Deon Paul Fouche

Performance Measurement, Estimating and Control of Offshore Modification Projects

Doctoral thesis
for the degree of doktor ingeniør

Trondheim, April 2006

Norwegian University of
Science and Technology
Faculty of Engineering Science and Technology
Department of Production and Quality Engineering

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PREFACE

In the course of the last ten years my work as an employee with a major oil company has been involved with project control and estimating of modification work in the offshore sector of the Norwegian oil and gas industry. At the time of starting to work with modifications, there were relatively few offshore modification projects from which to draw experience. The conventional wisdom at the time, drawn from the little hard experience that was available, amounted to recognition of the fact that modification work was subject to great uncertainty. The wags recommended the use of pi as a contingency factor.

The range of this involvement has at different times covered early phase estimating, preparation of contract compensation formats, bid check estimates and formats for contract bid evaluations, as well as detailed cost control follow up during execution. In parallel and more or less continuously, the major part of my work also included the collection and analysis of historical performance data as a basis for verifying and improving estimating methods.

The nature of this work, particularly that of operative estimating in parallel with collection and analysis of performance data from a wide range of modification projects, naturally led to exposure, at times very closely, to projects that experienced overruns and poor performance. Being an operative estimator, these experiences stimulated enquiry regarding the validity of the methods of estimating, the accuracy of the norms of performance and legitimacy of project control methods that in most instances failed to foresee impending overruns early enough for any mitigating action to have much effect.

In one instance this process of enquiry led to involvement in a multi-company program aimed at pooling modification performance data from several sources in order to establish a broader base of experience than any one company could muster alone. The essence of this study was to collect actual man-hours used and collate with installed weights in order to establish performance norms for offshore work directly, rather than interpolate from performance norms derived form onshore module fabrication adjusted by the use of offshore factors, which was current at the time, and in most organisations is still in use. The hard data was supplemented by information concerning the nature of the work and a quantitative/qualitative performance report that included comparisons of the initial budget values with the final results as well as a summary of the nature of problems encountered during the execution period. The approach established in the study was continued and extended and is the basis for much of the work in this thesis.

Subsequently, wishing to continue to draw on as broad a base of experience as possible, and in connection with enquiries regarding whether the subject of my work was of interest within the context of the PS2000 program, I came into contact with Professor Asbjørn Rolstadås, who suggested that the material might form the basis of a Dr.Ing study. The results of that study are presented in this dissertation.

The dissertation addresses the use of performance measurement as a core process and holistic basis for the many project control activities required in the short term of a project life cycle as well as experience transfer and organisational learning processes in a longer term multi-project perspective.

Acknowledgements

I would like to thank Prof Rolstadås whose good will and support, advice and assistance throughout made it possible to complete this project while maintaining a full work load and in spite of the extra time that a full work situation demanded. Specific matters that I could point to are the initial support for the project, as mentioned above, advice regarding the choice of supplementary studies that provided new perspectives on the core material of this study, and advice regarding the formulation of this dissertation.

All my line managers in my company have been supportive of this project, but I would like to thank three persons in particular, Ingve Forus, Terje Masdal and Dag Gabrielsen, with regard to encouragement and their efforts in acquiring technical support and approval of funding.

Finally, I would like to thank my partner, Olga Gjerde, for her forbearance over a long period of time with this egocentric project, not the least being a stoic acceptance of a far greater share than her rightful due of our common house-holding. In addition, her diligence in proof-reading several versions of this dissertation, particularly with regard to language presentation, and as a discussion partner, in spite of the need to acquire a necessary level of insight into the subject matter, has been of invaluable assistance.

Deon Paul Fouché

Asker,

April, 2006

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LIST OF FIGURES AND TABLES

List of acronyms, keywords and terminology

Absolute contra relative performance measurement implies measurement of resource use (cost, man-hours) in terms of material quantities processed as distinct from actual resource use measured in terms of planned resource use.

Absolute measures of performance express efficiency in specific physical units such as man-hours used per tonne of piping installed; resources used expressed in terms of the product of the process.

Benchmarking (BM) denotes the process of continuously measuring and comparing business processes against comparable processes in leading organisations to obtain information that will help the organisation identify and implement improvements.

Benchmarking contra performance measurement: benchmarking is seen as qualitative comparison of processes with a view to isolating root causes of superior performance compared to the essentially quantitative character of performance measurement.

BOQ denotes the term 'Bill of Quantities'.

CI denotes the term 'Continuous Improvement'.

Discipline: a grouping of specific types of work of similar character such as piping or steelwork. Discipline mix is the relative content of the disciplines making up the concept, also termed Discipline Balance. Sub-discipline denotes a sub-division of the discipline work into categories with characteristic properties.

EPCI: an acronym for a type of contract covering engineering, procurement, construction and installation all in the scope of work of one contractor.

Experience transfer: a process of organisational learning whereby events, processes and occurrences, both detrimental and beneficial, are made explicit and communicable to other actors in order to secure that lessons learnt in one project become part of the knowledge base of the project community of practice.

Generic: characteristic of a genus or class; applied to (any individual of) a large group or class; general; not specific or special – The Concise Oxford Dictionary The use of the term in BM context seems to derive from and apply to practices comparing core business processes regardless of industry, but accordingly may also be used in a general context to describe activities and functions characteristic for specific types of industrial applications (such as oil and gas projects).

Greenfield denotes 'new' development as opposed to 'modification'.

Integration denotes the offshore installation of the materials that can be lifted on board by the platform cranes as opposed to modularisation that denotes the installation of major sub-assemblies that require lifting by external crane vessel.

Modification: pertains to construction work on an oil production facility in production and means rebuilding and extending existing facilities for changed functions and duties, normally during ongoing production (often termed brownfield or retrofit).

MTO denotes the term 'Material take-off'.

Process: The term process seems subject to some ambiguity, being applied both to ongoing industrial, administrative or service activities in general as well as being synonymous with qualitative aspects of benchmarking performance. It is essentially multi-functional in nature.

Relative measurement expresses performance as a ratio of resources actually used to perform a certain activity in terms of resources planned and has no specific physical units of measurement.

TQM denotes the term 'Total Quality Management'.

VO denotes variation order, a formal change to contractual scope of work such as additions or deletions or changes to the premises for performing the work, such as the design basis or project milestones.

Volume of processed materials means quantities of materials subjected to a work process be it engineering (quantities designed and drawn), fabrication (quantities cut, fitted, welded, painted), installation (quantities installed in final location), or similar, and measured in appropriate units (number, length, weight, area).

1 INTRODUCTION

The purpose of this dissertation is to describe and demonstrate the practical application of techniques of performance measurement to the control and execution of modification projects in the offshore oil industry. The techniques were developed partly as a consequence of practical work in the industry and partly as a consequence of the work underpinning this dissertation.

The term ‘performance measurement’ as used here is a measure of efficiency, such as man-hours per tonne, that denotes resources used (man-hours) expressed in terms of the product of the activity (tonnes of processed materials). This form of measurement is regarded as absolute as opposed to relative forms of measurement which measure actual resources used (man-hours) with respect planned resource use (man-hours) to perform specific work operations. The distinction is central in this dissertation.

The term ‘modification projects’, as used here, is generally taken to apply to all work performed on offshore platforms and production facilities which are in production. The nature of modification work is very varied, typically covering tie-back of satellite fields onto existing production facilities, or process and utility upgrades in response to changing duties in the production process as reservoir depletion proceeds, or general optimisation of production facilities, often concerned with process optimisation, as well as discrete elements of maintenance and repair type of work. The work is normally performed as discrete projects and may vary in size range from approximately 40 MNOK (6 M$ US) up to about 2000 MNOK (300 M$ US).

Modification projects have intrinsic tendencies towards growth in material quantities and complexity of work. This is due to the indeterminate interface between the existing facility and the new installations, the general complexity of modification work and the special conditions related to work on a process plant in ongoing production. Such growth may lead to disruption of the orderly progress of the work, straining the project resource and time frame and posing particular project control challenges. The potentially high order of magnitude of these disruptive effects speaks for methods to identify scope and complexity growth as early as possible in order to provide the longest possible management horizon for corrective action. The normative approach to project control is relativistic and historically it has not succeeded in mitigating the overrun tendencies in modification work. The performance measurement techniques proposed in this thesis are deemed to have the necessary characteristics to mitigate this problem.

The terms performance measurement and benchmarking used here are loosely interchangeable and include processes for quantification of performance, both as a basis for project control purposes, such as estimating, and as a platform for qualitative analysis in order to identify causes of 'good' or 'bad' performance and thereby identify good practice. In effect, the major difference may be a matter of scale on the one hand, and intent on the other. Benchmarkers are often more concerned with qualitative issues while performance measurement processes often stop at quantitative level. However, it could be said that there is a continuum between the concepts that includes both qualitative and quantitative perspectives as prerequisites to the understanding of the underlying causality of underperformance.

Benchmarking and performance measurement have been available as management tools for several years. Nevertheless, few practical applications to the management of projects, either particular or general, have been developed beyond the principal theoretical stage or beyond applications at high levels of aggregation. The repetitive nature of projects and high degree of project control sophistication in the oil industry would seem to be conducive to the application of benchmarking methods, with respect to both control of individual projects and general development and improvement of project control techniques. However, in view of the transitory nature of projects, the organisational dispositions between the individual projects and the overarching project owner organisation must be taken into account in setting up benchmarking processes.

Although benchmarking is in use for comparing performance at high levels of aggregation (say field development costs in NOK/barrel) the parameters used, while adequate to document a major performance deviation, are less useful for identifying the prime cause(s) of deviations, be they positive or negative. This is due to lack of detail parameters that measure the central activities of the process under scrutiny. In effect, when using high aggregation performance measures to exclusion and having identified a deviation, a detailed benchmarking exercise will need to be planned from scratch in order to start to identify the real causes of the deviation and ultimately a basis for action or conclusion. This is not a practical proposition in the transitory world of projects. If, on the other hand, parameters that measure the core processes are built into the measurement structure, it will provide a basis for analysis in further detail that may more easily yield conclusive insights on which to base further qualitative investigation. From this point of view, benchmarking processes suitable for application to improvement of industrial processes will benefit by including a detailed substructure of significant parameters that measure core processes in order to sustain a detailed performance analysis.

To illustrate what is meant by substructure, consider, as an example, the overrun analysis of three projects that underpins the cost risk simulation model for modification work that forms one of the performance measurement applications presented as part of this thesis. The existence of detailed performance data permitted comparison of core activities for all the projects, thereby exposing a consistent overrun in all core activities and defining orders of magnitude. This information signalled that correlation effects are present in the most severe overrun cases thereby laying an important premise for the simulation model which hitherto had tended to ignore correlation effects since they were difficult to define and quantify. The existence of parameters that specifically measure efficiency in all core activities facilitates the type of quantitative-qualitative analysis of project performance presented in the Appendices of this thesis. In turn this supports the qualitative investigations that are the essence of benchmarking processes directly without needing to set up specific benchmarking exercises for which it would probably be too late anyway. Deviation may also be related to other factors that are not apparent at early stages of study such as concept maturity, changed complexity, schedule restraints, or project specific installation restraints seen either in isolation alone or interrelated. All such constraints may significantly impact performance and are of interest in an individual project control context as well as being of more general 'good practice' interest. It can at once be seen that these are 'micro' benchmarking perspectives of interest to the estimator and hence the project controller but exist in the domain many associate with performance measurement rather than benchmarking. However, this appears paradoxical given the detailed level of benchmarking activities in the manufacturing industry from which the whole concept arises.

Possibly as a consequence of the lack of detailed structure, or possibly as a consequence of insufficient account of the special organisational dispositions surrounding projects, techniques of performance measurement and benchmarking have not yet found a role as a project control tool either for setting or measuring performance targets for individual projects or as a tool for improving project control techniques in general. From experience in Norway and the UK, it can be claimed that this is valid for both oil companies and the major contractors. Project control and performance measurement continues to be based primarily on the <u>relative</u> project-specific goals that are defined by budget and milestone commitments. <u>Absolute</u> goals in the form of production efficiencies, measured for example in terms of quantities of processed materials (typically man-hours per tonne), as a measure of industrial production efficiency in project type work, are not in common and systematic use. This view is supported by the fact that the monitoring of quantities of materials comprising the scope of work of any project is generally only <u>*indirectly*</u> part of the project control monitoring effort. It may thus be said that project control as a management technique has a focus on reporting and budgeting rather than scope monitoring, production optimisation and problem-preventive analysis seeking to anticipate and manage potential problems and maximise project performance. Problem-preventive analysis, for which correlation between cost, man-hour use and worked material volumes is essential, will accordingly be dependent on maintaining a good practice of performance measurement. Such performance measurement may also have the long-term beneficial effect that both project control personnel and management personnel gain a better 'feel' for the product and for the commonly applied fabrication techniques and efficiencies, as exemplified by the 'rules-of-thumb' that were typical of shipyards and other construction industry in the past.

Many would object at the statements made above, pointing to the fact that man-hour per tonne factors and similar units are precisely the basis for estimating and that such factors are regularly extracted from close-out data. This is certainly so, but there is nevertheless little systematic ongoing practice of performance measurement and analysis in use as project control tools either in the short term perspective of a single project or the long term multi-project perspective. Accordingly, it can be said that in the absence of absolute measures of performance at any level of detail, continuous improvement processes will be handicapped by being restricted to evaluation of relative performance and qualitative experiences only. Fact is that many experience-recycling activities initiated as project start-up activities restrict the information exchange with other projects to qualitative experiences only, such as contractual, administrative and organisational problems, real success of a project being judged exclusively in terms of its relative goals (e.g. on budget, on schedule, acceptable quality).

The main purpose of this dissertation is then to describe the measurement structures and techniques that have been developed for measuring and comparing performance in modification projects. These techniques have application as specific project control tools, such as estimating tools, and in application as improvement tools for project performance in general, such as close-out reviews. These techniques are intended to extend and supplement, not replace, the normative project reporting practices and simultaneously provide 'rules-of-thumb' in traditional (pre-computer) terms of reference in order to give project management personnel a better general feel for the performance capability of the industry as a basis for continual performance improvement.

It must be pointed out that the promotion of these practices and methods has not been without challenge, so that this dissertation will also provide a review of the difficulties associated with gaining acceptance and implementation on a broad basis of the methods and techniques described here.

The structure of the dissertation is as follows:

Chapter 1 - introduction to the general background of the project control environment, the special nature of the modification work, the specific issues relevant to project control of modification work and the role of performance measurement

Chapter 2 – review of professional literature for related topics of research and other perspectives on the general theme of the dissertation

Chapter 3 - presentation of a generic data structuring format for performance measurement of modification work, including discourse on the metrics of performance measurement and characteristics of modification work

Chapter 4 – discourse concerning estimating and related project control applications based on performance measurement

Chapter 5 - discourse regarding risk and presentation of a generic cost risk analysis model for modification projects based on historical performance data

Chapter 6 - discourse and presentation of a generalised benchmarking process model for projects based on life cycle performance measurement processes

Chapter 7 - an organisation theoretical perspective on the project control environment, issues of experience transfer and processes of organisational learning

Appendix 1 and 2 – description of two project case studies illustrative of the application of the quantitative and qualitative review method, based on performance measurement processes

Appendix 3 – description of a practical basis for selection of estimating parameters from performance data that harmonises with the premises of basic risk analysis theory

The discourse will of necessity follow a cyclic nature due to the fact that several discipline perspectives influence the way project work is performed, the nature of the tools used to perform administrative tasks and the prescribed reporting structures. These discipline perspectives perform aspects of the project execution task that overlap, but that are not always aligned to common advantage.

1.1 The underlying estimating perspective

As mentioned above, the structures and techniques presented here have their roots in estimating techniques for modification work based on analysis of close-out data.

The nature of modification work is extremely varied, each new job providing new problems and challenges to the estimator, which in turn requires a more or less continuous follow-up and analysis of close-out data as a basis for continuously developing and refining the parameters and estimating techniques available. This on-going process, on which renewal and development of the estimating practices relies, is a natural basis for benchmarking and performance measurement, as the parameters collected from the set of projects which have been analysed is a natural measure of good or poor practice. It follows as well, in so far as estimating systems are product and process based, that estimating has the same concerns as, and is part of, project control.

An essential feature of any estimating system based on the analysis of close-out data is the correct and consistent structuring of data in a way which facilitates data collection in the field and that, on analysis, provides parameters which can be applied to information available from early engineering studies.

Were the general principles for structuring of data to be incorporated in the structure of contract compensation and reporting formats, it would facilitate the easy and efficient collection of data after close-out. This would provide, in the same manner, a basis for the efficient use of the reference data in a wider project control context, such as the basis for evaluation of tenders and the setting of absolute project performance targets based on production, rather than budgets, using actual performance levels in the industry as a standard.

The major advantage, however, would be acquiring the means to easily update the overall resource framework of the project on the basis of quantity updates combined with an objective assessment of likely performance. In short it would provide an alternative means of updating project baselines using the same estimating techniques as were used prior to sanction [1]. Alternatively, it would provide verification of baseline updates produced by other means, typically by aggregation from detailed work packages or by addition of VO-based costs and man-hour assessments. As mentioned previously, VO-based estimates leave a lot to be desired regarding accuracy and in any

[1] Noting that these methods are normally discontinued in the execution phase.

event only reflect changes and not concept development. Work package or task sheet based estimates are not complete until all the detailed engineering is completed, leaving the project in a state of *'information black-out [2]'* (Clark, Lorenzoni, 1985) for a long and critical period while the concept is matured as detailed engineering progresses. This information gap can be filled by continuation of the quantity based estimating practices after sanction as an integral part of the regular baseline updates, thereby providing a life-cycle role for active estimating in the project. Such a routine will also serve to promote the utility to the project of the feedback routines based on performance measurement on which the continual development of good estimating methods is dependent.

The applications and techniques described here are based on a structure of 'universal' applicability to all modification work, utilising the same basic parameters for both estimating and performance measurement. Thus the same parameters can be applied in the context of improving project control practices in general by iterative application in the full life cycle of the individual project.

The methods have been developed for offshore modification work, but the principles involved are more widely applicable, for instance for greenfield projects in the oil industry, both onshore and offshore.

1.2 The nature of modification work

As previously mentioned, modification work is extremely varied, each project having an own special character.

The purpose of modification engineering is to maximise the utilisation of the existing infrastructure for new functions and duties. The resulting physical interface between the project scope and the rest of the facility cannot be clearly defined at early stages of development. Not all systems will be affected and only parts of systems and not whole systems will be rebuilt. The impact of changes in one system may affect the duties and functional requirements in other systems while the effects will often only be identified as detailed engineering proceeds. The installation process will in itself often require extensive temporary works and site clearance may require extensive demolition or relocations, all of which are project specific. These aspects place other demands on the phasing of development engineering activities for modification work, which follows a different logic and is exposed to different uncertainties than greenfield developments.

In addition the nature of modification work is generally very complex, not only in the individual project, but also seen as a whole with resulting difficulty in identifying reference parameters which have universal validity and out of which project-specific requirements can be identified. For instance, it is normally not possible to interpolate on the basis of system or plant capacities, a technique much used in greenfield work. This topic is discussed in more detail in Chapter 5. Projects vary considerably in size, character and complexity all dependent on their purpose and the installations where the work will be performed. Material cost, installation methods and local circumstances relate to specific functions, a specific platform and specific locations for performing the work on the platform may vary considerably. This can be exemplified by considering a single discipline, typically piping, where for example, material quality, pipe dimensions, valve content and layout complexity may vary considerably between different projects. Considering equipment, one project may require a compressor, another a separator, a third only a pig receiver, all at significantly different cost and requiring different bulk infrastructure. Installation locations vary widely with regard to local constraints such as access, work method, congestion, weather exposure, safe practice and so on and the degree of exposure to the effects of local conditions is partly dependant on size. All such constraints may have considerable effect on the work content and cost

[2] Terminology borrowed from Clark and Lorenzoni.

of each individual project contributing to the high variability that can be observed in the performance data.

1.3 The project control challenge

From the above it is apparent that modification work has a significant risk exposure to change in the nature and quantity of the work to be performed as a result of the concept development processes, often resulting in volume growth in materials and man-hour use, schedule overrun and ultimately cost growth. Risk of material volume growth will endure at least until detailed engineering is completed whereas the risk of man-hour growth applies to all phases and is coupled to complexity and location, as well as quantity growth. Equally, the resulting strain on resources and disruption of the orderly progress of the work may have seriously negative effects on efficiency. All this in turn provides a focus for project control practices aimed at verification of the commitment frame after award of contract in the form of factual material volumes, the nature and complexity of the subcomponents and production constraints. Not the least important element of verification is the offshore accommodation requirements with respect to schedule and project milestones. This focus on verification of the scope of work is, however, by no means common practise.

It is of primary importance for successful execution that the factual volumes and nature of the materials be established as early as possible in order to provide as long a management horizon as possible for the implementation of corrective action in the event of significant deviation from the original assumptions and committed goals. Consequently routines for the establishment and follow-up of material volumes, with an appropriate degree of detail along with the associated assessment of cost, man-hour and schedule impact, are central to the methods described here and should be implemented as a central discipline in project control activities.

Paradoxically, material measurement systems are a routine and essential part of the engineering and procurement activities performed by the contractors. This suggests that the data are already available in the project management systems, but are not systematically employed in project control practices. What is required is a recognition of the added value that analysis of the data can provide, and the will to initiate and sustain programs of measurement and analysis throughout the lifecycle of the individual project and beyond in a multi-project multi-cycle context.

1.4 The original contribution

The dialog above points to the need to establish project control procedures that may correct the deficiencies of the current normative project control and project administrative practices which are observably inadequate with regard to identifying and resolving the problems experienced by overrun projects at a sufficiently early stage to limit the efficiency loss associated with many overrun projects.

Accordingly, that is the focus of the practical/theoretical work research and method development the results of which are presented in this thesis. The problem of performance failure (overrun) and inadequate experience transfer (inability to learn from past failures) has been examined in the context of first-hand experience with modification project work in the offshore oil industry in capacity of estimator and project controller. The methods presented are intended to promote a systematic and cyclic quantitative-qualitative type of performance review based on long term performance measurement processes.

The proposals of this dissertation form an holistic framework for systematic improvement in an experience transfer process model which extends the current project control practices with essentially four elements:

1) A data structuring model as a basis for collecting and collating performance data with metrics suitable for absolute quantitative performance measurement relating resources and quantity/complexity aspects of the product, suitable for comparing all types of modification projects in all phases of development . The breakdown structure in the model will serve as a coherent holistic basis for all project control activities, such as estimating as well as contract compensation formats and incentive mechanisms. This will increase the total utility of data collection and analysis effort and also eliminate frustrating and wasteful duplication of data processing effort in project administration. Consistent product-resource data structuring systems currently available are inadequate and also are not currently used on an holistic basis for the structuring of data.

2) A systematic review and re-estimation procedure for project baselines based on updated quantities and normalised historical performance data formatted in accordance with 1) above, as the concept is matured during detailed engineering. This scope verification and estimate update procedure should preferably take place as an inter-active process between the project controllers and estimators from the base organisation responsible for the early phase estimates. Such procedures are not part of current practice.

3) A cost risk simulation model for modification work based on historical performance data intended to better define the magnitude and range of performance related risk scenaria and validate the need for the other risk mitigating actions defined here.

3) A benchmarking process model based on systematic review of quantitative performance in a multi-project cycle context with a view to isolating qualitative issues affecting performance such as complexity, concept maturity, market problems, schedule pressures, and so on and the management methods and construction methods chosen in response to such problems. Applied in the context of a specific project, this implies a close-out review of projected and final performance in quantitative terms in order to identify anomalies of performance and benchmark them with respect to normative historical performance data for the purpose of establishing qualitative causal effects. Like 2) above, this should take place as an inter-active process between the project team and representatives from the base organisation. A special aspect of this model is recognition of the special organisational context in which project benchmarking takes place and how this may influence the functionality of benchmarking processes in project based organisations.

By contrast to the above proposals, the methods currently in use for project control are static and relative and performance measurement in absolute terms is sporadic. Experience transfer processes are performed ad hoc by the individual project, are qualitative in nature and generally lack continuity in a multi-project cycle context.

1.5 Research Method - the way the work was done

The methods presented here have their roots partly in a program to introduce performance targets to project control of modification projects. But the deeper roots are based in a program to improve estimating methods for modification work in general, which in turn stemmed from a project that experienced problems of material and complexity growth and associated strained commitment frame as related in the previous sections.

