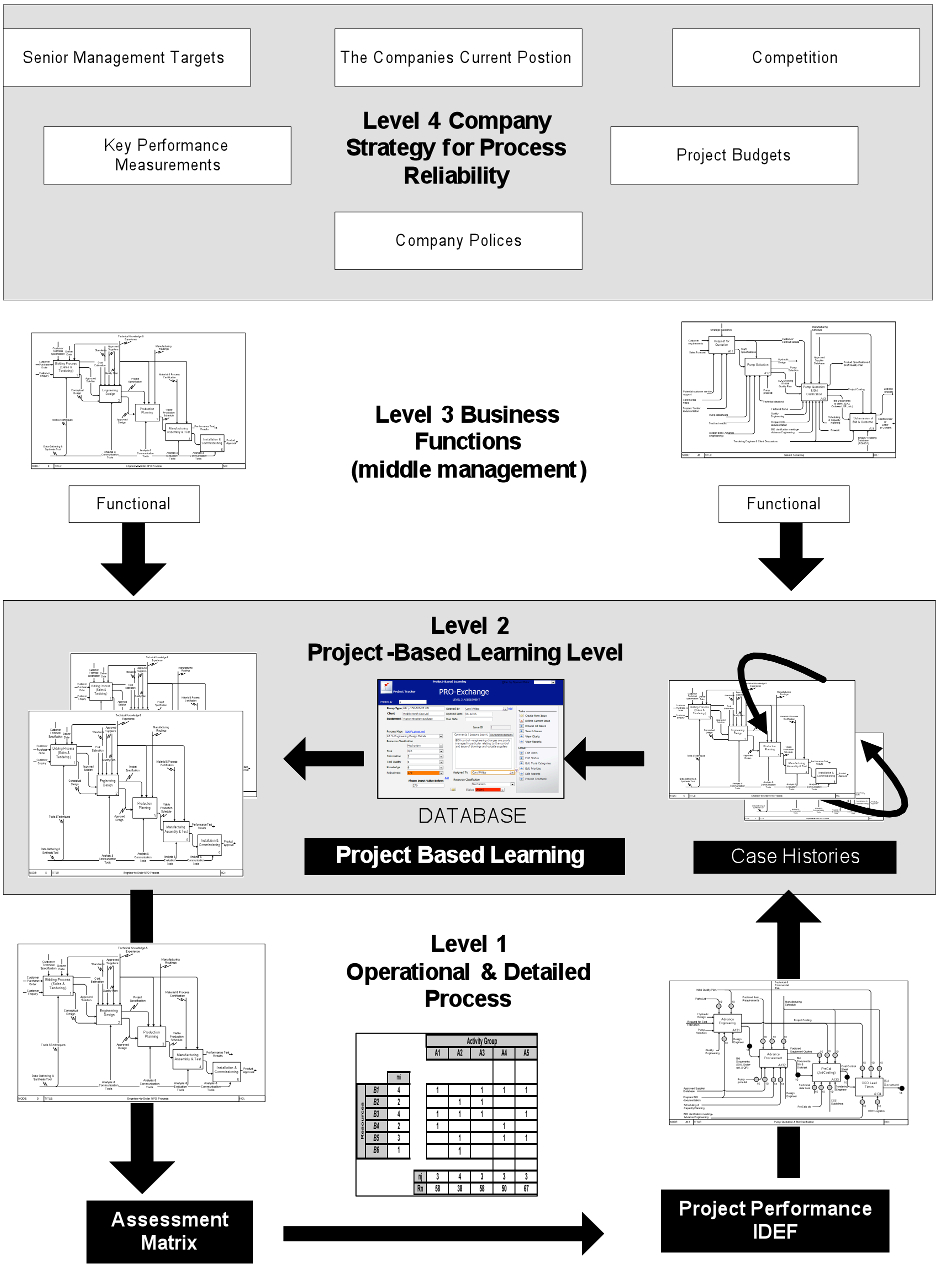

Figure 6: Framework for Project-Based Learning

7 Conclusions

The challenges for successful Knowledge Transfer was to incorporate six project 'Hotspot's or critical decision-making points within new MTO/ETO projects, were in the following NPD phases or stage-gates, as well as incorporating them to the company's key performance indicators (KPIs) system:

4) Project Header & Commercial Details (Non-physical)
5) Project Launch (Non-physical)
6) Order/ Review (Non-physical)

7) Design & Procurement (Non-Physical)
8) Manufacturing & Test (Physical)
9) Project Closeout (Physical)

The other challenges were the improving the reliability and robustness of the project's 'front-end' activities; improving the participation and commitment of non-core project members. The author also believes that no matter what tools and methods are applied the full benefits of developing a knowledge sharing culture, the proposed analytical methodology will not be realised until these issues are resolved. Due to the 'NPD-MTO uncertainties' the proposed framework will assist both MTO/ETO manufactures, as well as project-driven Small Medium Enterprises (SMEs), by improving the visibility of the process activities and the assessment of the reliability of the process. Knowledge Transfer is achievable via a process of reviewing and reflection, and the visibility to review past projects in a structured manner and transfer the 'Know-Why' is transferable via a number of tools and techniques, such as story-telling, expert systems or scenarios.

This paper has discussed the need and presented the requirements for a project-based learning to the NPD process within such MTO/ETO manufacturers. Our sample case studies highlighted the need for capturing the NPD-MTO knowledge transfer for developing the opportunity for learning from previous case experiences as highlighted in Figure 6 above. The outcome of this study would help MTO/ETO manufacturers in their complex product development processes in respect to eliminating potential errors and identifying the quality of the resources involved in bringing a product or system to market. Future work will attempt to develop a knowledge-base system that will support project managers creating a learning organization in order to support their future growth.

References:

Braiden, P. M. Sitoh, P. J. Hicks, C. Earl, C. F (1996) 'Manufacturing Strategy and Manufacturing Control System Performance for Companies Manufacturing Complex Engineer to Order Products', Integrated Design and Process Technology, 3, 342-349

Bravoco, R. R., Yadav, S. B., (1985) 'Methodology to model the information structure of an organisation', Journal of Systems and Software, 5(1)pp 59-71.

Caffyn, S., (1998) 'The scope for the application of continuous improvement to the process of new product development', University of Brighton PhD Thesis, Brighton.

Cameron, N. S., Braiden, P. M.(2004)' Using business process re-engineering for the development of production efficiency in companies making engineered to order products', International Journal of Production Economics, Volume 89, Issue 3, 18, Pages 261-273

Cameron, N. S., Braiden, P. M. (1999), Assessing the methodologies of business process reengineering, Advances in Manufacturing technology III, Proceedings of 15th Conference on Manufacturing Research, 6-8th September, University of Bath, UK, 395-400.

Caron, F. & Fiore, A. (1995) Engineer-to-order companies: how to integrate manufacturing and innovative processes, International Journal of Project Management, 13, (5), pp. 313± 319.

Cheng, L.A., (2000) 'Systematic Derivation of IDEF1X models from IDEF0 models', in: Proceedings of the 5th Annual Conference of the UK Academy for Information Systems (UKAIS), Cardiff, UK,

Civi, E., Knowledge management as a competitive asset: a review. Market. Intelligence. Planning., 2000, 18(4), 166–174.

Gingele, J., Childe, S. J. and Miles, M. E.(2003) 'Incorporating links to ISO 9001 into manufacturing process models using IDEF 9000', International Journal of Production Research, 41: 13, 3091 — 3118

Goulden, C. Rawlins, L.: "A hybrid model for process quality costing" International Journal of Quality & Reliability Management; Volume: 12 Issue: 8; 1995Hicks, C., Earl, C. F., McGovern, T., (2000) 'Analysis of company structure and business processes in the capital goods industry in the U.K', IEEE Transactions on Engineering Management, 47(4) 414-423.