The program was performed under the auspices of one specific oil company, in co-operation with project partners and several other oil companies that were invited to contribute. The program was based on performance data from a selection of modification projects contributed by each participating company, for which purpose a suitable data structuring system was required. A central feature of the program was to utilise actual reported man-hours from measured field work and collate with the installed materials expressed both in weight and, where possible, in other characteristic metrics such as metres. The role of the author was, as the representative of the coordinating company, to prepare the data structuring basis for the study, collate and analyse the data, prepare conclusions and submit a final report. The work took the form of a series of coordinating meetings and workshops in order to gain consensus from all the participants for the basis of the study and endorsement of the final product.

The study was limited in scope, addressing only man-hour and weight relations. Thus the basis and the conclusions of the program were subsequently developed further in-house by the author to encompass the full project scope and followed up by the systematic collection and analysis of data from some 50 projects, mainly in-house, in all stages of development up to the present time. The project portfolio used in this thesis includes some 38 projects. The data structures described in Chapter 3 were used to format the data on a consistent basis. Some of the results of these processes are presented in this thesis.

The data analysis constituted of the setting up of performance comparisons and life cycle profiles of the type presented in Appendix 1 and 2, in order that the performance might be judged against the background defined by the existing data. This process involved setting up the data in the formats presented in Appendix 1 and 2 and isolating quantitative anomalies. The purpose of these comparisons was to gauge whether the level of performance was representative of general or special characteristics and circumstances pertaining to the project at hand. It follows that qualitative criteria relating to each new set of data had to be established and this involved dialogue with project personnel.

In addition to the data analysis described above, the processes involved continuous dialogue with project and base organisation management in attempts to engage their commitment to the data collection procedures, using as primary argument the immediate value of performance data as a basis for estimating tools. An important aspect was gaining understanding for the usefulness, in a benchmarking context, of the qualitative insights arising out of the quantitative analyses. The nature of these insights is described in the case descriptions of Appendices 1 and 2.

One of the observations of these dialogues is that these issues easily translate into critique of methods and performance that invokes defensive responses. Accordingly, such dialogues are best conducted on an informal basis. The conclusions of this thesis are thus not based on analysis of the results of formally structured interviews, rather the synthesis of impressions gathered sporadically over longer periods of time.

Thus the material and conclusions presented here are based on observations and analyses made in the course of several years of interaction with projects and base organisations in several companies, both owner and contractor, in Norway, the UK, the USA and France, in addition to co-operative dialogues with professional organisations [3] working on the same matters. These interactions were part of a practical work situation as an operative estimator, which not only included collection and analysis of data for the purpose of underpinning estimating practices, but also the development of unified formats for data collection, estimating, contract compensation formats coupled to weight development and alternative weight estimating routines in project control. There is no discrete time-limited program of research underpinning this thesis.

It follows from the above that the author may be seen in the role of a practitioner-enquirer as defined by Argyris and Schøn (Argyris, Schøn, 1996). In their work, Argyris and Schøn maintain that a practitioner-inquirer, being a participant in the processes being studied, must necessarily study himself and his own work and may be predisposed concerning the outcome of the analysis.

[3] Performance Forum

This raises questions concerning the objectivity of criteria and the rigour of judgement in reaching conclusions. The implication is that the explanations and solutions proposed here may merely be coincidentally congruent with the circumstances; others may not see any alignment at all. However, as mentioned previously, the explanations and the proposals are the result of several years of reflection backed up by a breadth of practical experience in general construction and the oil and gas industry, gained while working with engineering, construction, QA (Quality Assurance) auditing, project control, estimating and contracting, at various times and partly in parallel. Not the least relevant experience is that of QA auditing, which was primarily concerned with verifying the correspondence of formal procedures of work with actual practice. A by-product of auditing experience is insight into the interaction effects provoked by enquiry. This insight leads to an understanding of the importance of objective judgement regarding to what extent deviation is significant to the final outcome of the work process under review.

In the final instance, however, that which is presented here is naturally the result of an attempt to systemise and explicate the more-or-less tacit (meaning un-theorised) conclusions of accumulated reflections resulting from practical day-to-day work with the matter of this dissertation over several years. In this regard, the formal studies of this Dr.Ing program have contributed the stimulus of new perspectives as well as a formal and rigorous basis with which to articulate the tacit conclusions of practitioner-enquirer reflections. This program has included studies in the fields of project management, project control, benchmarking, risk analysis and organisation theory.

Some of the views expressed here are in contradiction with the normative practices and theories of the project management community. In this light, it was considered important to seek endorsement for these views in the professional literature. This need was addressed by scanning the professional press for research publications in the same field as a supplement to the literature included in the formal studies forming part of this Dr.Ing project. Thus the literature studies have included three perspective levels, namely research and review articles in the professional press, literature specific to the various fields of project work, and the overarching organisation theory.

Notwithstanding the above considerations, it is important to emphasize that the motivation to pursue these investigations has all the time had a practical outcome as its goal, namely the promotion of the methods and procedures advocated in this thesis as normative practice in the project control community. This has an impact on the form the models take. They will be judged for the extent they are perceived to define and address legitimate problems and the way they work in the pragmatic circumstances of the everyday working life. The methods are intended to promote the insight which is essential to proficiency, through participation. In order to promote participation, transparency and flexibility of method and system are prerequisites. To this end, standard application software tools, graphical presentations and a descriptive rationale have been used, as far as possible.

Argyris and Schøn point out that a practitioner-enquirer will, for pragmatic reasons, tend to stop enquiry when a satisfactory conclusion has been reached. By contrast, academic enquiry is expected to endure as long as there exist unanswered questions to clarify. In this particular case, contrary to the above view, the methods proposed in this thesis promote institutionalisation of enquiry in the form of analytic and reflective project review and closure procedures. This is consistent with the general principles promoted by Argyris and Schøn concerning the nature of organisational learning. In an ongoing multi-project context this applies both to basic processes, such as estimating, as well as the over-arching multi-project analyses and recycling of current performance data on which renewal is based.

2 STATE OF THE ART - A REVIEW OF LITERATURE

STATE OF THE ART IN MANAGEMENT OF MODIFICATION PROJECTS - A REVIEW OF LITERATURE

2.1 Introduction

This chapter comprises a review of literature in the professional press concerning performance measurement, benchmarking and experience transfer as a basis for organisational learning and performance improvement in project based organisations.

The project form of organisation, in general and in the oil industry in particular, has long enjoyed a reputation as an effective form of organisation especially suitable for the realisation of one-off capital development projects. Success in bringing large, complex and technologically innovative developments to fruition under difficult environmental conditions (although not always within budget or schedule) has been associated with a management image of dynamism and innovation. These successes are, however, often marred by the recurrent, though sporadic, cost and schedule overruns that do occur in spite of considerable in-house expertise on the part of organisations that make repeated use of the project from of organisation. It is generally accepted that project-based organisations experience problems related to experience transfer and associated learning potential between projects with a view to performance improvement. They also appear to have difficulty in adopting many of the accepted techniques such as performance measurement and benchmarking as processes leading to performance improvement. The purpose of this chapter is to review relevant literature for publications by other researchers in the same or relatable fields.

2.2 Selection of the literature

A consequence of the focus of this dissertation is a need to scan literature on a broad basis and from several related fields in order to assess the extent to which the above issues feature in the literature of the various actors, schools, or professions that are operative in the project environment. The reason for this is the influence different sector interests exert on the approach to organisational improvement processes and particularly the way performance data is recorded and used before, during and after the project execution cycle. The central disciplines are project management, procurement management, project control/cost engineering/estimation, contract administration and accounting. The contributions of the professional weight engineering and weight based control and estimating consultants are naturally important. The schools of Total Quality Management (TQM)/continuous improvement (CI)/benchmarking (BM), have perspectives of relevance in an overarching sense. More peripherally, the knowledge management professionals and the contributions of the organisational theorists and management consultants and associated processes such as Business Process Reengineering, Work Flow monitoring and organisational learning processes, are important influences on the working environment of projects.

The selected papers have been supplemented with articles from trade publications (Flingtorp, 1999) and professional presentations [4] by consultant practitioners with commercial interests and, where appropriate, the latter have been incorporated in the discussion. These presentations have not been formally published in the professional literature and as such have not been subject to peer review. Nevertheless, the views represent current practise within specialist sectors of the industry.

In general it may be said that the literature scan did not reveal many papers with direct applicability to the themes of this dissertation, but all the selected papers include aspects of general relevance to the underlying rationale.

[4] Pace Project Services and The Performance Forum

2.3 Review of individual papers and discussion

The subject matter of the selected papers is organised sequentially progressing from the general theoretical perspective of the academic to the pragmatic problem-solving perspective of the practitioner. The specific subject matter includes such topics as the suitability of the standard project management techniques to manage all sorts of projects, organisational learning processes such as knowledge diffusion (tacit to explicit), simulation of project dynamics based on rework cycles, benchmarking and process performance measurement as a basis for performance improvement, total quality management analysis techniques, cost and weight estimating systems and a review of commonly recurring weaknesses in improvement processes.

The review and discussion will take the form of a brief review of the content of the selected papers followed by discussion and comment on the content in relation to the research background for this thesis. The conclusion will include a summation of the general background and general conclusions which may be drawn from a global evaluation of the selected literature.

2.3.1 The suitability of traditional project management techniques

In their paper *The Management of Innovation in Project-based firms*), Keegan and Turner (Keegan, Turner, 2002) take up issues concerning attitudes to innovation in project-based organisations such as the EPC engineering/construction industry.

Keegan and Turner's main thesis is that the traditional innovation literature largely ignores projects and that innovation as a theme is largely ignored in the project management literature. Project-based firms employ many of the organisational features associated with innovation, and projects are portrayed as a fast, flat and flexible approach to managing change and innovation. Most project-based organisations specialise in the design and construction of bespoke products and can therefore be said to be always innovating. "*Their work is always unique, always delivered to bespoke designs, always achieving something new….The necessity to produce bespoke answers to client needs has organisational implications. Project based firms should behave like innovative firms*". On the other hand, these organisations are seen to be mechanistic in their approach to management of projects particularly with regard to views on the usefulness of innovation and the application of standardised project control practices that stifle innovation, where the issue of slack resources is central.

Keegan and Turner conclude that the application of standard project management practices stifles innovation because of the focus on efficiency and control and the selection of projects through pre-conceived set of sanctioning criteria. The authors do differentiate between two types of project, namely innovation projects, (those carried out by companies on behalf of themselves), and more routine projects,(those carried out on behalf of clients), but their findings imply that the same mechanistic approach is adopted for all types of projects. However, their real concern seems to be that there is too little understanding for the right way to manage innovation, where organic management methods are to be preferred rather than traditional mechanistic project management methods. The paper then concludes finally that the project management methods should differentiate in a direction that is more supportive of innovation.

Firstly, it is more likely that the temporary nature of the organisation, the short term goals and tight economic constraints are responsible for the modus operandi of the project-based organisations. Flexible organisational formats such as matrix organisations are more a product of the need to establish the temporary project teams of skilled personnel quickly and are not necessarily focused on innovation.

The above argument does not have the same relevance for both types of project. The distinction between types of projects is an important one. A bespoke product does not necessarily imply a high order of innovation, rather variations on well-known technological/industrial themes, managed, designed and built by highly skilled personnel often within tight constraints of budget, schedule and performance specification. In such a context, project control is of central importance because of the need for efficiency and the need to maintain a focus on the short term goals that are the raison d'etre of the routine project. However, bespoke products may include innovative elements of greater or lesser magnitude such as new technology, extended applications of existing technology or new construction concepts that pose challenges of organisation and control. It is often in such circumstances that projects overrun and challenging technology often receives the blame. However, the magnitude of overruns suggests that there are other contributory factors that do not get caught up by the existing management techniques.

The project management literature focuses on the unique bespoke nature of project work as a central argument for the utilisation of the project organisational model and management methods. This focus on uniqueness encourages the view that individual projects cannot be compared with each other shutting the door on comparative performance measurement as a basis for improvement of project management methods and production techniques. The strong adherence to the standard approach is also a product of the need to establish a working organisation quickly and get on with the job. The routine project is thus not the best arena either for method or product innovation. The specialist personnel who man the projects bring these work procedures and technical expertise with them 'ready made' from the functional organisation, often termed a toolbox, in the form of best practice as well as own experience from previous work, mostly in the form of *tacit knowledge* (Nonaka, Takeuchi, 1995) and *skills as routines* (Nelson, Winter, 1982).

Conversely, it is suggested that, to succeed, the innovative project will need to focus and encourage other qualities than those required to see through a routine project. One may suggest that the routine project may pose similar challenges of definition and control as innovative projects, which by their nature lack definition. Methods that enhance and support control in innovative projects may also have relevance in apparently routine projects, which all have the potential to experience disruption effects that undermine efficiency. The current project management literature does not address those issues. But there is certainly an expectation that management of innovative work lies within the domain of the project management discipline.

Finally, it is appropriate to point out that while most routine projects shun innovation for the reasons mentioned above, projects may nevertheless exhibit great creative energy under special circumstances, for example when confronted with a crisis. [5] Under these circumstances resources will often not be an issue and motivation is normally very high. From this we may conclude that it is the skills of the personnel brought to bear on a problem within a known technological/industrial context that is the clue to success, not relaxation of controls. In fact the omission of activities such as progress control and scope management may be detrimental to the project performance as a whole.

The need for project management techniques to differentiate between the types of project is also endorsed by Shenhar, Dvir, Levy and Maltz in their paper *Project Success: A multi-dimensional Strategic Concept* (Shenhar, Dvir, Levy, Maltz ,2002).

Shenhar, et.al, differentiate between types of projects, grading projects in accordance with the level of technological uncertainty and the corresponding level of innovative technological creativity embodied in the projects goals. These levels are: <u>low-tech</u> (construction/road-building), <u>medium tech</u> (mainly existing base technology, but often incurring some new technology or facility upgrades), <u>high tech</u> (mainly new technology) and <u>super high tech</u> (developing new technologies). This spectrum of gradations corresponds for both papers. Shenhar et.al. conclude that success criteria and management techniques need to be differentiated according to types of project. Much

[5] Referring here to the successful project recovery after the loss of the Sleipner A GBS during construction, which resulted in serious proposals by some management consultants to stimulate creative energy in projects through artificial crisis situations.

of the traditional project management literature has treated all projects as the same under the assumption that '*one approach fits all*'. It must however be mentioned that the main thrust of their paper is to examine the role of projects in a wider strategic context beyond the immediate goal of completion within the traditional constraints of time, budget and performance criteria. That discussion is beyond the scope of this dissertation.

In some respects there is congruency between the conclusions of the above two papers and the position of this thesis in that project management literature does not differentiate between types of projects in so far that the control elements may need to be differentiated as a project progresses and for different types of project and for different elements. In other words, the "*one approach suits all*" approach is unsuitable. As an illustration many routine projects are initiated as studies often requiring a high degree of innovation (in terms of technology, or method of construction, or due to constraints in execution, and so on but within a specific field of expertise). These studies may progress through several approval decision gates to a construction phase where the control regime will be very different to a study. Even so, such a project may retain elements of high uncertainty such as prototype equipment that will require an own control regime, and conceivably an own budget and risk allocation within the context of the more common elements. For such projects, among which modification projects may often be found, the traditional approach alone will often be inadequate. In any event the control regime ought to be varied depending on the size, overall cost, character and risk of the project, but the paper does not address how this pragmatic issue should be handled.

The problem that remains, however, is how to secure a sufficient degree of balance between routine and innovation in the project control and management approach to the special problems that cause overruns in routine projects. Routines, such as monitoring of weight development during detailed engineering, that can expose latent problems sufficiently early that due action can be taken to eliminate the negative effects of surprises, is one of the particular elements that is not addressed as part of the project control effort in the industry as a whole.

2.3.2 Diffusion of knowledge in organisations as a basis for performance improvement

While on the issue of innovation and creativity it may be appropriate to look more closely at Armistead's and Meakin's paper *A Framework for Practising Knowledge Management* (Armistead, Meakin, 2002).

Armistead and Meakin are concerned with the diffusion of knowledge in organisations as a basis for performance improvement. The issues are those of tacit versus explicit knowledge, the locus of knowledge in individuals as opposed to organisations and the type of processes whereby tacit knowledge may be made accessible through codification. Their findings are that the majority of knowledge codification processes are '*prescriptive*' and formalised at the organisational level, they are strongly associated with information technology, and rely on the '*compliance*' of individuals in knowledge sharing routines. This approach is seen as mechanistic and control oriented. At the other end of the scale knowledge sharing processes are termed '*adaptive*' on the organisational level and '*self-determined*' on the individual level. These latter processes are more diffuse and are associated with informal networks and communities of practice and problem-solving interaction between individuals and in teams. On the individual level, adaptive knowledge sharing processes are associated with specialist roles and individuals empowered to a greater autonomy in the creation and use of knowledge. The type of knowledge featuring in adaptive processes is seen to be more difficult, and even counterproductive to encode because of its association with individual expertise, interactive creativity and its dependence on trust between individuals. That the latter is seen as creative and the former mechanistic echoes the main thesis of the Keegan and Turner's paper where control processes are seen as stifling for innovation.

Armistead and Meakin are careful to point out that the different categories will serve different purposes and that any organisation, having need of both types, will have to accept a trade off of disadvantages against advantages dependant on the circumstances of use.

There are however pragmatic issues that deserve discussion and that may have a bearing on trade-off, or preferably interaction, between types. It may be that in certain circumstances prescriptive processes are imperative to and precede the adaptive processes and that in fact both processes for making tacit knowledge explicit may form a continuum of data acquisition, analysis and transformation (into information) and ultimately knowledge. Specifically, acquisition of performance data falls in this category. The data format needs to be pre-structured for consistency and to ensure that the data actually will reflect important functionality in the processes under scrutiny and correlate with the right aspects of the product. Reporting of such data needs to be mandatory (prescriptive). It is in the ensuing correlations of process and product and analysis that the data may be converted into information in forms that can be disseminated widely. But it is equally important that this information should be sought out and used on a wider basis if it is to increase the total knowledge base and understanding of the processes in which the organisation is engaged.

The above papers all support the observations made in the introduction that project organisations are resistive to change of method in the longer term. In the absence of prescriptive measures, the resistance may be circumvented by the use of an adaptive knowledge exchange process in the form of a heuristic dialogue at base-line updates and at close-out. This dialogue should take place between the functional organisation and the project based on an assessment of project performance in the light of general experience and performance levels, own expectations and the specific experience gleaned from the most recent project. The focus should be on the basis and development (concept, scope, cost, schedule, performance) of the projects mandate, the actions taken by the project and the utility of the best practice routines in the face of problems experienced in the practical world.

The use of performance reviews in conjunction with base-line updates and close-outs is a routine intended to promote the dissemination and understanding of the uses of performance data. These data gathering processes are difficult to carry out in projects because they are seen to consume scarce resources. Difficulties in setting up and maintaining common data structures result in duplication of effort when sector interests hinder the establishment of common structures capable of serving several sector interests. Pragmatism may endorse the initial use of ‘prescriptive’ processes as pre-requisite for initiating such routines in the absence of voluntary commitment on the part of project management.

2.3.3 Organisational learning processes

The failure to systematically learn as organisations manage and execute multiple project portfolios is the theme of Cooper, Lyneis and Bryant in their paper *Learning to learn, from past to future* (Cooper, Lyneis, Bryant, 2002).

The paper discusses reasons behind the failure to systematically learn from past experience and it presents a project simulation model that facilitates cross-project learning. Principally, the authors attribute this failure to learn to four elements:

a) the misguided prevalent belief that every project is different with little commonality
b) difficulties in determining the true causes of project performance (failure or success)
c) long project cycles that inhibit systematic experience transfer on the part of project managers
d) lack of resources and appropriate organisational structures that practise multi-cycle project reviews

In answer to the matter of non-commonality, the authors present a model for simulating the dynamics of a project that facilitates cross-project comparison. The model consists of three important structures underlying the dynamics of a project, a) the rework cycle, b) positive and negative feedback effects on productivity and quality of work and c) positive and negative inter-action effects between overlapping phases of the work. These concepts are illustrated below in Figure 2.1. The model applies the effects of multiple time-varying conditions such as staff experience levels, work sequence, schedule pressure, progress monitoring, concept changes, quality, productivity and so on to performance in the rework cycle. The authors claim great success with the simulator as an ongoing learning system for managers through recycling of experience.

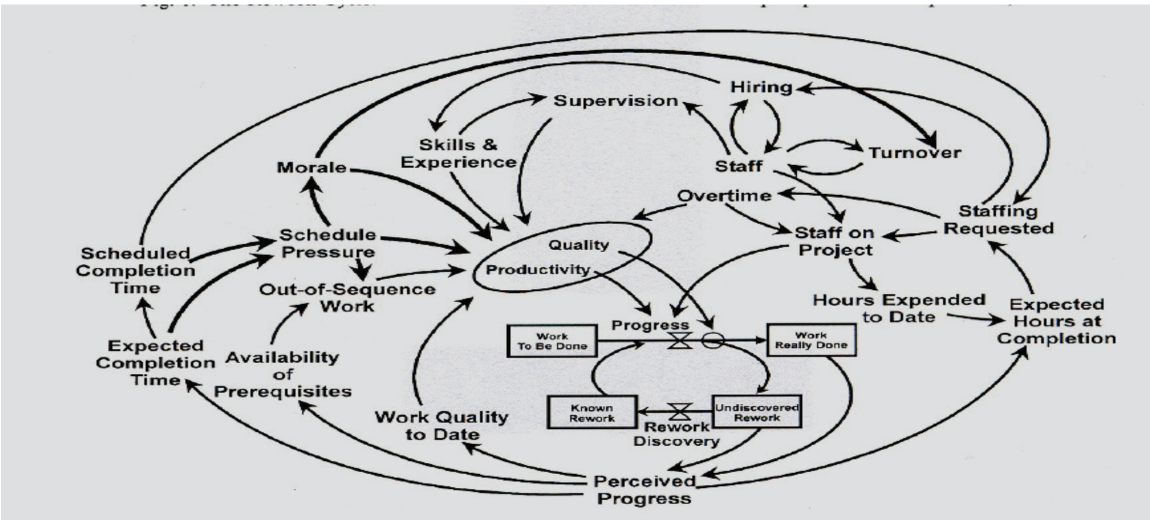

Figure 2-1: Feedback effects of the rework cycle (Cooper, Lyneis, Bryant, 2002)

The four factors affecting the failure to learn from experience support the conclusions of this dissertation. But the approach to experience transfer is much simpler being in essence based on two elements: a) ongoing quantitative benchmarking of performance using a set of preset parameters at a level of detail capable of highlighting all core activities, and b) ongoing qualitative analysis of benchmarking results at the interface between the functional organisation and the project organisation. Deviations from expected levels of performance can be established with reference to quantitative performance data that also provide a point of departure for qualitative discussions regarding the reasons for deviation and possible remedies. There are similarities in approach in so far as both recycle data, both understand the importance of a multi-cycle approach and both have routines for explicating experiences and improving best practices on an ongoing basis. Dialogues concerning issues affecting project performance would in any event feature elements frequently encountered, such as access to qualified manpower, specification stability, conceptual changes, schedule pressures, etc as listed in the above, in so far as they had a bearing on the problems encountered. A freer approach has the advantage of potentially picking up special items peculiar to the specific project under discussion, but also the disadvantage of being less rigorous. Both approaches could be supported by other means to overcome weaknesses.

2.3.4 Benchmarking as basis for improved performance in projects

Understanding how the benchmarking concept can be related and adapted to the unique working environment of the construction industry as a basis for performance improvement is the theme of the paper by Sherif Mohamed titled *Benchmarking and Improving Construction Productivity* (Mohamed, 1996).

The construction industry looks to the manufacturing industry for innovative precedents, among which the success of benchmarking has considerable appeal. But the construction industry has been slow to adopt benchmarking techniques which can be attributed to several factors: 1) misunderstanding of the benchmarking concept; for many practitioners it means measuring everything, 2) confusion surrounding benchmarking procedures regarding what and how to measure, 3) lack of reference data due to problems associated with the collection of data especially related to field based operations and 4) benchmarking requires radical changes in the way information is documented.

Mohamed sees a complete benchmarking program existing on three levels, internal, project and external. Internal benchmarking addresses the organisations overarching business practice of doing business through projects using traditional measures such as customer perspective (service, cost, quality), business evaluation (market share, successful/failed tenders, conflicts) and finance stability (turnover, backlog, return), and also covers comparison with other operators in the same industry. The project level of benchmarking provides measurement of performance of projects in which the organisation is involved using a common set of benchmarking measures consisting of productivity rates, allocated resources and cost analysis, in order to track performance at selected stages in the project lifetime against own expectations and initial estimates. This project level of performance feedback is seen as operational both in the short-term of the project cycle (improvement of efficiency and profit/basis for corrective action) and in the longer term internal multi-cycle context of feedback to the success or otherwise of actions arising from internal benchmarking. It also provides validation of estimating databases and qualitative feedback on technical, managerial and operational aspects to design and construction professionals alike. Two central issues regarding measurement of construction efficiency are awareness of the importance of the rework cycle and constructability and metrics aimed at measuring such effects should be incorporated into the common set of measurement parameters. External benchmarking is seen as adaptation and transfer of successful practices from other types of industry such as manufacturing. Typical examples are team design, simultaneous engineering and design for construction.

This paper is principally a very close parallel to the conclusions of this dissertation, especially regarding the views on interrelation of project and internal benchmarking. The perspective of this paper regards projects as a sub-element in a larger context, that of doing business through projects. Projects are not benchmarked in isolation but as a basis of overall business efficiency. Implementation of actions arising from benchmarking is recognised as taking place in the long term through the medium of the long term business organisation.

The extent to which estimating, monitoring and revision of quantities is included in the scheme is not entirely clear. Construction contracts are often based on preliminary assumptions regarding the quality and quantity of certain types of work that can be critical for the outcome of a project [6]. In such cases re-measurement would seem to be a central requirement of scope management and closely coupled to project economic success. There would thus be a basis for the establishment of ongoing practice of production performance monitoring in both relative (own goals) and absolute (general levels of performance) terms in the individual projects as a basis for internal benchmarking between projects. This routine is seen as a prerequisite for successful benchmarking against other operators in the same industry.

Regarding the matter of measuring everything, it is a fact, particularly in the oil and gas industry, that vast quantities of information are recorded as a consequence of the administrative routines. The challenge is to know what information is available, whether it is easily accessible in intelligible formats and how to correlate it in meaningful contexts.

[6] Two examples:

a) A contract for civil work on a refinery was based on incorrect assumptions regarding the number and nature of the various types of concrete foundation work. The contractor's price was based on M3 concrete which did not take into account the large number of small footings in the process area which only became apparent to the contractor after release of detailed drawings resulting in a large loss for the contractor.

b) A contract for a well-known railway tunnel was let on the expectation of small amounts of leak sealing and wall reinforcement. It subsequently became evident that this assumption was incorrect, resulting in large budget overruns due to the fact that the contractor's price for this type of work was very high.

2.3.5 Performance measurement as a basis for improvement

This theme of performance measurement is the subject of Peter Kueng's paper *Process performance measurement system (PPMS): a tool to support process based organisations* (Kueng, 2003).

Kueng's thesis is that despite dramatic changes wrought in the business environment by the application of concepts such as business process reengineering, " .... *most enterprises do not have an integrated holistic system of gauging their business process performance on a regular basis*". Most enterprises assess their performance mainly through financial measures and thereby fail to relate performance to processes. This inhibits understanding of the processes involved and thereby limits the insight necessary for improvement.

Kueng proceeds to describe and discuss several methods proposed for alleviating this shortcoming such as Balanced Scorecard, Self-assessment, Workflow-based monitoring, Statistical Process control, Activity-based costing (ABC) systems and ISO 9000 certification. None of these fully satisfies the criteria (work flow based monitoring and ABC systems come the closest) of Kueng's proposal for an appropriate process performance measurement system which 1) focuses on processes rather than business units, 2) measures performance holistically by measuring qualitative as well as quantitative aspects, 3) compares current values against historical and target values and 4) disseminates the results (such as current value, target value, gap, trend) to the process actors.

For the rest the paper identifies certain operative constraints and discusses premises for the selection and functionality of performance measurement parameters.. Of these the most important are the acceptability of the chosen indicators to the actors involved and the commitment and empowerment of managers at all levels to the institutionalisation of process performance management into management thinking and the daily practices of an organisation. Finally, Kueng concludes that while performance measurement in itself does not show which actions can be taken to improve a process, it does give a review process a clear direction, it provides a comprehensive performance evaluation and it identifies areas of weakness, all of which can direct attention to relevant facts that may otherwise not have been visible in the absence of a PPMS.

Moving on, another paper that endorses a systematic measurement-analysis approach in quality improvement processes is Søren Bisgaard's paper *The role of scientific method in quality management* (Bisgaard, 2000).

Bisgaard's concern is that the role of scientific measurement and analysis processes as fundamental components in a system of modern quality management, have not received due emphasis in recent expositions on quality management. Hence the article, which sees the potential to apply scientific method in the form of data collection, analysis, modelling and verification to everything we do as an efficient, effective and systematic process of learning and discovery [7].The paper further provides historical case histories in order to document applicability in differing contexts, terminating with perspectives for the future.

These two papers do not specifically address projects as such, but rather processes in general. Projects are time-limited processes, but not repetitive in the short term like manufacturing processes. In contrast to projects, the above papers have a longer perspective in mind. However, project life cycles comprise a few significant and interrelated processes (or phases) such as engineering, procurement, fabrication, installation etc, which are all crucial to the successful outcome of a project. In order to bridge the gap between the limited life span of the individual project and the longer term perspective addressed in the papers, projects may be viewed as batch processes in a long term process for implementing capital investments like oil and gas field developments, or facility upgrades, by use of multiple projects. At present individual projects are

[7] This parallels the theme addressed by Latour (Latour, 1987) and discussed in Chapter 7.5.6

largely measured in relative terms (in terms of project specific goals) such that cross project performance comparison in absolute terms is not available in the long term. For this to be possible it is essential to establish a standardised basis for objective measurement of project processes in absolute terms. With regard to projects, this translates into the need for a long term multi-project cycle of reviews using indicators that provide valid cross-project comparison and review processes. Such an approach limits the range of comparison to specific types work in specific industries

2.3.6 Data structures

The papers reviewed so far all present perspectives on project management improvement in general terms without providing any guidelines on how to go about the task beyond that of initiating some sort of Plan-Do-Study-Act cycle (the Shewhart-Deming cycle articulated by Dr Walter Shewhart and Dr W. Edwards Deming) of measurement and performance review. There is one exception. Cooper, Lyneis and Bryant present a computer simulation model based on a 'rework cycle', but this does not measure and compare in absolute terms. Mohamed suggests what should be measured, at the same time pointing to problems concerning data gathering and field work. Kueng points to the predominance of accounting systems as a basis for measurement, but which generally fail to record data that permit the correlation of performance with processes and product characteristics. The review has so far not identified any case- or project-specific models.

Seeking case-specific models, one may look to the cost engineering article reviews only to find, however, that the data structures which can support experience exchange and cross project comparative processes, and indeed experience exchange processes themselves, are not a focus of interest in the papers. What is a recurrent theme is the issue of cost reporting versus cost engineering, the latter being the alignment of engineering insight with economic and financial insight in support of rational decision making processes at all stages of project development, the former being the preparation of cost reports which are seen as primarily of value to financial issues and of limited support to project management (Drake, Falconer, 1988; Leese, 1986; Muir, 1986; Nunn; 1986). The perspectives of this thesis align with the latter, namely cost engineering. While the issue of historical data features in the discussions, none of the papers addresses the process in any detail or as a platform for periodic or close-out reviews, performance analysis and experience transfer.

The data structures in the articles (Beguinot, 1988; Bungard, 1988; Kok 1988; Leese, 1988; Neil, 1987) concern the build up of estimating, monitoring and reporting requirements of the individual project and are based, at the lowest level of detail, on correlated cost, time and resource elements. This is consistent with normal practice in the industry. These elements in fact provide a basis for the necessary performance and process correlations in so far as the material quantities are included. But the use of these elements for performance comparison would be unduly complex since the elements exist at the lowest level of detail. However, aggregation of all the detail elements up to levels appropriate for performance comparison, such as the major activities in any project, is unduly complicated due to inconsistent metrics and the lack of a unifying data structure. The result, in keeping with normal practice, is that the materials elements are not aggregated along with the man-hour and cost elements. Thus only relative performance and not absolute performance comparison is possible, in the absence of suitable metrics (such as materials quantified in tonnes) which would permit correlated systematic aggregation of all relevant resources such as costs, man-hours and quantities and calculation of typical absolute performance parameters such as man-hours per tonne.

The above papers reflect a situation dated by 20 years. Nevertheless, the situation is deemed to be currently valid apart from the fact that computer applications have developed enormously since then. Indeed, one might have expected that extension of computer capability would have facilitated structuring of the vast quantities of data generated as a natural consequence of the project administration processes.

An example of such a uniform data structuring system is the *Standard Cost Coding System* (NORSOK, 2003) prepared by the Norwegian Petroleum Directorate in cooperation with two Norwegian oil companies, Norsk Hydro and Statoil. There are no equivalent systems in the UK or other sectors of the oil industry. The system consists of 3 code concepts, namely the PBS code (Physical Breakdown Structure), the SAB code (Standard Activity Breakdown) ands the COR code (Code of Resource) of which the PBS would code the type of work [8], the SAB [9] the major processes and the COR [10] the type of resource.

It is generally presumed that the SCCS coding will provide a good basis for the gathering of experience data. The system, however, suffers from elements of inconsistency which, if applied unaltered, inhibit good correlation of performance and product, eg costs, man-hours and material resources. This inconsistency applies primarily to the correlation of materials and labour which do not have a matched breakdown structure. In addition the COR codes do not always align well with the SAB codes, such that process subdivision does not break down consistently when applied to engineering and construction processes and also cannot be applied with equal facility to all contract formats.[11] The consequence is that some contractors have developed their own coding structures and some adhere in broad terms to the SCCS system. The lack of a standard coding system for reporting of experience data may result in duplication of systems, it inevitably increases costs and undermines experience exchange processes. The issue is compounded by the fact that experience data reporting structures do not align well with current monitoring and control practices, not to speak of the constantly changing structure of contract compensation formats. The metrics for the proposed data structuring system for modification work, put forward in this thesis, are built on the basic precepts of the SCCS, but changes have been necessary to eliminate the above shortcomings.

The data structure is presented and reviewed in the succeeding chapters.

An article published in a commercial trade paper which addresses the issue of absolute rather than relative metrics is Henning Flingtorp's article titled *Cost control using weight calculations (Original title Kostnadskontroll gjennom vektberegning)* (Flingtorp,1999).

Flingtorp describes a database system for weight estimating and project screening using building block principles and based on systematic collection and analysis of historical weight and performance data. He points to inadequate scope definition as a result of poor weight estimating practices as a major cause of project cost and schedule overruns. Flingtorp's approach is to estimate the total project scope on the basis of the historical data and the early phase inputs rather than the simple sum of the specified components. A necessary foundation for such systems is access to a broad basis of systemised weight and performance data combined with the necessary expertise and insight to use the early phase design inputs in holistic combination with the historical data.

The system will of necessity require a consistent and systematic breakdown of weight, man-hour use and costs in order to provide a basis for cross project comparison, but the paper gives no indication of the breakdown structure or the building block elements which comprise the system. It is accordingly not possible to assess whether the intermediate levels of aggregation will provide a suitable set of parameters by which to evaluate a projects performance holistically.

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[8] PBS (Physical Breakdown Structure): elements such as topsides, substructure, pipelines, marine operations, etc

[9] SAB (Standard Activity Breakdown): Elemenst such as management, engineering, prefabrication, installation. etc

[10] COR (Code of Resource): Elements such as labour or materials by discipline and sub-discipline

[11] The SCCS aligns well with the conrtractual philosophy from early NS oil and gas projects which comprised an owner's management team, a project service contractor which included engineering and long lead procurement and series of fabrication and installation contracts some of which also include elements of engineering. Other contact strategies do not fit equally well, amongst these the EPCI form of contract much used in modifications. A clearer generic basic structure applicable to all forms of contract with varying contents of management, engineering and fabrication would greatly facilitate processes of structuring of data.

It should be mentioned that Leese's article *Factorial estimating and the "Factest" system - developed within ICI PLC* (Leese, 1988) concerning estimating practices in the chemical industry also bases the system on analysis of historical data.

The basic approach utilises 1) ratios of equipment costs to total costs sub-detailed by system and 2) cost ratios for major disciplines (such as piping) to total costs sub-detailed by system. The basis for this system is the detailed analysis of records from a considerable number of widely differing chemical plant projects.

This system too will of necessity require a consistent breakdown of historical records. It should be noted that the equipment costs are defined by item (this is input derived from early process studies), while the associated discipline components are defined as cost ratios. This approach, in contrast to that of Flingtorp, provides no data for assessing performance in absolute terms such as man-hours per tonne, and is therefore not suitable for cross-project performance comparison.

2.3.7 Knowledge management

No papers were found that address applications of kmowledge management in the specific context of the issues addressed in this dissertation. As previously stated, vast quantities of data are generated as a natural consequence of the project administration processes, such as material administration, payroll administration, weight reporting, work planning and control and reporting processes. This data resource seems currently under-utilised in so far there is some consensus in the literature that data are often not available from previous projects due to the weakness of close-out procedures in many organisations. Data that will provide a sufficient basis for absolute comparison between projects in the form of performance measurement and benchmarking are normally accessible. The necessary small format realignments of existing registers in order to serve multiple needs represent a potential added value as well as efficiency savings to all parties concerned.

2.3.8 Quality assessment of improvement processes

To round off the discussion, it is appropriate at this point to briefly refer to Joyce Nilsson Orsini's paper *Trouble shooting your activities for excellence* (Orsini, 2000).

Orsini's short paper focuses on four recurring weaknesses in the quality practices drawn from assessments of the quality efforts of 23 different companies in the USA. Of these the most important relate to process improvement. Orsini's findings indicate that the 'Study' part of the Plan-Do-Study-Act cycle is often neglected in improvement processes. This is compounded by the pressure to 'do something' so prevalent in many organisations and often resulting in suboptimal quick fixes. Orsini's findings also include system inconsistencies resulting in duplication and destructive internal competition between departments with uncoordinated procedures, amongst others.

Orsini's findings may be applied in a project context. In accordance with current practice the post project review cycle is either non-existent or takes a suboptimal form in that the project by itself conducts a review of own performance based on relative measures and subjective assessment of what went well or badly. The absence of absolute measures means that it is not possible to identify and focus areas of particular importance for performance evaluation. For example, firstly, whether the levels of performance were consistent with the specific characteristics of the project, and secondly, whether deviant performance such as a man-hour overrun for a particular process was the result of original underestimation, poor performance or altered circumstances ! No other outcome can be possible since absolute measures of project performance that relate process and product are not common practice in the industry. The result of such a review is passed on in the form of a report which the next project may or may not review as part of its own experience review start-up procedures (recommended good practise). There are often no organisational elements in place that participate in close-out reviews and analyse and recycle the results on a systematic long term multi-project cycle basis. Although many organisations use some form of database for recording of experience, there seems to be a general consensus that the database approach is not an unmitigated success story.

It is incompatible with the projects task to also have responsibility for experience transfer and associated organisational learning processes. This may be seen as a system inconsistency.

Other system inconsistencies are the source of conflicting sector interests and lack of coordination which leads to duplication of effort, causes confusion, increases cost and undermines commitment to experience exchange processes and the data gathering effort needed to support them. Amongst the effects of these sector interests will be found contract compensation formats and WBS structures that conflict with the requirements of performance measurement and thereby inhibit the application of performance measurement techniques in project control processes.

2.4 Summary and conclusion

In general it may be said that the incidence of articles concerning experience transfer, benchmarking techniques and performance measurement as a basis for improvement processes is much lower for projects than for manufacturing processes. This may simply reflect a perception of the project which is in line with the findings listed in the next paragraph, namely that such techniques are not considered appropriate in a project context.

The review clearly indicates the existence of a body of research that perceives the shortcomings of the current one-approach-serves-all project management methodology to handle all types of projects Aspects of the project modus operandi that restrain learning processes to emerge from the review are:

- standardisation of project management methodology
- perception of non-commonality between projects
- the short term goal oriented nature of project work
- prevalence of relative measurement formats

Consistent with the perspective of this thesis, the review clearly indicates that there is a body of research that endorses the adoption of performance measurement and benchmarking techniques as improvement routines in the management of projects. The important elements of a benchmarking/performance measurement approach as basis for improvement that emerge from the discussion are:

- measurement of own performance on an ongoing basis
- scope management through quantity and weight estimating and monitoring on an ongoing basis
- measurement formats that support performance comparison between projects
- measurement formats supportive of different sector interests
- recycling of data in the short term (project trend analysis) and in the long term (experience transfer, close-out performance reviews, multi-cycle trend analysis, organisational learning)
- routines for making tacit knowledge explicit
- routines for experience transfer across the interface between the functional organisation and the project organisation
- commitment of management

These themes are reflected in the subject matter of this thesis and will be addressed in the following chapters.

3 DATA STRUCTURES AND METRICS

PRINCIPLES OF DATA STRUCTURING IN PERFORMANCE MEASUREMENT OF MODIFICATION PROJECTS

3.1 Introduction

The discussion in the preceding chapters expressed the conviction that some form of standardised measuring system, capable of defining performance in the absolute terms (resource use in terms of the product of the work being performed), may provide an alternative (and holistic) basis for the central project control functions of estimating, risk evaluation, scope monitoring and forecasting. In addition, such a measuring system may be supportive of benchmarking practices aimed at longer term performance improvement by providing an objective basis for evaluating performance and identifying performance deviations as a point of departure for qualitative performance reviews.

This chapter presents formats for defining and collating the weight, cost and man-hour elements that form the basis of the proposed data structuring system for collection of experience data for modification projects. These formats provide a basis for estimating methods, monitoring of scope quantity and complexity development and generalised use as reference for other project control purposes (WBS, contract compensation formats and reporting).

The chapter also includes description of specific characteristics of modification projects arising from the metrics of the measurement formats and a case study demonstrating the nature of the performance reviews arising from performance deviations in the projects life cycle data.

3.2 Data structures

In the previous chapter it was noted that not one of the papers that were reviewed had presented any form of data structuring system for the recording of performance data. In the author’s view a representative data structuring system is an essential ingredient of any performance measurement system, and as an aid to understanding the follow-up discussion in the subsequent chapters, a brief summary of the proposed data structuring system will be presented here.

The data structures are presented in a tabular format for convenience of overview.

The breakdown structure is hierarchical and reflects an increasing degree of detail.

3.3 Properties of the performance measurement data structure and metrics

A system for performance measurement with benchmarking capability will need to:

- take due account of the nature and characteristics of the individual project and at the same time have validity for a large range of projects of differing scope, size and complexity
- have a clearly understandable applicability to clearly identifiable activities in current industrial practise for the organising of project work
- have appropriate metrics for the activities to which the performance measurement applies
- be based on data generated in the course of current practices for planning and control
- provide a structured multi-level hierarchical basis for analysis of performance deviation which enables identification of the source of the deviation (which will often be found in project-specific detail)

This has been achieved in the proposed method by use of the following principles:

- one-to-one correlation between cost, man-hour use and material quantities

- activity breakdown corresponding to current industrial practice (in Norway this corresponds closely to the SCCS SAB [12], but some adaptations are deemed necessary to achieve a modification specific breakdown with wide applicability)
- activity breakdown by discipline consistent across all activities (supplemented by sub-discipline data)
- material volumes (define project characteristics) expressed in consistent units (weight is used as a consistent basis in order to facilitate aggregations across discipline boundaries)
- an appropriate degree of simplification to permit overview balanced with sufficient detail to adequately describe the core processes in all modification work

The resulting set of parameters for performance measurement is illustrated in Table 3-1 below and is presented in a compact matrix format intentionally in order to provide an overall picture of all the essential core processes. This set of parameters in Table 3-1 provides a basis for performance measurement at several levels of aggregation, each parameter addressing core functions of relevance to overall project performance.[13]

Performance Measurement Parameters							
	Description	**Eq**	**Piping**	**El Bulk**	**Instr Bulk**	**Steel**	**Total**
1	**Cost Efficiency**	MNOK/Tonne	MNOK/Tonne	MNOK/Tonne	MNOK/Tonne	MNOK/Tonne	MNOK/Tonne
	Total excl Operations	0,523	0,640	1,423	2,332	0,338	0,528
	Total incl Operations	--	--	--	--	--	0,606
	System	--	--	--	--	--	0,784
	Labour	0,106	0,367	1,053	1,815	0,307	0,328
	Materials	0,393	0,173	0,235	0,427	0,018	0,182
2	**Discipline Balance**	%	%	%	%	%	%
	Module/Preassembly	24%	20%	2%	1%	53%	49%
	Integration (Offshore)	16%	43%	1%	3%	33%	100%
	Total	18%	41%	2%	3%	32%	100%
3	**Productivity**	Mhr/Tonne	Mhr/tonne	Mhr/tonne	Mhr/tonne	Mhr/tonne	Mhr/tonne
	Prefabrication	--	158	--	--	106	--
	Module/Pre-assembly	14	351	222	319	125	159
	Integation	33	247	1018	1237	171	188
	System Testing	--	--	--	--	n/a	13
	Engineering	86	257	741	1451	169	196
4	**Manhour Ratios**	%	%	%	%	%	%
	Man/(Tot Dir+Ind+Eng)	--	--	--	--	--	20%
	Eng/Total Direct	223%	67%	75%	116%	73%	77%
	Onshore Direct/Total Direct	--	32%	--	--	38%	28%
	Offshore Indirect/Offshore Direct	--	--	--	--	--	40%
	Standby/Offshore Total	--	--	--	--	--	1%

Table 3-1: Table of performance measurement parameters

These core functions have been grouped by category in the matrix:

- Norms of performance at discipline level for each core activity
- Cost performance correlated with weight of installed materials (cost per tonne)
- Materials content defined by the discipline mix of materials (discipline percentage of total)
- Direct man-hour performance correlated with weight of installed materials (man-hour per tonne)
- Indirect man-hour performance correlated with direct man-hours supported (man-hour ratios)

[12] Reference to the NORSOK Standard Z-104 Standard Cost Coding System Standard Activity Breakdown

[13] Noting that the values in Table 3-1 are drawn from a range of projects, they do not always 'add up' as values from one specific project would. As examples the Discipline Balance value for Integration Offshore would be 51% if the above were values from a specific project and the sum of Labour and Materials MNOK/Tonne values would equal the Total MNOK/Tonne value. This may be checked by comparing with the values in Table 3-2.

Due to the variation in discipline mix, performance is best measured and compared at discipline level, which is facilitated in the above matrix. Considering the wide diversity of modification work, it may indeed be difficult at all to find projects that have a sufficiently similar discipline mix at all levels to permit realistic comparison at a total (project multi-discipline) level of aggregation. It is of course necessary to acquire some understanding of normal levels of performance as reference against which to judge performance, but the necessary diversity can be acquired by considering results from different projects at discipline level independently.

The matrix of parameters has been simplified by incorporating indirect costs and subordinate activities, such as painting, within the scope of the relevant discipline. This simplification has been deemed necessary for the sake of overview and to reduce complexity.

The picture of the modification process provided by the matrix, although still relatively complex in spite of the simplification, requires an additional degree of detail, namely the sub-discipline detail, which reflects the characteristic nature of the work scope of each discipline. As mentioned previously, the nature of the work scope can vary widely from project to project, both in terms of relative content at discipline level and at sub-discipline level. The sub-discipline detail is necessary and characteristic with regard to modification work in order to provide a complete basis for comparison and is likewise necessary when developing estimates. In the interest of overview, sub-discipline detail will be addressed separately later in this chapter. The breakdown conforms hierarchically to the above set of parameters.

The data presented are median values taken from a wide range of projects of all sizes. Median values have been chosen, rather than the normative practice of averaging, as they are less susceptible to the effects of extreme values in the records. It is however important to mention that the results of analysis of size effects has shown that the parameter values correlate with size of the project overall and with the size effects at discipline level which in turn are aggregate effects of the sub-discipline complexity. The values presented in the matrix are thus most representative of size-wise mid-range projects.

3.4 Cost, man-hour and weight summary

The basic principle for structuring the data is 1:1:1 correlation of cost, man-hours and weight elements. This structure is reflected in the Cost, Man-hour and Weight Summary Table in Table 3-2 below.

The main products, core activities and main performance parameters are listed vertically in the column on the left. The remaining columns include the total and main discipline values. Note that painting and insulation and other smaller activities are aggregated into the main discipline elements in the interest of simplicity and overview.

The parameters in italic text are the basic set of core performance measurement parameters used, a set of cost per tonne, man-hour per tonne, weight parameters at total and discipline level for each core activity and a corresponding set of weight distribution parameters. The parameters are derived directly from the cost man-hour and weight data in the respective columns in the tabulation. These core parameters correspond with Table 3-1 above and they are discussed in detail later in this chapter.

The reference weight is the total installed weight that includes all new items, temporary installations and moved items.