Gunasekaran, A. and Ngai, E. W. T.(2007) 'Knowledge management in 21st century manufacturing', International Journal of Production Research, 45: 11, 2391 — 2418.

Hendry, L. C. (2009) 'Product customisation: an empirical study of competitive advantage and repeat business', International Journal of Production Research,, First published on: 12 June 2009 (iFirst)

Hicks, C., Braiden P. M., 2000a, Computer-aided production management issues in the engineer-to-order production of complex capital goods explored using a simulation approach International Journal of Production Research, 1366-588X, Volume 38, Issue 18, 2000, Pages 4783 – 4810

Hicks, C., McGovern, T., Earl, C. F. (2000b) 'Supply chain management: A strategic issue in engineer to ordermanufacturing', International Journal of Production Economics, 65 (2) pp.179-190.

Hicks B.J., Culley S.J.; Allen R.D.; Mullineux (2002), G.A framework for the requirements of capturing, storing and reusing information and knowledge in engineering design, International Journal of Information Management, Volume 22, Number 4, August 2002 , pp. 263-280(18).

Howick, S., Eden, C., (2007), 'Learning in disrupted projects: on the nature of corporate and personal learning', International Journal of Production Research, Vol. 45, No. 12, , pp.2775–2797 (15).

Hunt V.D., "Process Mapping: How to Reengineer Your Business Processes", John Wiley, New York, 1996

Konijnendijk, P. A., (1994) 'Co-ordinating marketing and manufacturing in ETO companies', International Journal of Production Economics, Vol. 37 pp19-26. Kransdorff, A. (1996), 'Using the benefits of Hindsight' The Role of Post Project Analysis ' The Learning Organization, Volume 3, Number 1, pp11-15.

Lewis, M.W. (1998), "Iterative triangulation: a theory development process using existing case studies", Journal of Operations Management, Vol. 16 pp.455-69.

Maffin, D., Thwaites, A. (1998), Regional competitiveness, University of Newcastle upon Tyne, Newcastle upon Tyne,

Michael Beer, Sven C. Voelpel, Marius Leibold, Eden B. Tekie (2005), Strategic Management as Organizational Learning: Developing Fit and Alignment through a Disciplined Process, Long Range Planning, Volume 38, Issue 5, October 2005, Pages 445-465

Muntslag, D., (1994) Profit and risk evaluation in customer driven manufacturing International Journal of Production Economics, volume 36 pp97-107

Nonaka, I., Takeuchi, H. (1995), The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation, Oxford University Press, Oxford.

Rahem, A., Rahim, A., Baksh M,. (2003), The need for a new product development framework for engineer-to-order products. European Journal for Innovation Management Volume 6 No. 3, pp.182-196.

Reid, I., Cockerham G., Pickford C., (2004) A Methodology for Project–Based Learning within Engineer-to-Order (ETO) Product Development, International Conference Manufacturing Research (ICMR, 2004) Sheffield Hallam University, Sheffield UK.

Reid I (2009) A Project-Based Learning Framework for Complex Systems and Products. 32nd Institute for Small Business & Entrepreneurship Conference. ISBE, 137 Euston Road, London, NW1 2AA, Liverpool pp 1-18.

Ridley, I., Braiden, P. M., 1997, 'Key Business Processes in the Role of New ETO Product Development', Engineering Design Centre, University of Newcastle, Newcastle upon Tyne, UK.

Rush, H & Hansen, K (1998). Hotspots in Complex Product Systems: emerging issues in innovation management. Technovation, May.

Teng Sheng-Hsien, Ho Shin-Yann, Failure mode and effects analysis—an integrated approach for product design and process control, Int. J. Qual. Reliab. Manag. 13 (5) (1996) 8–26, MCB University Press.

Winch, G.M., Carr, B. "Processes, maps and protocols: understanding the shape of the construction process", Construction Management and Economics, Vol. 19 No.5, pp.519-31. (2001),