Project:	Name XX					Date: 2000
Result : Main Activities						
ACTIVITY	Result	Discipline Breakdown				
EPCI COSTS	MNOK 00	Eq	Piping	El	Instr	Steelw
Preliminary/Facility	408,1	*Contractors Overhead*				
Management /Administration	165,6	*Contractors Project Management and Administration*				
Engineering	328,2					
PROC - EQ	253,2	253	n/a	n/a	n/a	n/a
PROC - BULK	372,7	n/a	222	27	90	34
Prefabrication for Integration	54,3					
Module Fabrication + Assembly	114,4					
Offshore Installation incl Commissioning	307,0					
SUM 1 - EPCI COST	**2003,5**	358	752	118	279	497
Total MNOK/Tonne wrt SUM1	*0,550*	*0,503*	*0,785*	*1,973*	*6,709*	*0,266*
Labour MNOK/Tonne wrt SUM1	*0,379*	*0,147*	*0,553*	*1,527*	*4,546*	*0,248*
Materials MNOK/Tonne wrt SUM1	*0,172*	*0,356*	*0,232*	*0,445*	*2,163*	*0,018*
System MNOK/Tonne wrt SUM1	*1,131*	--	--	--	--	--
COMPANY COSTS						
Project Team + Insurance	253,5	*Company's Management*				
Studies	incl	*Third party verifications, warranties etc*				
Base Services + Supply Boat Transport	10,7	*Bulk and consumables transport*				
Personell Transport (Helicopter)	25,2					
Accomodation Costs	31,8	*Includes both Accomodation on board or on flotell*				
Platform Operator Costs	19,6	*Operator overhead due to project and Operator support*				
Flotel Hire	64,7	*Mob/demob and Vessel Hire Cost*				
SUM 2 - EPCI + COMPANY COSTS	**2441,8**					
Total MNOK/Tonne wrt SUM 2	*0,671*					
System MNOK/Tonne wrt SUM 2	*1,379*					
MANHOURS	**Total**	**Eq**	**Piping**	**El**	**Instr**	**Str**
Management/Admin Onshore	389637	No split				
Management/Administration Offshore	81605	No split				
Engineering Onshore	795010	74374	345908	64746	189480	248288
Engineering Offshore	127786	Included above - no split				
Prefabrication for Integration (Onshore Direct)	180245	n/a	87899	n/a	n/a	92346
Fabrication Modules	399824	8550	112335	39527	23084	216327
Offshore Direct (inkl M+M direct)	635487	72961	266404	37232	65684	193206
Offshore Indirect (incl M+M Indirect)	144218	No split				
Comm + Vendor offshore	37015	No split				
Standby	32336	Split not relevant				
Sum Mhrs Base Estimate	**2823163**					
Total Offshore manhours	1058447					
Eng - Mhrs/Tonne	*254*	*105*	*361*	*1079*	*4559*	*133*
Module fabrication Mhrs/Tonne	*251*	*40*	*482*	*855*	*1330*	*199*
Integr - Dir Mhrs/Tonne	*311*	*146*	*367*	*2699*	*2714*	*247*
Eng - Eng/TotDir Mhr Ratio	*74 %*	*91 %*	*74 %*	*84 %*	*213 %*	*49 %*
WEIGHT	**Total**	**Eq**	**Piping**	**El**	**Instr**	**Str**
Total Installed Weight	**3640**	711	958	60	42	1869
Integration offshore	2044	500	725	14	24	781
Module/Preassemblies	1596	212	233	46	17	1088
Demolition	737	399	0	0	0	338
Eq Wt/Total Installed Wt	20%					
Bs/Total Installed Wt	29 %	*Bs=System Bulk=Piping+El Bulk+Instr Bulk*				
Str/Total Installed Wt	51 %					
Weight Breakdown Integration	*56 %*	*24 %*	*35 %*	*1 %*	*1 %*	*38 %*
Weight Breakdown Modules	*44 %*	*13 %*	*15 %*	*3 %*	*1 %*	*68 %*
Weight Breakdown Total	*100 %*	*20 %*	*26 %*	*2 %*	*1 %*	*51 %*

Table 3-2: Cost, man-hour and weight summary table

3.5 Weight elements

The weight data and the relationships between the various sub-elements define the characteristics of the concept under review. Thus weight monitoring procedures are essential during the study and the detailed engineering phases of the work as a basis for estimating, planning and project control (monitoring concept quantity and complexity development), and similarly for close-out data as basis for assessing actual performance in terms of the characteristics of the work performed and recycling as basis for estimating. For these project control purposes a greater degree of detail will be required than is normal with weight monitoring for purely technical purposes. The detail is necessary in order to define the complexity of the work and to register the many small items of low total weight, but which generate a large proportion of the offshore installation man-hours. The weight basis should also be updated more frequently, at least quarterly, during detailed engineering in order to ensure good trend lead time, and finalised at close-out.

Principle weight breakdown structure:

- Separate totals per module and for total offshore integration
- Each module and total integration to be split by discipline
- Each discipline item split into sub-discipline components
- Reference weight is total installed weight

In addition identify:

- Materials temporarily installed (Temp)
- Materials moved (Move)
- Materials demolished permanently (Perm Demol)
- Dismantling for moving and removal of temporary installations (Temp; Move)
- Material volumes subject to special installation methods such as hot work
- Upgrading of equipment components in-situ (Revamp)
- Basis for procurement (has relevance for New Permanent and Temp weights)

The general formatting principles are illustrated in the tables below. The sub-discipline detail is particularly relevant with respect to defining the complexity of the offshore integration work.

The reference weight for offshore installation is the *total installed* weight consisting of the new permanent, temporary, moved and revamped weight components and is used to calculate reference parameters at aggregate level such as overall engineering man-hour per tonne. Note that the tabulation also includes *handled weight,* which is used by many actors as a reference weight. Handled weight includes the weight of an article every time it is installed or removed. This means that temporary weights will be included once for installation and once for removal, or more often, should they be reinstalled in new locations. Handled weight has the disadvantage as a reference weight that the resource use per weight unit for both engineering and installation is generally much lower for demolition tonnage than installed tonnage. In circumstances with large demolition tonnage this practice leads to large distortions in the man-hours per tonne and cost per tonne parameters. This is particularly problematic regarding engineering, which is estimated either on the basis of man-hours per tonne or as a factor of the fabrication man-hours. The fact that demolition man-hours are often not distinguishable in the recorded expended man-hours aggravates the problem. This problem can easily be circumvented however, by registering and estimating demolition weights as separate items thus rendering them visible such that they can be taken into account when assessing performance and when estimating, in accordance with the cost, man-hour and weight breakdown structure shown in Table 3-2.

3.5.1 Discipline and product weight summary format

A standard format for discipline and product related weight breakdown is shown in the table below.

DISCIPLINE WEIGHT TABLE													
DISC/ CATEGORY	New Perm	Temp	Move	Revamp Insitu	Total Installed	Prefab for Integr	Module	Integr Offshore	Perm Demol	Total Demol	Nett Installed	Handled Wt	Basis for Proc
					(1+2+3+4)				excl 2+3	2+3+9	(5-10)	(5+10)	
	1	2	3	4	5	6	7	8	9	10	11	12	13
SUM EQPT	**419,9**	**110,7**	**13,5**	**167,3**	**711,4**	**0,0**	**211,7**	**499,7**	**275,0**	**399,2**	**312,2**	**986,4**	**697,9**
Mech	374,5	110,7	13,5	167,3	666,0		211,7	454,3	275,0	399,2	266,8	941,0	652,5
Electro	8,3				8,27		0,0	8,3		0,0	8,3	8,3	8,3
Instr	37,1				37,12			37,1		0,0	37,1	37,1	37,1
HVAC					0					0,0	0,0	0,0	
SUM BULK	**2644,9**	**268,1**	**13,0**	**2,1**	**2928,1**	**1369,2**	**1384,3**	**1543,9**	**67,1**	**348,2**	**2579,9**	**2995,2**	**2915,1**
Pipe incl M+J Valves	958,0				958,0	594,4	233,1	725,0		0,0	958,0	958,0	958,0
Manual Valves	61,8				61,8		28,6	33,2					61,8
Steelwork	1543,3	268,1	13,0	2,1	1826,6	774,8	1051,8	774,8	56,5	337,6	1489,0	1883,0	1813,5
Instr excl JValves	41,6				41,6		17,4	24,2		0,0	41,6	41,6	41,6
Instr Valves	180,6				180,6		83,2	97,3					180,6
Electro	60,0				60,0		46,2	13,8		0,0	60,0	60,0	60,0
Architect	42,0				42,0		35,9	6,1	10,6	10,6	31,4	52,6	42,0
HVAC					0,0					0,0	0,0	0,0	0,0
PFP	*1543,3*				*1543,3*		*1051,8*	*774,8*			*1543,3*	*1543,3*	*1543,3*
Insulation	*958,0*				*958,0*		*233,1*	*725,0*			*958,0*	*958,0*	*958,0*
Surf Pro	*2501,3*	*268,1*	*13,0*	*2,1*	*2784,6*		*1284,8*	*1499,7*	*n/a*		*n/a*	*n/a*	*2771,5*
Vektkontroll													
TOTAL	**3064,8**	**378,8**	**26,5**	**169,4**	**3639,6**	**1369,2**	**1596,0**	**2043,6**	**342,1**	**747,4**	**2892,2**	**3981,6**	**3613**
Gr/Seaf Barge + HLV not LOB				--	--		38,0	--	--	--	Ref Barge and HLV		
Temp Seaf in Module LOB				--	--		32,4	--		32,438	Ref Barge and HLV		
Spreader;Rigging on module LOB							165,9	--		165,927			

Table 3-3: Discipline and product weight summary table

3.5.2 Sub-discipline weight summary formats

Standard formats for sub-discipline breakdowns are presented in the tables below:

Piping: Breakdown by material quality and size (diameter) preferably also split in piping/manual valves/instrument valves/pipe supports. See table below. Note that instrument valves are considered part of the piping discipline.

Piping hot work: Definition of the installation methods, especially the extent of hot work, can be very important in defining norms of performance and assessing performance. This may be defined by a separate listing of the offshore hot work quantities defined by weight of the welded-in spools and grouped by material quality and by diameter.

Piping Insulation/Painting: Definition of the insulation and painting volumes can be very important, particularly insulation of the integration piping that must be done in the field (offshore), due to the fact that insulation work is highly man-hour consuming and can have a large impact on offshore man-hour requirement if extensive insulation is required. This can be done by identifying the weight (or the length) of the lines to be insulated, preferably grouped by diameter. Painting can be handled in a similar manner. Engineering line numbers may be useful for isolating this information especially since many systems include a painting and insulation code in the line numbers.

Normative practice in the industry is to measure painting, insulation and fire protection scope in weight terms at aggregated levels. The author regards this as little representative for the nature of the work to be performed and a poor basis for defining the performance in absolute terms such as man-hours per tonne, hence the proposals above for alternative units for measurement of insulation and painting for piping. The insulation of steelwork is not so easily resolved.

PIPING AND VALVE Materials					Grouping of Spools by Diameter															
SCCS COR Codes					2	4	6	8	10	12	14	18	20	22	24	30	36	Totals	% Ford	% Ford
TOPSIDES - Total (Module + Integration)																				
B	BL	BLA	BLA*	CS - Pipe	3,3	31,1	19,2	8,2	14,7	24,9	5,5	53,5	0,0	83,9	1,7	0,0		283,8	30,5 %	41,1 %
	BL	BLB	BLB*	CS - man ventiler	1,1	7,1	0,3	2,0	0,0	2,4	0,0	0,0	0,0	0,0	0,0	0,0		19,8	2,1 %	inkl
	BJ	BJB	BJB*	CS - instr ventiler	0,2	6,7	9,6	3,4	2,8	2,4		4,1	0,0	33,5	0,0			78,6	8,4 %	inkl
	BL	BLA	BLA*	SS - Pipe	7,3	20,2	3,6	2,0	0,3	3,0	2,8	0,0	13,5	0,0	24,1	21,1		116,4	12,5 %	15,2 %
	BL	BLB	BLB*	SS - man ventiler	1,0	1,2	1,4	5,5	0,0	2,5	0,0	0,0	9,5	0,0	0,0	0,0		22,9	2,5 %	inkl
	BJ	BJB	BJB*	SS - instr ventiler	0,7	1,4	0,0	0,0	0,0	0,0		0,0	0,0	0,0	0,0			2,1	0,2 %	inkl
	BL	BLA	BLA*	6MO - Pipe	0,2	3,1	3,1	0,0	18,3	2,5	1,7	0,0	0,0	0,0	0,0	0,0		34,7	3,7 %	7,4 %
	BL	BLB	BLB*	6MO - man ventiler	0,6	0,2	0,3	0,5	1,9	1,1	0,0	0,0	0,0	0,0	0,0	0,0		4,6	0,5 %	inkl
	BJ	BJB	BJB*	6MO - instr ventiler	0,1	1,0	0,7	0,0	4,9	3,7		0,0	7,3	0,0	9,2			29,3	3,1 %	inkl
	BL	BLA	BLA*	Duplex - Pipe	0,4	21,7	27,0	13,9	32,4	39,7	0,0	0,0	13,0	0,0	0,0	0,0		171,5	18,4 %	27,5 %
	BL	BLB	BLB*	Duplex - man ventiler	0,7	2,4	0,0	0,4	2,0	5,9	0,0	0,0	0,0	0,0	0,0	0,0		14,5	1,6 %	inkl
	BJ	BJB	BJB*	Duplex - instr ventiler	0,0	11,3	18,8	0,7	9,9	22,5		0,0	0,0	0,0	0,0			69,6	7,5 %	inkl
	BL	BLA	BLA*	Titan - Pipe	0,6	6,2	2,3	3,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0		13,7	1,5 %	1,5 %
	BL	BLB	BLB*	Titan - man ventiler	--	--	--	--	--	--	--	--	--	--	--	--		0,0	0,0 %	inkl
	BJ	BJB	BJB*	Titan - instr ventiler														0,0	0,0 %	inkl
	BL	BLA	BLA*	GRE - Pipe																
	BL	BLC	BLC	Supports														69,5	6,9 %	not inkl
B	--	--	--	Total Topsides	16,2	113,5	86,4	39,5	87,3	110,7	10,0	57,6	43,3	117,4	35,1	21,1	0,0	930,9	99,5 %	100,0 %
				Distr Topsides	1,7 %	12,2 %	9,3 %	4,2 %	9,4 %	11,9 %	1,1 %	6,2 %	4,7 %	12,6 %	3,8 %	2,3 %	0,0 %	100,0 %	75,9 %	
B	B*	B**	All	Insulation - Total	12,9	82,3	67,2	31,3	72,6	85,7	4,5	4,1	43,3	33,5	33,3	21,1	0,0	577,7	62,1 %	
B	B*	B**	All	Surf Pro - Total	12,9	82,3	67,2	31,3	72,6	85,7	4,5	4,1	43,3	33,5	33,3	21,1	0,0	577,7	62,1 %	
B	B*	B**	All	Demolition - Total	4,6	65,5	7,8	3,1	4,3	15,0	2,2	2,0	0,0	0,0	1,0	0,0		100,2	10,8 %	

Table 3-4: Piping sub-discipline weight format

Consistent with the principles of the product breakdown, separate tables should be prepared for piping in modules and integration piping.

Separate tables for offshore hot work piping should be prepared.

Steelwork

The steelwork sub-discipline complexity is very important regarding the integration work offshore (structural reinforcement, field-erected support structures, etc). The man-hour norms (mhrs/tonne) are very sensitive with respect to the size of the individual items. This complexity can be defined by grouping the individual installation items by size (wt) and in accordance with the installation method (ie welded or bolted) and may advantageously be combined with installation engineering activities.

The sub-discipline complexity is defined in the table below.

STEELWORK MATERIALS					Weight Category (Tonnes)							
				Category	Cat1	Cat2	Cat3	Cat4	Cat5	Cat6	Cat7	**SUM**
				Wt by Category	<0,25	0.25-1	1-5	5-10	10-20	20-50	>50	
SCCS; COR				**Integration**								
B	BN	BNA	--	Prim/SecStr (Welded Reinf)		5,3	36,6	45,1	26,6		152,9	**266,6**
		BNB	--	Outfitting Structures	15,7	59,8	145,2	44,2	45,2	85,1		**395,1**
		BNC	--	Temporary Installation Aids	2,7	8,6	28,4	20,4	30,9	34,2		**125,2**
		BND	--	Grillage / Seafastening / Loadout								**0,0**
		BNZ	--	GBS	1,1	5,0	4,6					**10,7**
				SUM Integration	**19,5**	**78,8**	**214,8**	**109,7**	**102,7**	**119,3**	**152,9**	**797,6**
				Demolition	**4,0**	**14,2**	**75,6**	**58,3**	**62,5**	**101,3**	**0,0**	**316,0**

Table 3-5: Steelwork sub-discipline weight format

Separate tables should be prepared for steelwork in modules and integration steelwork.

Separate tables should be prepared for integration hot work.

The Weight Category breakdown is relevant to integration steelwork and is not required for module steelwork.

Electrical and instrument bulk materials

Electrical and Instrument bulk materials are in total a relatively small part of the total installed weight but include many small items of low weight, that are highly man-hour intensive. This is partly due to the small size of the items, but also a significant weightless component of work, such as termination and testing of cables. Having low overall total weight these items are often neglected in the technical weight estimation, but they are of great importance in weight estimation performed for project control purposes such as estimating and performance evaluation.

The sub-discipline complexity is defined in the tables below:

Instrument & Telecommunication Bulk									
SCCS COR Codes				**Category**		**Mod**	**Integr**	**SUM**	**Demol**
B	BJ	BJA	--	Instruments		4,0	3,2	7,2	
		BJB	--	Instrument Valves		83,2	97,3	180,6	
		BJC	--	Cables & Cable Accessories		20,2	9,6	29,8	
		BJD	--	Junction Boxes		0,0	0,0	0,0	
		BJE	--	Tubing		0,0	0,0	0,0	
		BJF	--	Telecom. Appliances		0,0	0,0	0,0	
		BJG	--	Accessories		0,4	2,1	2,5	
		BJZ	--	Other Instrument & Telecom. Bulk		2,0	0,0	2,0	
				SUM		**26,6**	**15,0**	**41,6**	
				SUM Incl J valve wt		**109,8**	**112,3**	**222,1**	

Table 3-6: Instrument sub-discipline weight format

Electrical Bulk									
SCCS COR Codes				**Category**		**Mod**	**Int**	**SUM**	**Demol**
B	BE	BEA	--	Cable & Cable Accessories		40,9	10,7	51,5	
		BEB	--	Cable Supports & Transits		0,0	0,0	0,0	
		BEC	--	Lighting		2,6	0,6	3,2	
		BED	--	Junction Boxes		0,5	0,0	0,5	
		BEE	--	Accessories		0,7	2,5	3,2	
		BEZ	--	Other Electrical Bulk		1,5	0,0	1,5	
				SUM		**46,2**	**13,8**	**60,0**	

Table 3-7: Electrical sub-discipline weight format

Separate tables should be prepared for electrical and instrument work in modules and integration.

Note instrument valves are normally included with the piping.

Equipment

The equipment sub-discipline breakdown follows the same pattern as the structural breakdown.

EQUIPMENT ITEMS					Weight Category (Tonnes)							
				Category	Cat1	Cat2	Cat3	Cat4	Cat5	Cat6	Cat7	**SUM**
				Wt by Category	<0,25	0.25-1	1-5	5-10	10-20	20-50	>50	
SCCS - COR CODE				**Integrert**								
E	E*	--	--	Mekanisk	0,0	3,4	12,9	55,1	172,9	185,9	0,0	**430,2**
	EE	--	--	Elektro		0,8						**0,8**
	EJ	--	--	Instrument	0,3	0,3	2,0			31,0		**33,6**
	??			Safety (not Chartec)								**0,0**
E	--	--	--	**SUM Integrert**	**0,3**	**4,4**	**14,9**	**55,1**	**172,9**	**216,9**	**0,0**	**464,5**
E	--	--	--	**SUM Module + Integrert**	**2,1**	**8,4**	**16,8**	**71,9**	**183,4**	**331,8**	**61,0**	**675,4**
E	--	--	--	**Demollition Content**	**4,0**	**14,2**	**75,6**	**65,8**	**93,1**	**165,4**	**0,0**	**418,2**

Table 3-8: Equipment sub-discipline weight format

Separate tables should be prepared for equipment in modules and integration equipment

3.6 Cost and man-hour elements

The breakdown shown in the Table 3-2, the cost, man-hour and weight summary table, is further detailed out by discipline and sub-activity in the cost and man-hour tabulations laid out below.

The breakdown is generic, intending to reflect all the basic functions required to perform the work irrespective of the form of contract. It is presumed that the level of detail reflects the level of detail any project control system would require for adequate overview of the work and activities to be performed and that the data will be readily available from the weekly and monthly reports.

The form of contract may impose hindrances regarding the type of information available such that information at detail level is not available in the specific format laid out in the tabulations. However, the objective is to produce a set of core performance parameters corresponding to the cost, man-hour and weight related parameters of Table 3-1 and Table 3-2 above, and this may be achievable by reporting at higher levels of aggregation than those shown in the tabulations.

COST AND MAN-HOUR DETAIL TABULATIONS

MANHOUR ELEMENTS BREAKDOWN																												
SAB	All Disc	Sys Disc	Safety	Process	All Eq	Piping	Man Valves	El Bulk	Instr Bulk	Aut Valves	Tele	Str	Arch	HVAC	Surf Pro	Insu lation	PFP	Multi Disc	Admin/ Tech Field	ATS*5	Total Direct	EPCI Indir	M+M Indir	Total all Prod	Lost Prod (Stdby)	Waiting /Travel	Non-Prod mhrs	Total (excl Waiting)
Contr Proj Admin	--	--	n/a	n/a	n/a	n/a		n/a	n/a			n/a			n/a			389637	81605		471242	n/a	n/a	471242	incl	incl	not incl	471242
Engineering	675098	482547	27197	52282	53212	247444	no data	46324	135567	no data	incl J	192551	0	0	37	47	0	40349	127786	0	922796			922796	incl	incl	not incl	922796
Contractor Supply	--	--	n/a	n/a	n/a			n/a	n/a			n/a			n/a				50651		--			--				n/a
Company Supply	--	--	n/a	n/a	n/a			n/a	n/a			n/a			n/a				58005		--			--				n/a
Prefab for Integr	157495	n/a				77661						79834			16624			6126			180245	??		180245			not incl	180245
Module Fabr+Assy	315450	161837			8510	90462	no data	39340	22975	no data		153613	144	406	56377	8280	18218	1499			399824	??	??	399824			not incl	399824
Offsh Integration	428171	295324			15049	183566		34118	60190			132847		2401	68363	42696	635	39084		56538	635487	144218	124494	904199	32336	12863	62734	936535
Install Module/PAU	--	--	n/a	n/a																	0			0			incl ??	0
System Testing	--	32245			1973	3605		6127	20540									4770			37015	no data		37015	incl	incl	incl ??	37015
Company Man																		no data			0			0				0
Heli/Accom																		1182941			1182941			1182941				1182941
Operator Support																		no data			0			0				0

Table 3-9: Man-hour elements detail format

COST ELEMENTS BREAKDOWN																												
SAB	All Disc	Sys Disc	Safety	Process	All Eq	Piping	Man Valves	El Bulk	Instr Bulk	Aut Valves	Tele	Str	Arch	HVAC	Surf Pro	Insu lation	PFP	Multi Disc	Admin/ Tech Field	ATS*5	Total Direct	EPCI Indir	M+M Indir	Total all Prod	Lost Prod (Stdby)	Waiting /Travel	Non-Prod mhrs	Total (excl Waiting)
Prelim/Facility	--	--	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a		408,1	--	n/a	408,1	n/a	n/a	408,1	n/a	n/a	n/a	408,1
Contr Proj Admin	--	--	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a		131,0	34,6	n/a	165,6	n/a	n/a	165,6				165,6
Engineering	231,6	165,5	9,3	17,9	18,3	84,9	inkl rør	15,9	46,5	inkl rør	inkl instr	66,0	0,0	0,0	0,0	0,0	0,0	13,8	55,5		328,2	n/a	n/a	328,2				328,2
Contractor Supply	581,6	--	n/a	n/a	237,5	91,7	27,3	25,1	84,3	87,4		24,9	3,5		1,9		3,9	38,4		0,0	625,9	n/a		625,9	--	--	--	625,9
Company Supply			n/a	n/a	--	--	--	--	--	--	--	--	--	--	--			--	n/a		0,0	n/a	n/a	0,0	--	--	--	0,0
Prefab for Integr	47,5	--	n/a	n/a		23,4	n/a			n/a	n/a	24,1			5,0			1,8	n/a	n/a	54,3			54,3	n/a	n/a		54,3
Module Fabr+Assy	90,3	--	n/a	n/a	2,4	25,9	inkl rør	11,3	6,6	inkl rør	no data	44,0	0,0	0,1	16,1	2,4	5,2	0,4	n/a		114,4			114,4	n/a	n/a		114,4
Offsh Integration	129,0	--		n/a	4,5	55,3	inkl rør	10,3	18,1	inkl rør	inkl instr	40,0	0,0	0,7	30,7	20,1	0,3	11,8	n/a	17,0	208,9	33,0	52,1	294,0	no data			294,0
Install Module/PAU	--	--	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a		n/a	n/a	0,0			0,0				0,0
System Testing	--	--	n/a	n/a	0,7	1,3	inkl rør	2,2	7,2	inkl rør	inkl instr	0,0	0,0	0,0	n/a	n/a	n/a	1,7	n/a	0,0	13,0			13,0				13,0
Company Man																		253,5			253,5			253,5				253,5
HLV/Transport																		32,8			32,8			32,8				32,8
Supply Boat																		5,7			5,7			5,7				5,7
Supply Base																		5,0			5,0			5,0				5,0
Helikopter																		25,2			25,2			25,2				25,2
Accomodation																		31,8			31,8			31,8				31,8
Flotell Hire																		64,7			64,7			64,7				64,7
Driftstøtte																		19,6			19,6			19,6				19,6

Table 3-10: Cost elements detail format

3.7 Metrics of performance measurement

3.7.1 Cost efficiency

The aggregate effects of size on the cost performance parameters are illustrated in the Figure 3-1 below. The overall Cost per Tonne values for an array of projects plotted on the left axis correlate with the Total Installed weight plotted on the right axis. Note that, consistent with

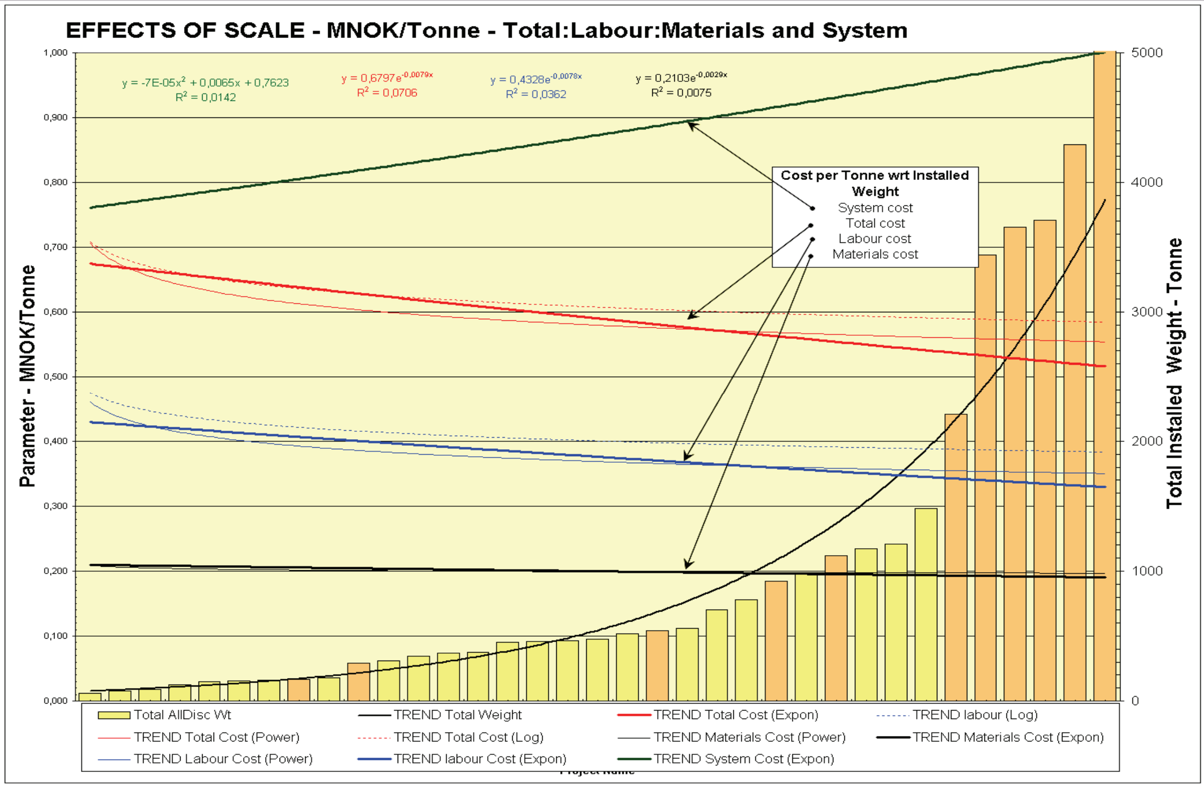

Figure 3-1: Effect of scale on the cost per tonne performance parameters

the scale effects commented earlier, small projects will generally exhibit higher values while large projects have lower values as can be seen referring to the trend lines EPCI Total Cost per Tonne and EPCI Labour Cost per Tonne. The range of the EPCI Total Cost per Tonne trend line, from highest to lowest, has an order of magnitude of +26/-22% with respect to the median value. It should be noted that although the trend is clear, there is considerable variation in the reference material of an order of magnitude of +50/-30%with respect to the median value, emphasising the importance of project specific characteristics in assessing performance and in preparing estimates.

Cost performance is measured primarily in three cost per tonne parameters which reflect the cost per installed material unit (tonne) overall and with separate measures of labour content and materials content. Referring back to core parameters in Table 3.1 and the effects of scale in Figure 3.1 above:

- Total excluding Operations is the Total EPCI Cost per Tonne excluding the client company's management, logistics and marine operations costs.
- Labour Cost is the EPCI Labour Cost per Tonne and includes the contributions of contractor management, engineering, fabrication and installation activities
- Material Cost is the Total Cost per Tonne of installed materials both temporary and permanent

- System Cost is the Total Cost per Tonne referred to the weight of the system components (includes equipment, piping, electrical and instrument materials, but excludes steelwork)

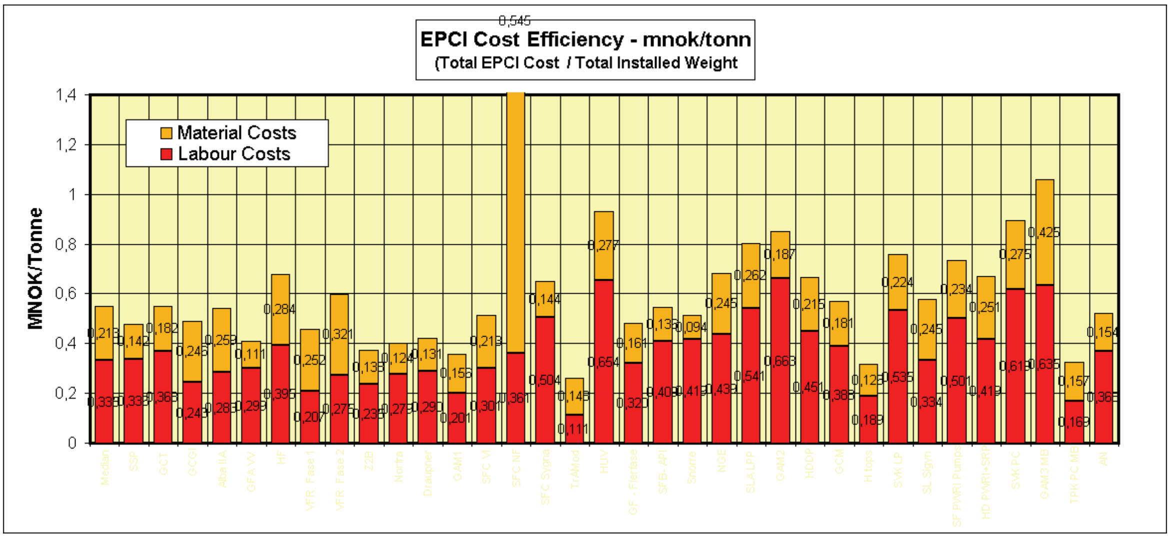

Figure 3-2: EPCI cost efficiency (cost per tonne) with split of labour and materials

For performance comparison purposes materials cost will reflect the nature and complexity of the concept and is to a large extent outside the influence of the contractor, often dictated by the characteristics of the reservoir, often by LCC [14] considerations, often by sheer weight considerations. Labour cost, however will reflect the efficiency with which the scope of work has been executed and directly reflects the technical competence and the organisational skills of the contractor (performance) as well as the complexity of the work itself. Variation between labour cost and materials cost elements at the highest order of aggregation for the total project (EPCI Total Cost per Tonne) is illustrated in the diagram above (Figure 3-2) in the form of a stacked bar chart (note that Total is the sum of Labour and Material Cost). Noting the large variation in the height of the bars for both material cost and labour cost, it is apparent that both material cost and labour cost parameters should be taken into account when assessing overall performance because overall aggregation may mask the relative contributions of material cost and labour performance. The variation is relatable to several factors, the discipline mix, the complexity of the individual discipline, the size of the project and the circumstances of execution of the work.

In addition to labour and material cost-per-tonne parameters, Table 3-1 includes the System Cost parameter, which is measured only at overall project level. System cost is intended to provide a measure of the overall cost per tonne required to install the operative systems. System cost is accordingly measured as overall cost/system weight [15] and provides a high level measure of the efficiency of the installation solution adopted for the project, for instance integration solutions compared to modularised solutions. The System cost per tonne has been plotted in to Figure 3-1 above (green trend line) and can be seen to increase with overall size. This parameter may also provide a basis for comparison of greenfield work with modification work. Greenfield work is generally considered more cost effective than modification work, but this may be due to inconsistent use of metrics to evaluate relative costs. It is sufficient to

[14] Life Cycle Cost considerations may often dictate the use of high grade materials to offset corrosion preventative maintenance even in circumstances where the medium is not particularly corrosive. This is an added consideration in circumstances where high strength and the elimination of corrosion allowances is advantageous from a sheer weight saving point of view.

[15] System weight is the weight of equipment and piping, electrical and instrument bulk but excludes steelwork.

point to projects that have elected to refit as a cost-effective alternative to module installation or installation of a new jacket to support new equipment. Examples of such projects can be found in the data.

The parameter Total including Operations covers both the EPCI cost and the costs covered by the client company for owner management, logistics, heavy lifting services, flotel services, marine operations and other costs outside the EPCI scope of responsibility. It is necessary to keep these costs separate and evaluate them separately due to the large project-to-project variation, especially regarding flotel and heavy lift costs, since these costs will be relatively higher for smaller projects when compared to the overall cost. These items could be excluded for greater consistency, but important cost elements would then be excluded from the cost picture. Since there is no advantage in taking averages for these costs items as a group, better then to include all the cost items, but accept to evaluate them on a case specific basis.

3.7.2 Discipline balance

Discipline balance is a measure of the mix of material content unique to the project, defined by the breakdown by discipline of the total weight that constitutes the scope of work. In addition, the scope of work breakdown includes two essential sub-elements, specifically the quantity of materials built into modules and the quantity of integration materials. This differentiation is particularly important as an aid to structuring the material, man-hour and cost content to achieve correct correlation between man-hours and materials particularly with regard to the offshore integration scope of work. If the integration man-hour content is not carefully correlated with the integration material content, the resulting performance parameter will be completely non-representative. Similarly, with regard to onshore fabrication, if materials and man-hours for fabrication of modules and fabrication of components for piece-small integration offshore respectively, are not registered separately, it will not be possible to extract accurate and meaningful measures of performance from the data. One might expect that project control requirements would naturally result in a product based follow-up, but such is apparently not the case judging by the frequency with which poorly structured data are encountered in practice. Accordingly one might ponder how it is then possible to maintain an adequate level of project control over these two important material streams.

It has been found convenient to define modules as pre-assemblies of such a weight and size as to require heavy lifting services for offshore load-in. Correspondingly all integration materials are defined as lift-able by platform cranes, of which the bulk integration materials are the most important as they determine the offshore man-hour volume.

Both concept cost and labour cost will be influenced by the mix of materials in the scope of work, for which reason the ‘discipline balance’ has been included as an essential reference parameter. The reason for this will become apparent when comparing the relative size of the cost per tonne parameters for the different disciplines in Table 3-1 above. As an example consider a project with a high content of steelwork where the low material cost of steel will reduce the overall cost per tonne, when compared with a project with low steel content. Clearly, direct comparison at project level of aggregation will be potentially misleading as a measure of performance if the mix of materials is not taken into account. Refer to Figure 3-3 below for an illustration of the variability of the material mix in a selection of modification projects. The projects are not aligned in any particular order.

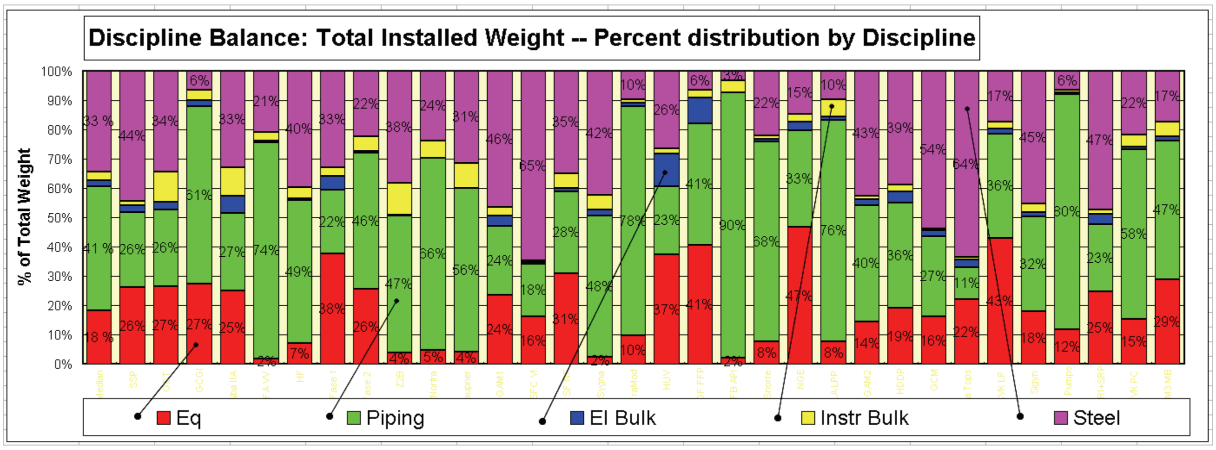

Figure 3-3: Discipline balance - Percentage distribution of total installed weight

Considerations of discipline balance may explain why modularisation is often considered more cost efficient than in-situ construction as a consequence of the higher overall content of steel in the concept, resulting in an overall lower cost per tonne if measured at high order of aggregation only. In reality the modularised concept will incur much extra cost on the extra steelwork labour content onshore and incur a penalty cost for heavy lifting services. The result is that the total cost per tonne for installation of the revenue earning processing equipment and bulk materials may be of the same order of magnitude as for wholly integrated solutions. This effect can be observed in the plot of the System Cost per Tonne trend line in Figure 3-1 which increases with size consistent with the increase in steelwork content due to the cost of the steelwork but not the weight of the steelwok being included in the parameter calculation. Modules are seldom self-contained and contain a high proportion of equipment, which is normally relatively cheap to install in terms of labour cost per tonne. Thus the main advantage of modularisation lies in the provision of new area for installation of new equipment and it may indeed provide the only solution on congested platforms. Examples can be given of projects which have discovered the advantages of optimising the degree of modularisation with respect to integration. In one case involving a floating production platform, weight limitations led to layout optimisation studies and it was found possible to reduce long two-way loops of large diameter heavy wall pipe and break up the single large module originally planned. This reduced superfluous structural weight and led to a reduction in the amount of offshore piping integration in addition to the reduced material costs, but unfortunately cost an additional year of development studies. Two separate cases involving congested jackets where the base case was the installation of a new bridge-connected jacket, were optimised to a fully integrated solution in the one case and a small piggy-back module with extensive integration in the other.

High steel content may also explain why greenfield work is considered more cost effective than modification work, due to the distorting effects of extra steelwork required for new construction, if not accounted for in the parameters used for comparative purposes.

Cost performance parameters at discipline level thus permit performance comparison where comparison at project level would be misleading or irrelevant due to unequal weighting of discipline content overall. Considering the high degree of variation in modification work, breakdown by discipline provides a broader range of experience data for analysis, comparison and estimating purposes, because data by discipline can be interchanged between projects. In this way the discipline cost parameters can also provide a rough basis for estimating, given that reasonably accurate material quantities are available for each discipline. In the parameter table (Table 3-1) median cost per tonne parameters for the primary disciplines, equipment (all disciplines), and the bulk material disciplines piping, electrical, instrumentation and steelwork illustrate this point.

It should be noted that differences in the material mix at sub-discipline level will need to be taken into account when evaluating performance at discipline level in a similar fashion to comparing performance at project level.

While material mix effects will apply directly to material costs, effect on labour performance costs can also be considered in the man-hour performance context of production efficiency.

3.7.3 Weight modelling

Records of the discipline weights and the mix of disciplines defined by the discipline balance can also be used to support early studies. For example, to provide a basis for building models for weight estimating of bulk quantities on the basis of equipment content, or modelling the effects in early conceptual studies of different installation scenarios by the sizing of module and integration content.

The chart below, Figure 3-4, is a plot of the relationship between the main discipline balance elements from Table 3-1, the equipment content (trend line B), the system bulk (piping, electrical and instrument bulk) content (trend line C) and the steelwork content (trend line D), with respect to the total installed weight. The source data, the actual weights from the array of projects, have been included in order to illustrate the variance underlying the trend lines. Note that the dark columns denote modularised projects and the light denote integrated projects.

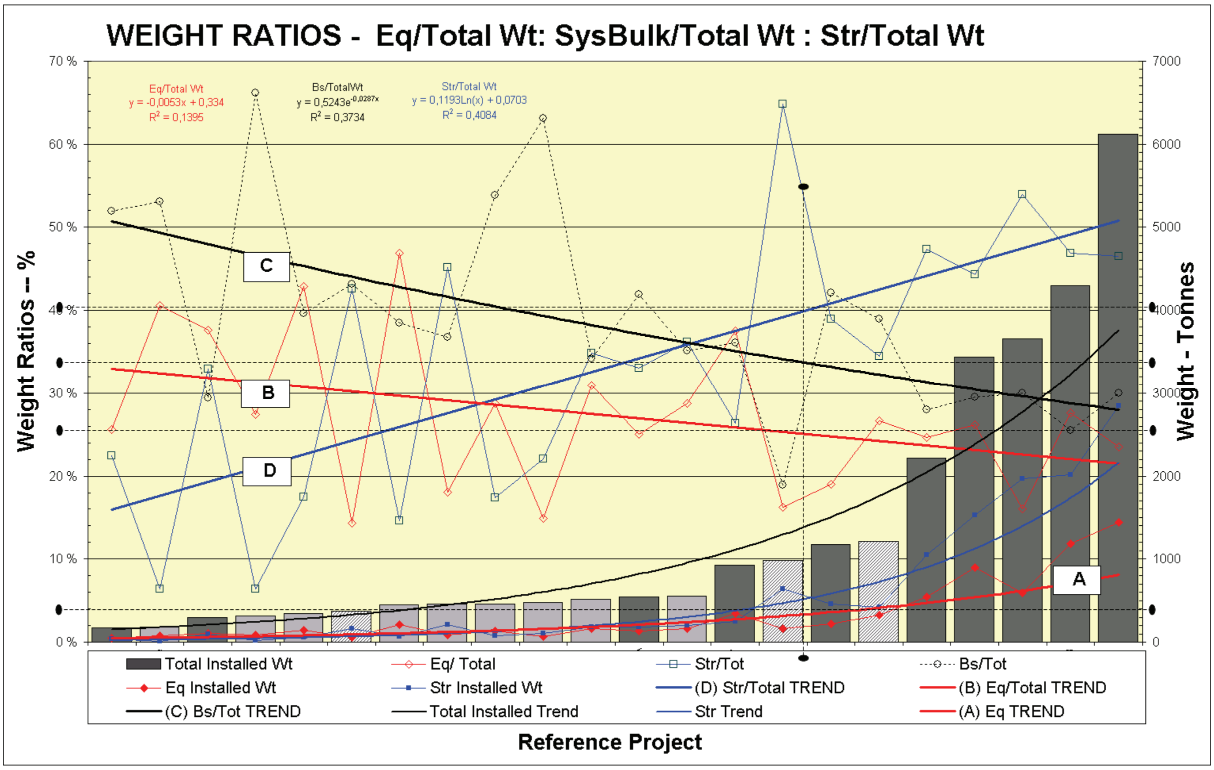

Figure 3-4: Discipline weight ratio trend lines for modifications

From the chart it can be inferred that the equipment content and the related system bulk content decreases with increasing size while the steelwork content increases. The trend lines from these weight ratios can be used for purposes of modelling bulk materials in early phase conceptual estimating by using the equipment weight (trend line A) as input value.

Alternatively, the ratios of Equipment and System bulk weight (piping+electro bulk+instrument bulk) and the Steelwork and System Total (equipment +piping+elektro bulk +instr bulk) may be used for modelling bulk weights. The Equipment/System Bulk ratio (E/Bs) is relatively flat but increases with size indicating that the E/Bs parameter may be influenced by the peripheral location of the modules. Individual values vary considerably about the median of 77%, particularly regarding the smaller projects, ranging from P10 at 41% to P90 at 108%. The ratio of piping, electrical bulk and instrument bulk is relatively stable and may be used to define the discipline content of the system bulk content.

The steelwork content increases with total size and for the larger projects is related to modularisation content. The effects of modularisation are thus incorporated in the weight ratios and the cost per tonne parameters with sufficient accuracy for early studies with low degree of definition. Thus it is really only useful to model modularisation when the equipment block layouts provide a basis for modelling module content on the basis of well known discipline factors from greenfield work. Integration content follows from the total installed weights defined on the basis of the above chart by subtraction.

It is important to remember that weight, man-hour and cost data should be collected separately by module since modules may have variable discipline content and will be sensitive to effects of scale.

3.7.4 Production efficiency

The activities included in the matrix of Table 3-1 are considered to be the core activities comprising modification work. Performance in these major project execution activities is measured in man-hours per tonne, with the exception of Management:

- <u>Management</u> (defined as comprising all management and administration activities including procurement and planning)
- <u>Engineering</u> (defined as direct and multi-discipline engineering activities including field support)
- <u>Prefabrication</u> (defined as workshop fabrication onshore of materials for integration offshore that can be lifted by platform crane – ref. *integration* below)
- <u>Module/pre-assembly</u> (defined as fabrication and assembly of modules and large pre-assemblies for installation offshore by external lift vessel)
- <u>Integration</u> (defined as comprising all piece-small installation items that can be lifted by platform crane)
- <u>System Testing</u> (initial part of Commissioning activity)

The metric for all activities (with the exception of management) is <u>man-hours per tonne</u> and the activities are split by discipline consistent with the cost parameters above. Man-hour performance comparisons contribute to explaining deviations in cost performance, which may be related to deviation in one or all of the core functions overall or in individual disciplines.

The use of directly measured man-hours per tonne for offshore integration work contrasts with the normative estimating practise in many organisations of applying offshore factors to norms of performance derived from onshore module construction. The approach above reflects conditions in the field (offshore) directly, thereby avoiding the use of offshore factors which are, at best, subjective judgements. Similarly, prefabrication performance and module fabrication performance are measured directly and can be used directly, in contrast to normative practice which is to split onshore module fabrication norms into two components, fabrication and erection. The prefabrication norm components are applied to both prefabrication for integration and prefabrication of module sub-elements prior to erection at a separate site. This mixing of material streams is unfortunate since the products of the work, which have very different control requirements, are obscured.

Another consideration supporting the use of direct measurement in the field is the difference in method of installation applied to offshore work. Offshore work relies to a greater and greater extent on bolted type connections while onshore module fabrication relies on welded construction, and the norms of performance are significantly different. For these reasons one may perhaps be excused for assuming that organisations that use offshore factors for estimating do not actively measure performance on an ongoing basis.

The activity split between Prefabrication and Module construction requires explanation as it reflects the general construction logic employed in the industry, but not necessarily the monitoring logic reflected in the WBS structures of many projects. The chosen split is necessary in order that the calculated parameters accurately reflect the actual man-hour and tonnage relationship relevant to the activity. Thus it is important that the quantity of materials installed respectively as integrated or in one or several modules should be separated into separate entities and correlated with the actual man-hours required to perform the work on each item.

The prefabrication activity concerns only the materials to be installed (integrated) offshore piece-small (hook-up and tie-in infrastructure) and includes onshore workshop fabrication of primarily piping spools, steelwork components and sub-assemblies and, though to a much lesser degree, small multi-discipline skids. All are presumed optimised size-wise suitable for installation offshore by platform crane and in order to minimise platform erection man-hours. The breakdown will naturally include a size gradation of appropriately sized sub-assemblies which is reflected in the sub-discipline breakdown formats shown earlier in this chapter. In contrast, the module/pre-assembly activity reflects both the fabrication and assembly activities of module construction, the module being loaded in offshore as a complete unit.

But as mentioned earlier, it is by no means given that separate treatment of these two very different material streams will be set up naturally as a logical consequence of the project control requirements. Of course this is not a problem where there are no modules to consider, as is the case with the majority of modification projects.

Figures 3-5 and 3-6 illustrate the performance parameter variations for steelwork engineering and offshore integration, plotted as man-hours/tonne for engineering and integration activities. The integration production efficiency is measured in terms of integration weights while engineering efficiency is measured in terms of the total installed weights, which will include module weights if relevant, due to the difficulty of separating module engineering effort from the overall engineering scope. As mentioned previously the values in Table 3-1 are median values in contrast to averaging, which is the normal practice for deriving a norm from a dataset. Examination of the charts in Figures 3-5 and 3-6 indicates a high degree of variance with respect to the median. Note that the medians can be seen in the charts on the extreme left hand. These norms have not been arranged in any particular order and at first sight one might assume that variance represents a performance variability applicable to any modification project. In fact, though the performance span is almost always relatable to the sub-discipline character of the work, there is a significant degree of scale effect present in the data sets.

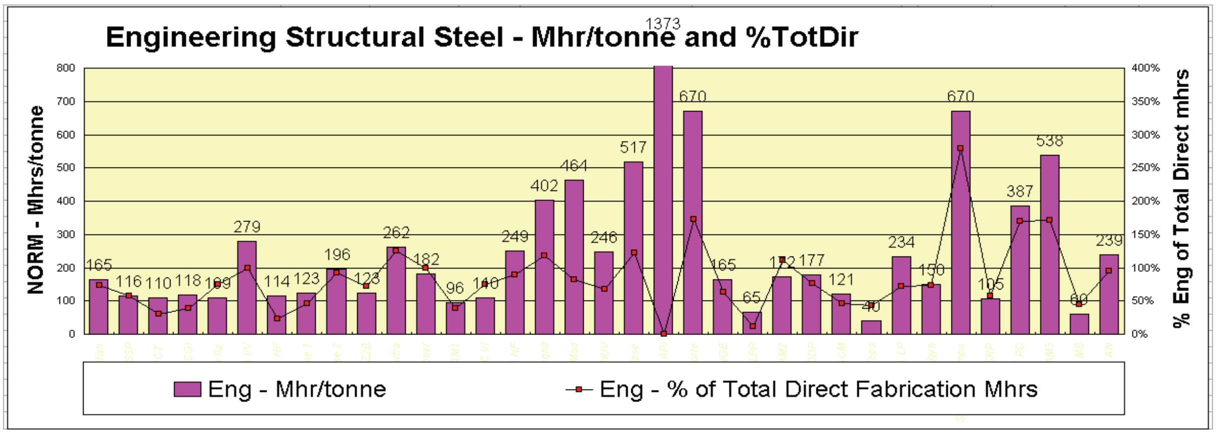

Figure 3-5: Performance variation steelwork engineering

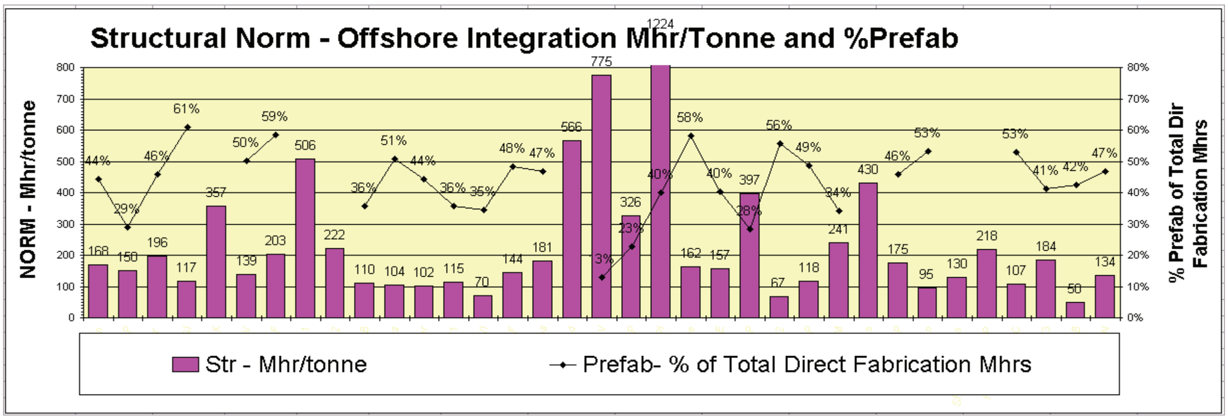

Figure 3-6: Performance variation offshore integration steelwork

In order to demonstrate this phenomenon of scale effect, the man-hour/tonne norm data from Figures 3-5 and 3-6, which have not been sorted in any particular order (but are in the same sequence in both charts), have been re-arranged in the chart in Figure 3-7 below. The man-hour/tonne values (left axis) have been correlated with the corresponding total integration weights (right axis) for each project in the array. This correlation permits sorting by size, which brings to light this effect of scale. Note that the Engineering man-hour/tonne trend line lies very close to the integration man-hour/tonne trend line; accordingly, the integration trend line has been drawn as a dotted line.

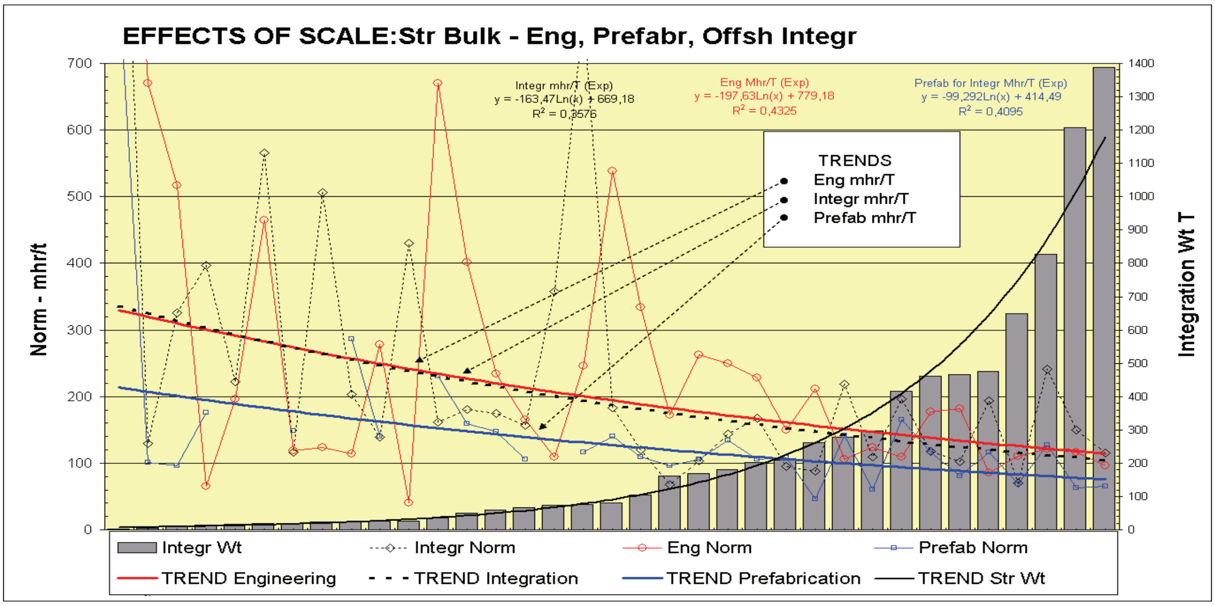

Figure 3-7: Integration steelwork effects of scale

Several interesting size-related properties can be read from the chart. First, the marked effect of size on the norms can be seen in the trend lines. Second, there is a large variance of the actual performance values with respect to the trend lines. Third, the ratio of prefabrication to integration increases with size (the larger the project the greater the prefabrication content). This property has also been plotted into Figure 3-6. Fourth the ratio of the engineering norm to fabrication is also stable, at least for wholly integrated projects. Note that fabrication is the sum of the prefabrication and integration. This property has also been plotted into Figure 3-5.

All the parameters from Table 3-1 may be used to compare norms. It follows that effects of size must be taken into account when judging expected levels of performance. Equally, it follows that the normative practice of using averages or medians for deriving norms for estimating from a dataset is an unreliable practice. It must be stressed that the effects of scale demonstrate a trend that complexity increases inversely proportional to size, but finally it is the sub-discipline complexity that should be considered if a suitable level of detail is available.

Here again the treatment of modularisation requires special mention. Engineering of modules cannot effectively be isolated from the engineering of the integration work so that the quantity relation is based on the total installed quantities including both module and integration work. The natural consequence of this is that modularised projects generally exhibit a lower man-hour/tonne value for engineering overall and for steelwork overall, but not necessarily the other disciplines. In Figure 3-7 only the integration weights have been shown in the interest of simplicity. This implies an inaccuracy regarding the plot of integration norms and prefabrication norms for the modularised projects on the right hand side of the array. The inaccuracy has little overall effect on the trend lines. This aspect will be discussed later in section 3.8 in this chapter, in relation to dealing with the sub-discipline complexity.

Since the sub-discipline characteristics of the individual projects in the above array are known, it can be stated that the variance of the source data about the trend lines can, in several cases, be linked to the sub-discipline character of the work. Sub-discipline considerations will be handled in detail later in this chapter. Some cases can however be linked back to inefficiencies arising out of execution circumstances, in some cases inefficiencies can be linked to organisational issues and in some cases several effects are in play.

Similar weight related effects of size, with the exception of the piping discipline, can be found throughout the parameters in Table 3-1 as can be observed in the charts for each discipline that have been laid out in Figure 3-13 at the end of the chapter. The piping discipline has, however, weight related scale effects coupled to diameter, the man-hour per tonne norms of performance decreasing with increasing diameter. But the material cost driver seems to be the material content, the materials cost per tonne increasing with increasing content of high grade steel in the material mix. The scale effects are not as marked for piping as the other disciplines. More detailed discussion is referred to the later sections of this chapter dealing with sub-discipline complexity.

3.7.5 Man-hour ratios

<u>Management</u>

Weight metrics are not considered suitable for activities such as project management and administration because they are only indirectly related to the quantities of materials embodied in the works. These activities, being supervisory in nature, are accordingly measured as a function of the labour man-hour volume in the measurable activities (ie are based on quantities of materials or some other physical production). In practice it is often convenient to measure Project Administration cost as a function of Total EPCI labour Cost as shown in the Chart below, Figure 3-7. In a similar manner the Company Management is more markedly influenced by the effects of scale, which is understandable in view of the fact that Company Management is not supervisory, being rather more functional in nature. It will be found that the Contractors Preliminary/Facility costs display similar trends since they have a large component of man-hour related overhead costs.

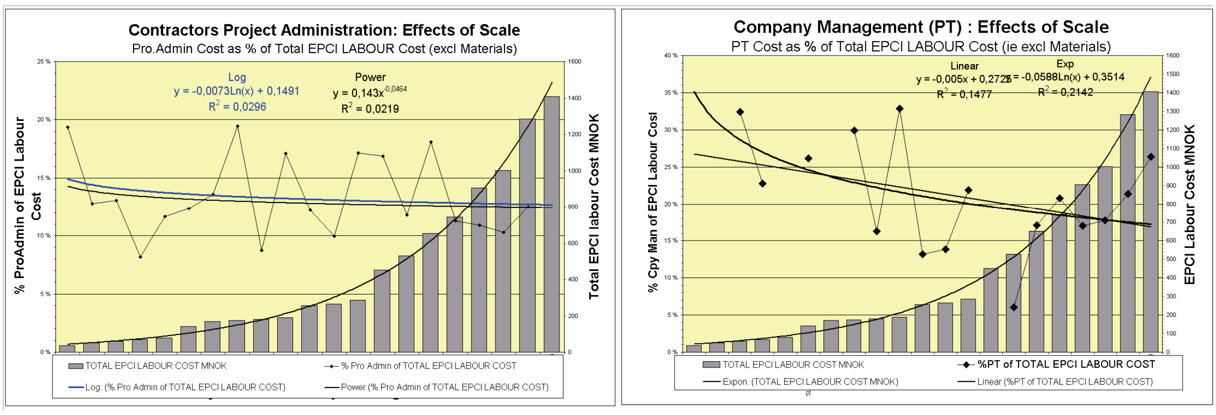

Figure 3-8: Management and administration cost - effects of scale

<u>Indirect Production Support</u>

The volume of indirect production support man-hours, being only indirectly related to the material quantities, is similarly measured as a function of the volume of the direct man-hours supported. However, the indirect volumes, while displaying a high variance, appear largely independent of scale effects

<u>Engineering Effort</u>

Man-hour ratio parameters relating engineering effort to production effort and onshore prefabrication effort to total fabrication effort, have been included in the charts of Figure 3-4 and 3-5 shown on the right axis. The same effects can be seen in the relationships between the trend lines in Figure 3-6 as described above. The reason for showing these properties is the fact that many actors often estimate engineering effort as a simple factor of fabrication effort (prefabrication + integration) most likely based on averages. Judging by the steelwork trend lines, this relationship appears stable and confirms this approach to be reasonably reliable, at least regarding fully integrated projects, given that the fabrication effort is correctly judged in the first instance. However, the factor is normally applied at multi-discipline level. Considerations of the high variability of discipline mix in modification projects suggest that engineering effort should be evaluated on a discipline basis.

Prefabrication for Integration

Prefabrication for integration of steelwork is seen from the steelwork curve to be very sensitive to size. This same effect is not apparent in piping where the effects of scale are manifest as sensitivity to diameter which appears to be the dominant factor influencing norms.

Prefabrication may relate to integration as a measure of performance due both to the complexity of the work situation and the nature of the work. For instance, access conditions may limit the size of sub-assemblies that can be handled, thereby forcing a greater degree of on-site erection, which naturally limits the degree of prefabrication possible. Or the nature of the scope may entail large quantities of small items, or structural strengthening requiring welded construction, both of which require much in-situ work and are not conducive to extensive prefabrication. The ratio of prefabrication to integration is a useful post hoc measure of performance, but unfortunately such influences are difficult to identify in advance.

Normative practice for deriving norms is often based on onshore module fabrication norms assuming a fixed split between the onshore prefabrication part and the offshore erection part of the work. Offshore factors are then applied to the erection part. This approach does not, however, pick up the size effects manifest in the trend patterns and is at best relevant to larger prefabrication items. In addition it must be added that the nature of the work is decidedly different now compared to some years ago, considering the preference for bolted construction in contrast to onshore module fabrication which will naturally utilise welded construction. These effects will change the balance between prefabrication activities and erection activities. An added complication is the subjective nature of the offshore factors, which are presumably derived by comparison of offshore erection man-hours per tonne with onshore erection man-hours per tonne. This approach must surely be subject to the same general shortcomings mentioned above.

Field measurement of actual man-hours correlated with actual installed quantities avoids all the above pitfalls and is a perfectly feasible alternative approach requiring no extra effort beyond the correlation of information already available within the project registers.

3.7.6 Conclusion regarding the metrics of performance measurement

The set of performance measurement parameters defined in Table 3-1 provides a basis for measurement of each core activity and each discipline separately in absolute terms of resource use correlated with properties of the products. For direct activities this takes the form of weight and man-hours. For indirect activities this takes the form of man-hour ratios related back to the core weight related activities. Consistent units permit multidiscipline hierarchic aggregation. The curves demonstrate that the metrics are sufficiently detailed to demonstrate adequately the existence, magnitude and location of performance deviations, but not necessarily to explain the reason for such performance deviations, be they positive or negative.

The nature of modification work is such that there may, in the individual project, exist special aspects at sub-discipline level that are related to concept complexity and that override the generalised basis of taking averages or medians and even trending with respect to size. This can be seen from the variance about the trend lines even after the effects of scale, which are themselves aggregate effects of sub-discipline complexity, have been taken into account. For this reason insight into the effects of sub-discipline complexity can be very useful. In the following section hierachical sub-discipline detailing downwards in consistent metrics and essential characteristics that are definitive for performance will be discussed.

3.8 Sub-discipline complexity

Comparisons at discipline level need to be supported by sub-discipline data with which to qualify and, if needed, quantify performance measured at discipline level. This is consistent with and similar to the way in which discipline level information qualifies performance measurement at project level. Generally three levels of detail, the overall level, the discipline level and the sub-discipline level will be required to fully analyse the performance of any given project quantitatively. To exemplify, the values of the parameters at overall project (multi-discipline) level are determined largely by the relative weightings of the discipline material content. Similarly the parameter values for any one discipline will be largely determined by the complexity and material mix at sub-discipline level. To exemplify, consider the effects of impact of a high content of large bore pipe on the discipline characteristics compared with a high content of small bore piping.

In so far as changes in sub-discipline complexity will influence the man-hour requirements, without any corresponding overall weight change, project control would benefit by monitoring of sub-discipline complexity, as a supplement to overall weight change. This is particularly relevant in the period of detailed engineering during which significant detail that may affect the resource requirements will be defined. This applies particularly to structural steel details resulting from detailed installation planning. These details often include many small items of low total weight, but that require high installation man-hours. Instrument and electrical detail is often underestimated in studies due to the low overall weight impact, but also here detail requires high installation man-hours. This lack of focus on items of low weight that require high installation man-hours is probably a consequence of weight monitoring generally not being a feature of the project control practices, while traditional weight estimating practices have a technical focus that tends to regard small low weight items as negligible.

Considerations of sub-discipline complexity may explain, on an intuitive basis, the effects of scale. It follows on a general basis that the smaller the overall weight of the work concerned, the larger the content of small items. Since small items are more man-hour demanding than large items, the aggregate effect will be higher norms. Small projects may nevertheless consist of a few large items or a multitude of small items, with the resulting variance about the *mean* value defined by a size-related trend line. Similar considerations apply to large projects which may include a large component of small items with resulting high prefabrication and integration man-hour requirements.

It would follow from the above that measurement of performance should take place at a greater level of detail than the discipline level, in order to provide the basis for norms of performance at discipline level. However, a comprehensive measuring system that includes both weight and man-hours at sub-discipline levels of detail requires rigour and discipline with regard to data recording. Thus, while it is impractical to institute such a level of detail in every project, it may be done from time to time, given willingness in the organisations concerned. It remains however to decide on an appropriate level of detail. Norm sets at considerable detail exist, for instance Page (Page, 1991), and are extensively used for the purposes of man-hour estimating at detailed planning task level, such as cutting, grinding, bevelling, welding or bolting of individual items. Such a level of detailing is only available as a result of detailed engineering and the norms are of no use for early phase estimating when such detail is not yet available. And it is practically impossible, in the course of ordinary project work, to initiate measurement of actual man-hours at such a level of detail.

In practice, the level of detail defined in the sub-discipline weight formats presented in this chapter has been found appropriate with regard to the information available from early studies and reasonable with regard to the level of information that can be extracted from project data with an acceptable degree of accuracy. Even with the fairly low degree of detailing chosen, it is by no means sure that actual man-hours will be available at the same level of detail from every project. But it is sufficient if this can be done from time to time, as was done in the studies on which this work is based. Given that some performance data at the same degree of detail exists, much can be achieved by monitoring man-hour data at discipline level while collecting weight data at sub-discipline level in order to provide the necessary insight into sub-discipline complexity. Some organisations practice the use of control objects in detail registers to facilitate the tracking of steelwork sub-assemblies and piping spools. These items individually often form the basis of single job-card task used in the detail planning and against which actual progress and planned and actual man-hours are reported. This potentially provides a means to measure performance on a more regular basis at a sub-discipline level equivalent to the sub-discipline formats shown earlier in this chapter particularly if single discipline task formats are used.

Collection of weight data at sub-discipline level is easily done, using sorting tools built into modern PC software and supplemented by an appropriate coding system. Good discipline, regarding coding, from the very start while building up the weight registers will promote quality, efficiency and usability.

3.8.1 Principles of sub-discipline breakdown

Closer examination of the sub-discipline weight tables reveals two types of elements in the breakdown structures, 'type of material' on the vertical axis and 'component weight' on the horizontal axis. Both these types of elements will be found in other breakdown structures such as SCCS and Page, but neither provide a matrix type breakdown incorporating both size and type elements, unless on a very detailed basis. For early phase estimating extreme detail is unusable[16]. For collection of experience data on a general basis extreme detail is impractical, [17] although it is theoretically possible to aggregate up to appropriate levels of detail for early phase estimating and performance measurement. In a project context the detail work orders are estimated on the basis of detailed norm sets like Page but 'actual man-hours' as a performance measurement metric will only normally be available for the work order as a whole. These job cards are a useful measuring point since they are also used to measure earned value. For modifications, job-cards are most often system-related and of a limited size consisting of discrete items such as a single equipment component, a steelwork element such as a foundation or a ladder, a single pipe spool or short run of pipe in the same system, a run of cable, and so on. This provides a very convenient basis for defining the content in terms of both size and type of work as well as planned and actual man-hours for each task sheet and at an appropriate level of aggregation in a manner consistent with current industrial practice. However, some organisations prefer to operate with fewer multi-discipline packages as control objects. Such an approach would naturally render the whole process more difficult to follow through.

In the introduction it was stated that weight was used as a basic unit of measurement since it permits hierarchical aggregations in consistent units. In a weight context size considerations translate generally into weight categories.

[16] At early stages of concept development information at equivalent levels of detail is not yet defined.
[17] It is impractical and inconsistent with current industrial practice to measure man-hours at such levels of detail.

Modification work is very variable and some idea of the sub-discipline complexity is necessary in order to understand the performance and to be able to estimate. However, some degree of aggregation is obviously necessary not to drown in detail while studies must be able to deliver a similar degree of detailing for estimating purposes. These complementary requirements are deemed satisfied in the sub-discipline breakdown formats presented in this study.

3.8.2 Steelwork sub-discipline

To elaborate in the interests of clarity, consider steelwork. Greenfield topsides estimating practices normally consider only three classes (ie types) of steel work, primary, secondary and outfitting, where the physical differentiation is primarily the size of the cross-section. Modification work on the other hand may consist of several subcomponents of very different size (weight category) and type and in addition may include other items such as the strengthening of existing structures, and temporary installations such as landing platforms, skid-beams and lifting aids. Modification also includes demolition of both temporary and permanent works as well as seafastenings that may have come on board in modules. A consequence of this is that the size elements are of greater significance than type elements in defining the offshore man-hour requirements.

A complicating aspect is the fact that demolition is seldom defined on separate job-cards and demolition man-hours are accordingly included in the integration man-hours for each category. Demolition quantities need to be registered in order to have a measure of the total volume of such work, both for estimating purposes and for performance evaluation.

Analysis of job-cards indicates, as might be expected, a strong effect of size on norms of performance, but also provides a measure of man-hours per tonne of the different size categories. A plot of the results of such an analysis is shown in the chart Figure 3-9 below, where the norms of performance are plotted as lines on the left axis while the columns plotted against the right axis show the size range distribution by weight category.

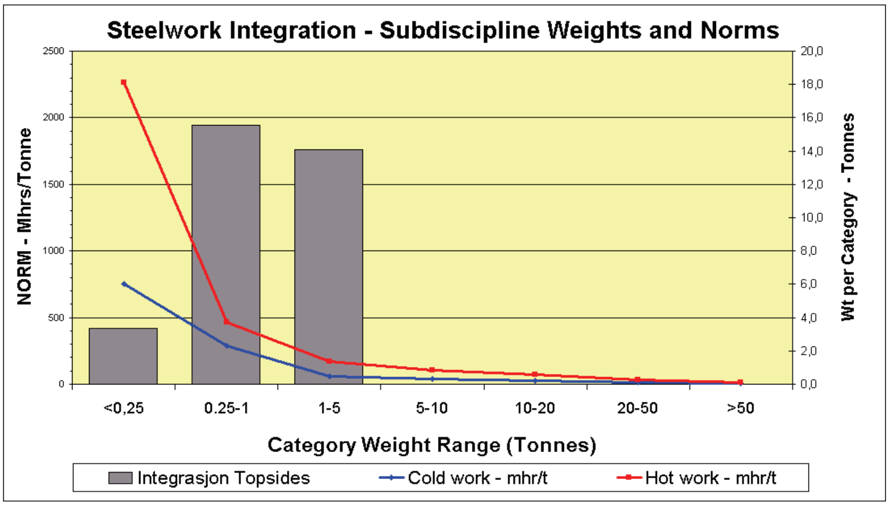

Figure 3-9: Steelwork sub-discipline weight breakdown and norms of performance

It is easy to see a parallel in the shape of the man-hour per tonne norm curves to the effects of scale shown in the previous chart, Figure 3-6, the effects of scale at discipline level. The aggregated value from the array on the right axis aligns with the value corresponding to discipline total weight in the Figure 3-9 chart above. Given that the component of small steelwork, as an example, showed signs of growth, this would be a variation and a signal that considerations of sub-discipline complexity justify a need for more man-hours. Knowing that it is in the detailed engineering that most of the small items are defined, this makes a case for monitoring sub-discipline complexity as part of the project control scope monitoring effort. Illustrative of the order of magnitude effects of small items in the total scope, the case depicted in Figure 3-6 where the small items require up to 50 % of the total integration man-hours while comprising only 10% of the total installed weight, are not untypical.

The size element is reflected in the weight categories in the breakdown formats for steel work while the type of work is reflected in the primary/secondary/outfitting categorisation similar to the greenfield breakdown, where the modification specific categories, such as temporary installation aids are also included. It has been found that the size category is the most significant but it also appears, at first sight, to be the most difficult to isolate. This is due to the fact that the sub-assemblies installed offshore are generally not defined in the MTO registers as discrete items, but rather as individual subcomponents prior to prefabrication. However, most modification studies include an installation study, part of which is to determine the optimal degree of prefabricated sub-assemblies consistent with minimising the number of offshore man-hours. Such studies naturally define the sub-assemblies, and it is a very natural step to further define each sub-assembly as a control object for controlling the production process in terms of drawings, materials control, task sheets, prefabrication progress, offshore delivery times and the like. In spite of this, and due to the lack of such routines, it remains a problem to define the weight and category of the individual sub-assemblies from the MTOs. This may be a consequence of the normative project control practices of using standard man-hours that disregard the nature of the work.

This process of identifying steelwork sub-assemblies within different size categories is consistent with the principle of separating large modules from integration work and an added differentiation of the nature of the integration work.

Noting that the man-hour per tonne norms of performance associated with the low weight per item categories are very high, it is appropriate to mention that ‘weightless work’ will naturally tend to accumulate in the lowest weight category, which provides an extra component apparently inflating the small category norms. In this way high norms function as a sort of contingency for the type of small work that inevitably turns up in the field, but is seldom defined on the drawings. This sort of work is conceptually equivalent to the ‘small bore’ and ‘bolts, nuts and gaskets’ type of allowances applied to piping weight estimates and suggests that implementation of similar practices in weight estimating of integration steelwork may be appropriate.

3.8.3 Equipment sub-discipline format

The discipline sub-division of equipment falls naturally into a weight categorisation similar to steelwork. The assumption here is that the norm covers installation and alignment of the equipment items while hook-up to piping, electro and instrument bulks is covered by the piping, instrument and electro disciplines. For equipment items delivered as skids all the multidiscipline elements in the skids are considered part of the equipment package.

The Master Equipment Lists (MEL) produced as standard documents in all studies provide a natural supplement of sub-discipline detail since they include detail such as weight, size and cost for each equipment item making it an easy matter to define the weight categories and type categories in the sub-discipline weight breakdown table. Note that the type categorisation has been reduced to a categorisation by discipline since the type categorisation in coding systems such as the SCCS provides no intermediary levels of aggregation. For all practical purposes discipline-based type categorisation can be ignored for the purposes of assessing installation man-hours per tonne.

From the equipment cost per tonne and man-hour per tonne plots in Figure 3.13 it can be observed that also the equipment is sensitive to effects of scale in aggregation with regard to both material and labour costs. Care should be observed regarding use of the trend line for assessing equipment material costs due to large variation in cost per tonne for different types of equipment, particularly regarding small items.

Under normal circumstances priced equipment lists will be produced by the engineering disciplines based on either own in-house data or quotes from vendors. For estimating purposes this source is normally the best information available. As has been pointed out earlier, the overall cost of materials may be controlled by project specific circumstances to the effect that materials costs and labour costs should be evaluated separately.

3.8.4 Piping sub-discipline format

Piping sub-discipline breakdown falls into a somewhat special category using both type and weight categorisation, but which is nevertheless suitable for differentiation using weight metrics. The traditional approach to piping in detail codes, such as Page, has always been to subdivide in accordance with diameter, wall thickness and material quality. This approach has been maintained in the sub-discipline weight formats presented here, but the split is at a higher order of aggregation into piping, valves (both manual and instrument) and pipe supports and expressed in weight metrics for the convenience of hierarchical multi-discipline aggregation.

Typical sub-discipline diameter related norms derived from job-card analysis for carbon steel piping, are shown plotted as lines (hot work uppermost) against the left axis in the chart in Figure 3-10 below. The columns plotted against the right axis define the size profile for any particular project under consideration in terms of weight per diameter category split into piping and valves. The project depicted in the figure is seen to have rather high valve content.

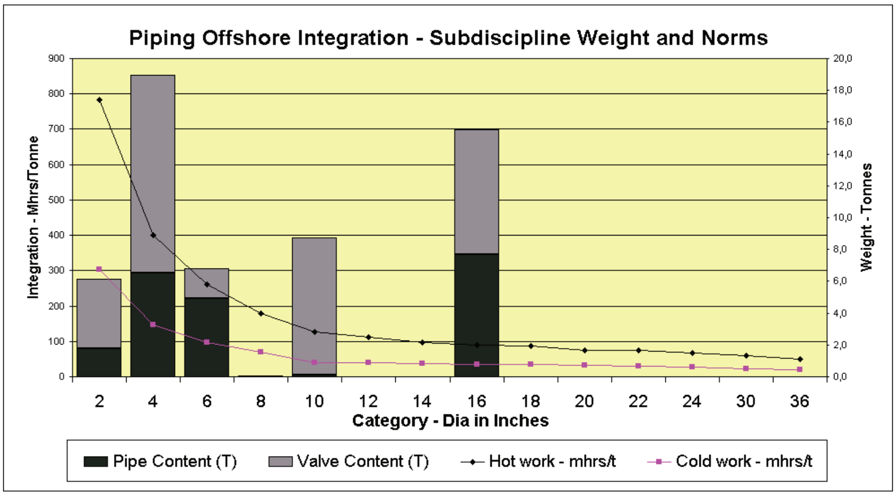

Figure 3-10: Piping sub-discipline weight breakdown and norms of performance

Comparison of the sub-discipline piping norm curves (Figure 3-10 above) with the discipline based scale effects curves in Figure 3-13 indicates similar trends, although the trend line is much flatter. Note that in contrast to the equipment, steelwork, electrical and instrument bulk, plots of piping man-hour per tonne and cost per tonne norms show no marked effects of scale with regard to discipline weight. In fact the content of high grade steel in the material mix is seen to be the cost driver for both materials and labour, but the curves are very flat. And indeed the diameter seems to be the man-hour driver exhibiting marked trends that are not visible in equivalent cost per tonne curves. These low effects of scale may be due to the particular multi-variate nature of the piping work scope. The piping work scope consists of a highly variable content of piping and valves, different material mixes, different degrees of hot and cold installation methods, and so on , all of which have strong effect on the norms so that the effects of one property may cancel the effects of other properties. Typically bolted installation methods are more efficient than welded construction in terms of man-hours per tonne, both direct and indirect, so that high valve content may cancel the effects of welded construction. Bolting of piping spools will tend to lower the overall man-hour per tonne norms both in terms of pure efficiency, but also as a result of the increased weight per spool, due to the flanging. In a similar manner considering cost per tonne, high valve content will increase material cost per tonne while lowering labour cost, due to bolting. High grade steels will increase material costs per tonne even more not only as a consequence of the higher material cost, but also as a consequence of the lower weight for equivalent units. It can be seen that piping is a very complex discipline and it is probable that these multi-variate effects tend to mask any effects of size that might intuitively be expected, judging on the basis of the piping norm curves in Figure 3-10 above. Alternatively, it may be argued that there is no particular reason why piping should have a scale effect similar to that of steelwork since spools sizes are primarily limited by length with respect to diameter and secondarily by such considerations as access conditions and local complexity. In other words the distribution of size elements for piping, such as spool sizes, may be physically limited in a way that disciplines such as steelwork sub-assemblies and equipment are not.

Examination of the performance norms for individual projects reveals nevertheless that projects with certain special characteristics can be identified in the array of reference projects. Particularly large diameter piping is visible due to low norms. This specific effect may be observed directly in the man-hour per tonne piping charts in Figure 3-13. Several projects have low values relatable to large diameter or high content of straight run piping when judged on the basis of the norms of Figure 3-10; however with the notable exception of some known underperformers. This effect is also observable in the aggregated EPCI cost per tonne charts Figure 4-3 and 4-4 in the next chapter (referring to the projects labelled C). These particular projects are characterised by a large content of large diameter piping.

It is thus to some extent possible to isolate projects on the basis of known characteristics such as large diameter versus small diameter, or hot work versus cold work, or high or low valve content, or carbon steel versus high grade steels, using medians or averages as a basis for expected levels of performance. However, in order to be reliable, since the above categories are by no means clear cut, this approach requires sub-discipline data from a broad array of reference projects and must be used with care. It follows that for piping in particular, discipline aggregate norms derived on the basis of sub-discipline detail are more dependable than norms derived from effects of averaging or the effects of scale.

It should be noted that the man-hours for painting and insulation have been included in the norms on which the curves of Fig 3-13 are based but not the curves of Fig 3-10. Insulation in particular may require high offshore man-hours, depending on the volume of insulation, and is an additional item in the multi-variate nature of piping work that should be taken into account. Thus it is important to verify the volume of insulation requirements specifically rather than uncritical use of average-based factors.

In the same way as mentioned above in connection with the steelwork section, the inevitable weightless field work elements that are seldom defined on drawings, tend to inflate the small work actual performance norms and thereby act as a buffer for this type of work in the estimates. In this category the man-hour effects of insulation work may be included.

3.8.5 Electrical and instrument bulk materials sub-discipline format

Electrical and instrument work is characterised by the 'type' subdivision of elements rather than size consisting of a mixed bag of electrical and instrument subcomponents, supports, cabinets, cables and trays, penetrations, instrument tubing, and so on. Included is also a not insignificant weightless component of work in the form of the termination and testing of cables and on occasion control room upgrades. Rather it may be said that all components are of small size, falling into a single weight category when compared to the weight categories adopted for equipment and steelwork, and accordingly have low overall weight. The exception here is cable that has a variable length-related dimension, in addition to the number of cores that will strongly influence the termination requirements. The net effect of the low weight is a high man-hour per tonne norm, so much so that many regard the use of weight metrics as inappropriate for these disciplines, preferring the use of signals as a metric. This alternative approach is not without validity, but, as has been stated previously, weight metrics permit hierarchical aggregation in consistent units like no other metrics. As long as weight metrics provide a reasonable measure of performance, they may however be used, if that provides overriding advantages. To judge by the effects of scale plots though, referring to charts in Figure 3-13, the instrument and electrical bulk norms for engineering and integration display an equivalent degree of consistency, when compared to other disciplines, even though they are perhaps even more multivariate than piping.

There is no reason why weight metrics may not be supplemented by alternative metrics that are more appropriate for use as more precise measurement units, but as yet none have been found that perform adequately in all phases of work. Indeed, where this is possible, it is recommended to establish alternative metrics that more characteristically express the nature of the work, such as number, length, and so on, for all disciplines, not only the instrument and electrical disciplines. Success with the use of sub-discipline norm and weight data will in any event depend on due diligence being exercised in registering of all the subcomponents in the scope of work and more or less irrespective of the metrics used. And as discussed previously all items must be registered in the MTOs for purposes of procurement, making it a relatively easy matter to generate weights estimates and appropriate categorisation automatically. That the total weights of the small electrical and instrument components do not enjoy the same attention as steelwork, equipment and piping, may be due to the fact that they are of little consequence for structural loadings and stability considerations, hence of small impact on the technical weight monitoring for structural and stability purposes.

Instrument valves are often included in the instrument weight for the reason that they are generally specified by the instrument engineering discipline, in spite of the fact that the valves are normally physically installed as part of the piping discipline scope of work. This convention is not used here for two reasons, firstly, the wish for correlation of material scope with labour scope [18] and secondly, due to the disproportionate ratio of the valve weights with respect to the instrument bulk materials. Elaborating, instrument valves are primarily part of the work scope of the piping discipline both in terms of engineering and in terms of installation, although there is a component of instrument engineering to be taken into account. More important, especially with regard to representative metrics, is that the weight of the valves, being approximately tenfold that of the instrument bulk, normally dominates so totally that resulting norms would be entirely without meaning for the instrument bulk part of the work. Regarding the valve installation part of the work, the bulk instrument man-hours would normally be much higher than the valve work scope alone, to the effect that the resulting norm is also non-representative for the valve work scope. This point may be illustrated by comparing the relative size of the median piping and instrument man-hour per tonne norm shown in the parameter table, Table 3-1.Better then to define instrument valves as piping, accepting a small inaccuracy regarding instrument engineering, and noting the need to ensure that instrument valve costs are included in the piping material costs.

[18] Consistent with the principles for data structuring outlined in paragraph 3.3

Both electrical and instrument work exhibit marked effects of scale and a large variance, which, with respect to the trend line, is greater for the smaller projects. The effect of scale may be attributable to the nature of the work in smaller projects, which often include revamping, short cable runs and larger termination and testing content. Control room upgrades are another form of weightless work that may contribute to the high variance, particularly with regard to larger projects. Also the extent to which cabling can be installed on existing trays, is another common factor contributing to the large variance.

3.8.6 Summary of sub-discipline effects

Given the obvious difficulties and uncertainties associated with sub-discipline complexities, it remains to ask what the gains are that justify the data gathering effort.

It is presumably clear from the discussion in the above sections that knowledge of sub-discipline complexity helps towards better understanding of the nature of the work to be performed and hence better estimating of man-hours required. Particularly so offshore, which is important considering the time-wise constraints of available beds, manning limitations in a production environment, general manpower density related efficiency effects and the added costs associated with offshore personnel logistics, particularly if flotell support is required. Dynamic tracking of the complexity changes that may occur as consequence of detailed engineering provides a picture of the total man-hour requirement, which may be used to test established scope assumptions. The formats for sub-discipline structuring described above provide a suitable intermediate level of aggregation for estimates of this nature.

Since all offshore work is controlled under job-cards which include a definition of materials, it is theoretically possible to compare the quantities already installed to the man-hour performance as a basis for judging performance in a manner that takes into account the specific nature of the work. It follows that the basis for predicting the remaining man-hours can then be based on the nature of the work to be performed in a similar manner. This is more precise than the standard man-hour approach of simple extrapolation of past performance into the future on the basis of earned versus actual man-hours and irrespective of the nature of the future work.

This approach of defining the scope in terms of sub-discipline components and characteristics echoes the practices defined by Clark and Lorenzoni in their work on process plant construction (Clark, Lorenzoni, 1985) and is discussed in more detail later in Chapter 5.

3.9 Some results of quantitative and qualitative performance review

The ultimate purpose of performance measurement is the improvement of project execution methods both in the short term, the lifetime of a project, and in the long term, experience transfer between projects and to future projects. This ambition cannot be achieved solely by quantitative analysis of performance, but must also be supported by qualitative identification of the causes of any given result such as the physical installation methods, organisational structures or administrative methods adopted by the individual project. The quantitative measurements can, however, be used to guide a process of review that investigates the sources of deviations from expected results as an experience transfer process, a process akin to benchmarking. This approach may be used at all stages of a project execution, transferring experience by benchmarking from the base organisation to the project during execution and vice-versa after close-out. In this way many experiences from the project will already have been formulated (made explicit) before close-out thereby resolving some of the problematic issues related to experience transfer in projects after close-out when many key personnel have already remobilised on new projects.

A case study will serve to illustrate the procedure which entails tracking the development history of selected performance parameters through the whole life cycle right from early estimates and evaluating performance at regular intervals against planned or anticipated performance. This is of course superficially similar to project control practices based on relative performance measurement, but in addition evaluates the effect of material quantities and work complexity development on the man-hour needs. This is by no means common practice.

A project life cycle analysis

The main features of the case study are laid out in Figure 3-11 below, which brings together the reported weight, and labour and materials costs from the project baselines, for purposes of comparison and analysis.

A major anomaly can be noted by comparing the growth history of the materials costs, the labour costs and the weight development curve. The labour cost forecast (the upper section of the stacked bar) increases from the target cost value (TC) at each base-line update (BL1, BL2, BL3, BL4) throughout the project life cycle and including the final close-out value (CO), in successive large increments for the full project duration (14/ 90/195/148/49). In total this makes up 56% growth with respect to the TC, but only 22% with respect to the Study estimate. In contrast the material cost increments (the lower section of the stacked bar) flatten out early after only 33% of the duration (140/49/18/0/49). In total this makes 68% with respect to the TC, but only 30% with respect to the Study estimate. In contrast to the cost development, the reported weight curve (W1) increases by 17% and only 6% with respect to the TC and the Study estimates respectively. Note the lack of correspondence between the weight profile and the cost profile, particularly the initial decrease from Study to TC and the marked jump (3031 to 3824 tonnes) at BL3 (50% duration). The jump is reflected in the labour cost growth at BL3 and BL4 but is not reflected in the material cost development profile. How is this to be interpreted ?

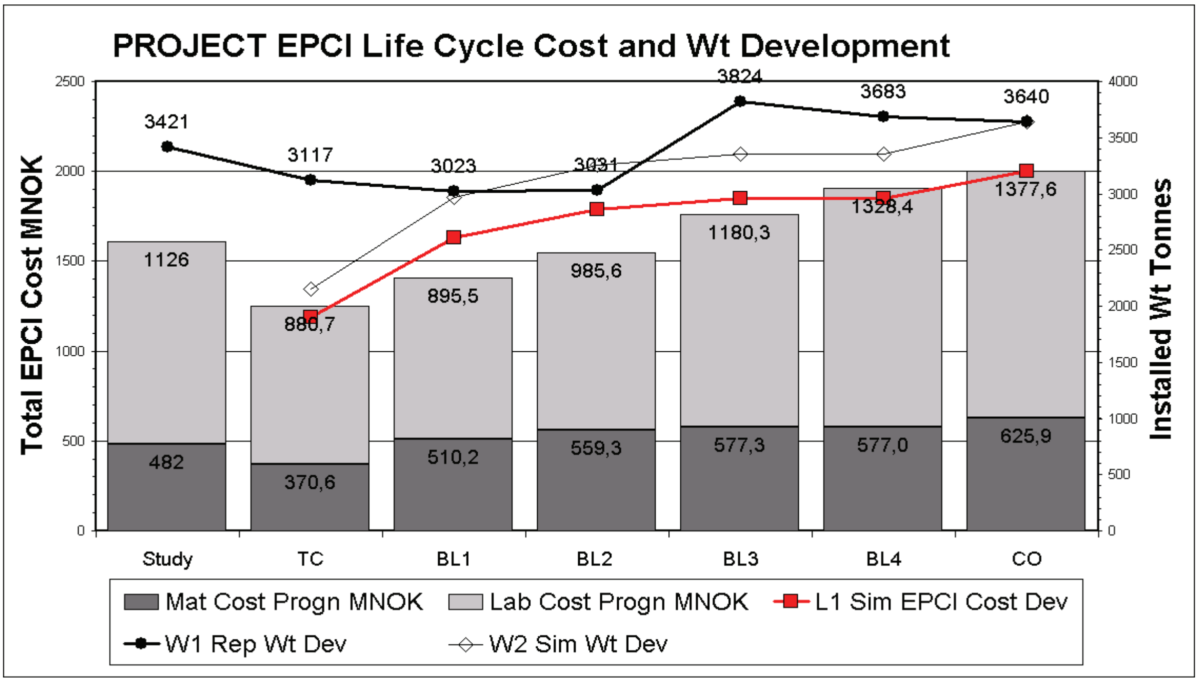

Figure 3-11: Case Study - Cost and weight life cycle development

The materials cost prediction was 82% of the final value within the first BL period ! At the same point in time the labour cost prediction was only 65% of the final value. The material costs are directly MTO related implying that the MTO basis for a good weight estimate was available, but was not worked into the weight estimates until they were updated at BL3 for the first time since award of contract. This effect is illustrated in the curves W2 and L1 on the chart. The curve L1 is based on a *reconstructed* labour cost prognosis based on the materials cost development profile and close-out (CO) values and illustrates a hypothetical total cost prognosis profile.

Comparison with the tops of the bars illustrates the labour prognosis shortfall. The curve W2 indicates the equivalent *reconstructed* weight development curve, meaning the weight content equivalent to the estimate value. Comparison with the reported weight curve W1 illustrates the weight shortfall. Noting that the reconstructed labour cost and weight development curves have markedly different profiles from the reported profiles, it may be deduced that the project was in possession of the correct weight data, but apparently made no use of the information in setting up labour cost prognoses.

The materials cost growth is unlikely to have provided any signals to the project since this is not a monitoring point in normative practice. Had a properly updated weight estimate been used as basis for updating the estimates, a labour estimate would most likely have achieved a similar degree of accuracy and the project would have received an early warning of potential overruns already at BL1. It is certain that weight estimates were not the basis for the labour estimates since the project at no time used weight tracking as a basis for project control. This was established by informal communication with project personnel.

It is evident that the methods used to update the labour estimate were not particularly accurate. That the project lacked a reliable basis for estimating resource requirements is evident from the chart below, Figure 3-12 that illustrates piping life cycle man-hour and weight development. The most striking feature is the continuous rise in piping engineering man-hour forecasts throughout the project life cycle; in contrast the piping weight estimates are relatively stable. A normative level of performance would be about 270000 man-hours corresponding roughly to the prognosis at BL3. Thus a weight based estimate would have indicated from the start that that the engineering resources were too low. One can only presume that such methods were not used.

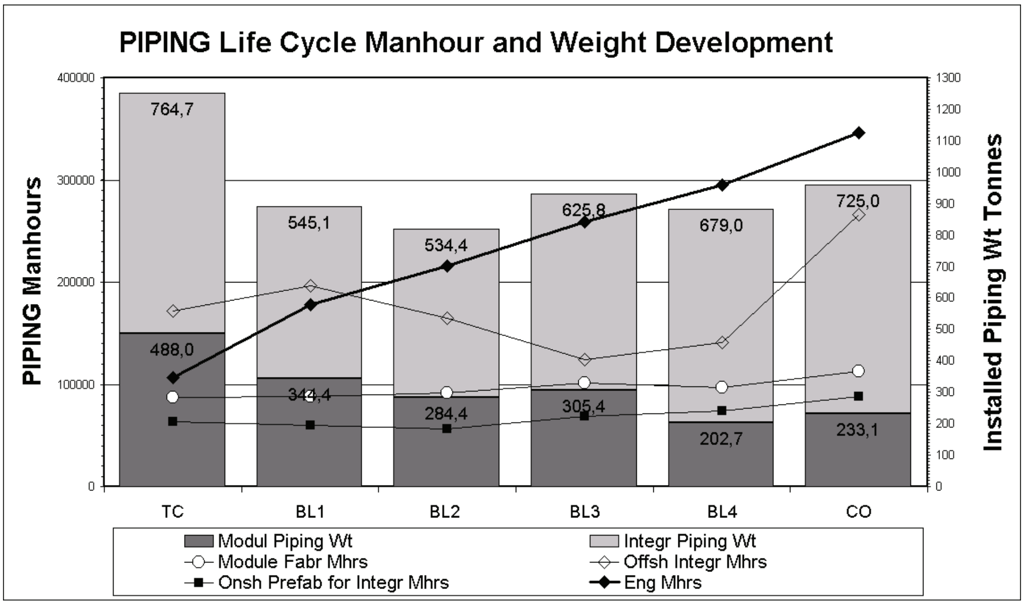

Figure 3-12: Case Study - Piping man-hour and weight life cycle development

The low manning stems from the fact that the contractor severely underestimated the resource requirements initially, but subsequently refrained from resourcing adequately up-front due to the low target cost. As can be seen from the diagram, the contractor continually increased manning, but evidently too little too late, presumably lacking a good basis for estimating likely resource requirements[19]. As a result the project was perpetually behind schedule on piping engineering with resulting stress on all downstream activities. This had a marked effect on the overall efficiency, which was well below comparative work.

The overall root cause may be traced to the contractors' belief that their design would result in a significant weight saving compared to the existing concept. This is reflected in the low weight and cost of the Target Cost (TC). As can be seen from the chart, this was achieved, at least regarding the module piping, but not for the integration piping, which is a major cost driver. However, this implied the possible need for some front-end conceptual re-engineering for which the target cost had obviously not been resourced. Yet it appears that no special action was taken to ensure adequate resourcing up front and to mitigate the negative effects of quantity and complexity changes.

There is more to this case, but as this case is discussed in more detail in Appendix 1: Case Study 1, it is sufficient for the time being to point to the anomalous 'roller coaster' shape of the Integration Man-hour curve when compared to the flat weight development histogram in Figure 3-12.

This case provides an argument for the use of weight development monitoring as a basis for project control during detailed engineering in line with the Clark and Lorenzoni BOQ update procedure. Weight monitoring would in this case have provided useful project control insights, even in the absence of a broad base of reference data on which to base labour estimates. Given the large discrepancy between the study estimate and the contractors target estimate (TC), in terms of both weight and cost, one might have expected that the owner's team would have been on the lookout for discrepancies in the project basis and would have initiated mitigative action. One might perhaps be justified in concluding that the overall underperformance is largely an organisational issue.

Finally, it is interesting (and symptomatic ?) to note that although the poor engineering progress and low engineering manning was well known in the project, this problem had not been addressed in the experience reports.

3.10 Conclusion

The discussion in this chapter has described the basis for the breakdown structure and metrics chosen for modification work. Further, some of the characteristics of modification works derived from analysis of data from several projects have been presented. Amongst others, the high degree of variance of both project characteristics and levels of performance has validated the high degree of detail in the data formats for performance measurement of modification projects presented in this thesis.

The set of performance measurement parameters defined in Table 3-1, some of which are illustrated in the charts of Figures 3-13, 3-14 and 3-15, and supplemented by sub-discipline weight information, provides a measurement point for each core activity and each discipline separately. The breakdown is sufficiently detailed to demonstrate adequately the existence,

[19] Since it is known that the contractor's in-house base organisation has fully adequate estimating competence, this suggests rather that the lack of insight was limited to the contractor's project organisation and the nature of the methods for forecasting used in the project. This in turn raises issues of an organisational nature such as communication between the contractor's base organisation and the contractor's project organisation, which apply equally to the operator's project team.

magnitude and location of performance deviations with respect to median industrial levels of performance, but not necessarily to explain the reason for such performance deviations, be they positive or negative. Insight provided by the supplementary sub-discipline weight detail provides additional information regarding the specific nature of individual project complexity and may contribute to explanation of specific levels of performance that deviate from the trend patterns.

There remains however a residual element of performance deviation that often cannot be explained in terms of product characteristics as such, and that may be related more to the project execution circumstances and how they might affect the levels of performance, such as the drop in efficiency often associated with overrun circumstances. Depending on the order of magnitude of the deviation, the identification of expected levels of performance using sub-discipline characteristics may assist in identifying the presence of such effects in the recorded performance data.

The case study and procedure presented briefly in section 3.8 demonstrates that quantitative performance measurement processes can support qualitative enquiry and that the breakdown structures and metrics presented here are of sufficient sensitivity to expose significant detail that may otherwise not come to light using other methods. This is due to the fact that the analyses are based on historical data recorded at regular intervals during the project life cycle that may highlight a pattern of performance deviations over time that supports enquiry as to the qualitative nature of observed performance deviations.

The discussion above is primarily directed at the evaluation of performance in relation to the selected breakdown structure and associated metrics. However, considerations of estimation also feature in the discussion which is logical in so far as estimation is based on the correct assessment of product characteristics and appreciation of the normative levels of performance achieved by the industry. Equally, estimation processes need to take into account the range of variability in the product characteristics, and the variability in levels of performance attributable to properties of the product, or to the circumstances of execution.

The above conclusions point to applications of the performance measurement approach to project control with regard to estimating, assessment of risk and benchmarking practices aimed at long term improvement processes. These applications will be addressed in the following chapters.

Effects of Scale (1): Discipline Cost and Man-hour per Tonne [20]

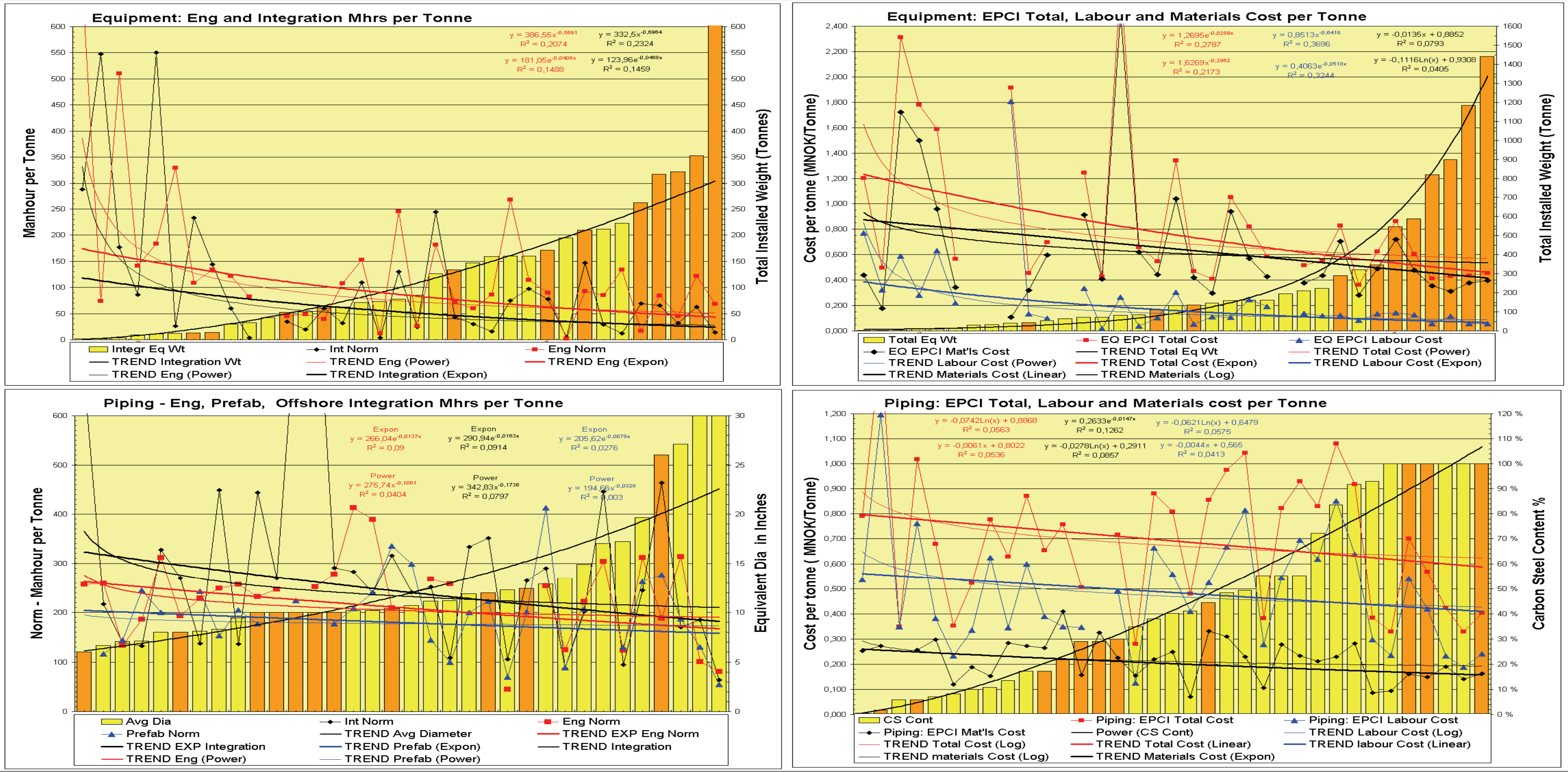

Figure 3-13: Effects of scale - Equipment and piping cost and manhours per tonne

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[20] Regarding the charts in Figure 3-13 above:
Columns – dark tone – modularised projects; light tone – integrated projects
Man-hour norm charts show only integration weights irrespective whether modularised or not.
Cost norm charts show only total installed weights including module contents.
The charts are only intended as illustrations of the consistency of the effects of scale.

Effects of Scale (2): Discipline Cost and Man-hour per Tonne [21]

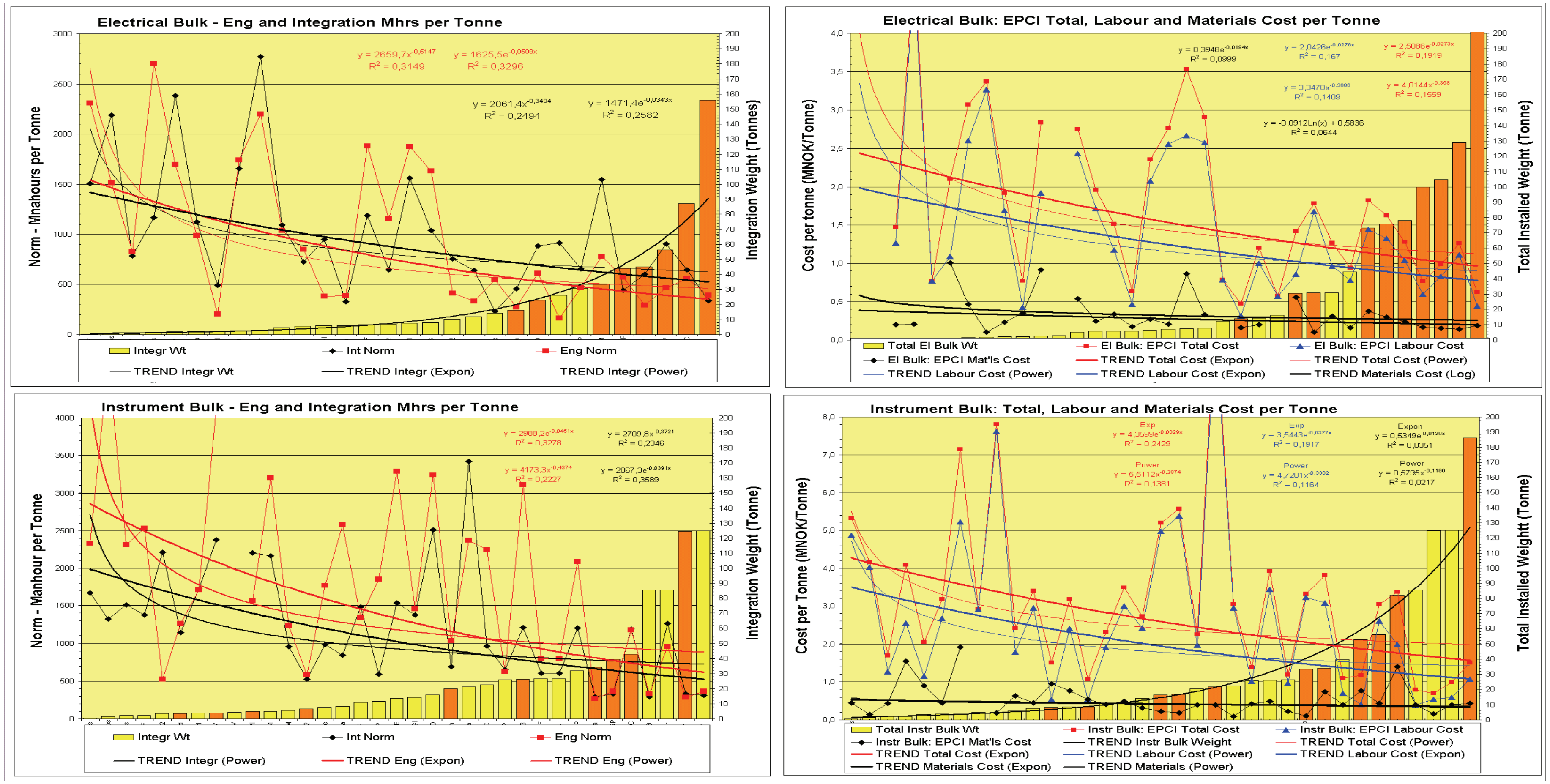

Figure 3-14: Effects of scale - Electrical and instrument bulk cost and manhours per tonne

[21] Regarding the charts in Figure 3-14 above
Columns: dark tone – modularised projects; light tone – integrated projects
Man-hour norm charts show only integration weights irrespective whether modularised or not.
Cost norm charts show only total installed weights including module contents.
The charts are only intended as illustrations of the consistency of the effects of scale

Effects of Scale (3): Discipline and Total Cost and Man-hour per Tonne [22]

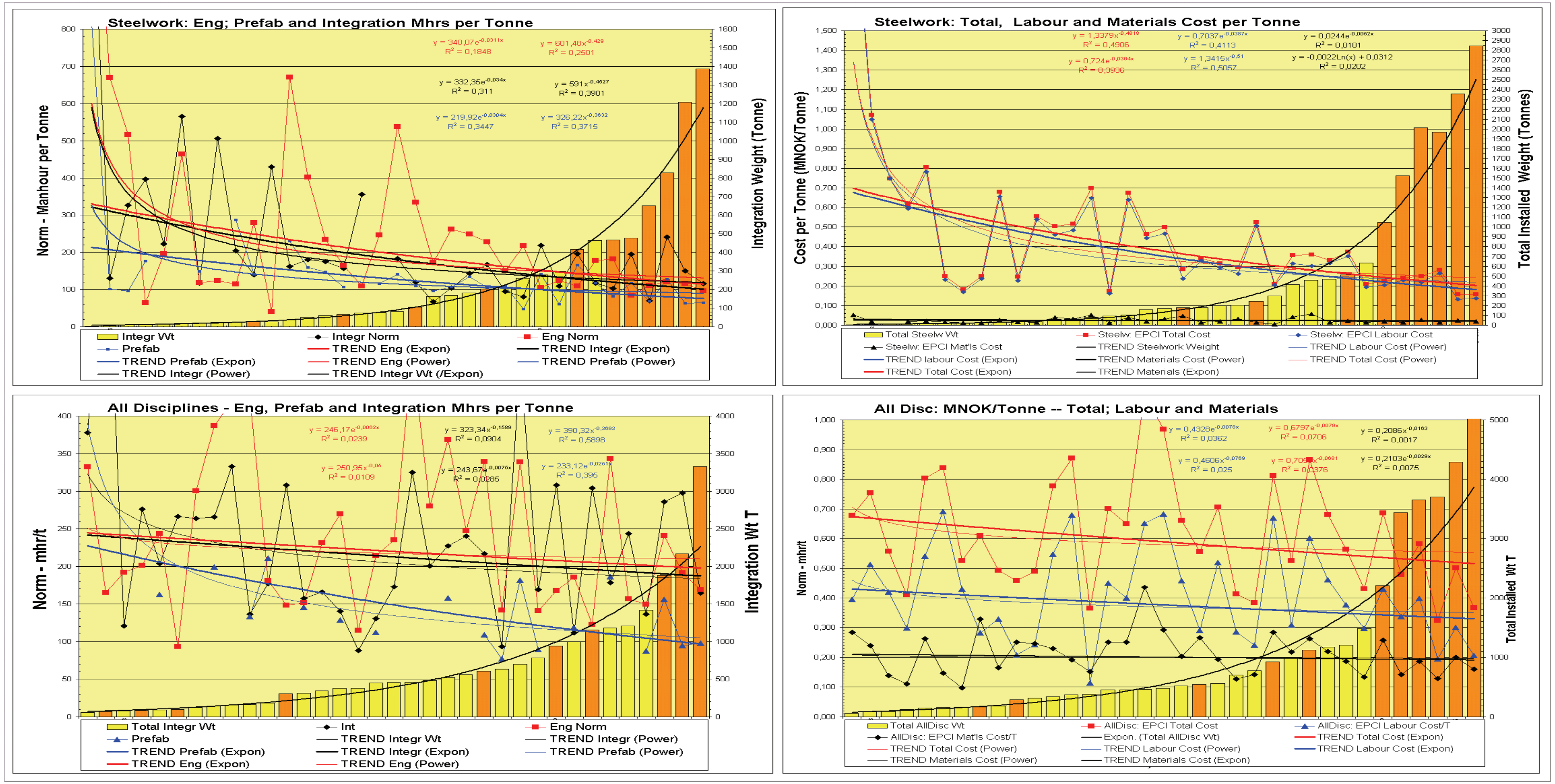

Figure 3-15: Effects of scale - Steelwork and all disciplines cost and manhours per tonne

[22] Regarding the charts in Figure 3-13 above
Columns: dark tone -- modularised projects; light tone -- integrated projects
Man-hour norm charts show only integration weights irrespective whether modularised or not.
Cost norm charts show only total installed weights including module contents.
The charts are only intended as illustrations of the consistency of the effects of scale

4 PROJECT CONTROL APPLICATIONS/ESTIMATING

THE APPLICATION OF PRINCIPLES AND METHODS BASED ON PERFORMANCE MEASUREMENT IN PROJECT CONTROL OF MODIFICATION PROJECTS

4.1 Introduction

The term ‘project control’ contains an ambiguity, namely an ambiguity of understanding that exists between the terms ‘project control’ and ‘project management’.

For the general purposes of this discussion, the term project management may be understood to mean the administration of the processes whereby a concept is first developed to an acceptable level of technical, constructible, economic and social feasibility for sanctioning (planning phase), and thereafter constructed and brought into operation within the planned constraints (execution phase). [23]

In a likewise manner, the term project control may be seen as the quantitative and qualitative processes concerned with establishing measurable baselines by which to verify that the project during the execution phase conforms to the resource framework, established during the project planning phase and which is the basis for sanction. Project control functions may be involved in both the establishing of baselines through processes of estimation and controlling of conformance/deviation during execution through monitoring and reporting processes. On this basis, project control activities are essentially processes of measurement, estimation and planning, followed by successive cycles of re-measurement, re-estimation and re-planning. These processes naturally include corrections for any deficiencies that may exist in the original planning basis, as well as the problems associated with the logistics of execution that inevitably arise, in order that the project satisfies the initial overall technical, economic and social objectives related to its conception. The project control function is thus a central project management support activity and project control methods are central project management tools, among which estimating methods are central to project control success.

Unfortunately, experience has shown that the project control methods have not always been successful in providing early warning to management of impending overruns thus inhibiting the effectiveness of mitigating action due simply to lack of time to assess alternatives. This thesis contends that this deficiency is largely due to the absence of formal estimating processes from the standard array of project control tools normally applied in the execution phase. The case study summary presented in the previous chapter has demonstrated the manner in which formal measurement functions (monitoring of scope development) as a basis for re-estimation might have provided the project team with the necessary insight to predict at an early stage the necessary resource basis for efficient execution.

By what standards should performance be judged ?

Project success is normally measured with reference to the success with which the project object as such is in fact executed within the planned constraints, normally expressed as within schedule, under budget and in conformance with the specified quality. This is a fairly narrow view, though traditional and highly within the project control domain. In the oil and gas industry however, conforming to schedule normally has the greater priority, even if this is often achieved at a cost to efficiency. The cost to efficiency is a consequence of suboptimal manning levels, overtime and multi-shifting in addition to other problems such as rework. In the case of modification projects, this may also take the form of hire of expensive offshore accommodation rigs, or the extension of planned shutdowns, resulting in the postponement of

[23] Many authors wish to extend the range of the project management function to include the operational phase. As the tools and methods addressed in this thesis only have applicability in the planning and execution phases, the operational phase will not be a matter of any consideration in this thesis.

revenue. On the other hand project success may be judged with reference to the success with which the project meets the longer term overall economic and social objectives for which it was originally conceived. Oil price development has normally ensured that projects seldom result in a loss.

Estimating as a project control function has applications from the earliest conceptual evaluations and as long as conceptual development is still taking place, and even during the detailed engineering phase. Conventional wisdom, or in any rate current practice, seems to judge otherwise since high aggregate estimating methods used prior to project sanction, are normally discontinued during the execution phase.

4.2 Other project control applications - holistic relations

The use of a standardised generic format as a reference for structuring of data may benefit project control practices on a wider basis than the narrow performance measurement and estimating context with which data structuring formats are often associated. The major reason for this is naturally that the use of similar data structures for contract compensation formats facilitates the use of historical norms of performance to support other project control activities. Thus, wishing to promote ease of use of performance data, it should be borne in mind that the structures of the compensation formats dominate reporting requirements to a large extent and often irrespective of other administration requirements that may be included in contracts.

Experience shows that many projects do not see the need to consider the performance measurement reporting requirements when establishing the project control basis because these are seen as relevant only for close-out data. This view is compounded by the general lack of understanding regarding the role of estimation processes as project control tools.

The following aspects and activities are relevant to consider. As mentioned in the introduction, most of these activities fall into the category of estimating processes in one way or another:

Compensation Formats and Performance Incentives

The performance measurement perspective suggests that compensation formats should be structured to facilitate project control processes that focus on quantities and related resource use. Production efficiency incentives should be aligned in a consistent fashion. The production efficiency incentives may take the form of man-hours per tonne per discipline corresponding to the core activities in Table 3-1. The basis for compensation is adjustable on a measurable basis while historical performance data provides a basis for verification of realism in the performance goals. Target costs may thus be based on the assumed final weights of the concept as defined in terms of Table 3-3 and be adjustable on the basis of final measured quantities. This ensures alignment between committed contract values and the project control basis.

A disadvantage regarding committed norms of performance as incentives, is the need to consider that changes in the sub-discipline complexity as a result of concept development may effect the committed norms. To this end some form of definition of the sub-discipline basis for the norms will be required, for which purpose the sub-discipline weight Tables 3-4, 3-5, 3-6, 3-7 and 3-8 have a suitable degree of detailing.

A particular aspect of a weight based approach is the concept of changes that do not result in weight or complexity changes.

Evaluation of Tenders

The performance measurement perspective provides a basis for verification, normalisation and sensitivity evaluation of tenders using standard methods of estimating that seek to predict the final value of the tenders and quantify performance risk. For the sake of consistency the tenders should be evaluated and aligned with the project's internal budget estimates as a basis for verification and ranking, thereby simultaneously eliminating the need for separate bid check estimates. Such processes would be facilitated by the consistent structuring of compensation formats on a generic basis, as mentioned above.

It follows that for ease of overview, highly detailed quantity definitions should be avoided. The breakdown structure of Table 3-3, supplemented by detail equivalent to Tables 3-4 to 3-8, is considered adequately detailed. One disadvantage associated with highly detailed quantity definitions is the inability to quantify undefined weights at such an early stage of concept development. These undefined weights often have the character of small complex items that are defined during the course of detailed engineering and the resulting norms are non-representative of the final work scope while the contract value is often too low by a large margin.

Project Control Reporting and Forecasting

Universal formats focus core activities appropriate for detail monitoring of ongoing project work at levels of detail corresponding to Tables 3-9 and 3-10 but hierarchically consistent with above data structure and set of core parameters and ensure good alignment between the project control basis, the contract reporting formats and the historical experience data.

This facilitates verification of the commitment frame ie high order verification of contractor baselines that are based on detailed estimating methods, by the use of weight monitoring and estimating as detailed engineering progresses.

Universal formats that focus core processes and key products and roll-up forecasts into formats such as presented in Figures 3-13, 3-14 and 3-15 facilitate communication between project controllers and project management and client and contractor organisations.

In the longer term:

Effectiveness of Forms of Contract and Asessment of General Performance

Effectiveness of different compensation formats and forms of contact may be gauged by analysis of close-out results with regard to final and tender production efficiencies. In view of the tendency for project contract formats to change regularly, an underlying standardised performance measurement format may facilitate comparison of different contractual instruments. Unfortunately, a preference for the inclusion of Lump Sum elements as incentives and risk mitigaters, also tends to prevent the acquisition of performance data unless the matter is specifically addressed.

Consistent structuring of data for the purposes of performance measurement and comparison has already been discussed in the preceding chapter. Ways in which comparison and analysis of performance deviations may facilitate investigation into the qualitative causes underlying poor or good performance will be examined in a Chapter 6.

4.3 Estimating applications

The discourse so far has focused on performance measurement as a basis for performance evaluation and improvement processes. The estimating processes as such have only been briefly or indirectly addressed in the discussion on metrics in the previous chapter, regarding the characteristics of modification work that were highlighted as intrinsic elements of the estimating process.

Estimating processes based on performance measurement are essentially a reversal of the performance evaluation perspective, but the estimating perspective is a central consideration when deciding the measurement breakdown structure. The question of 'what to measure' may be answered by considering the task of the estimator and the nature of the development processes through which a concept is brought to maturity by engineering study. In other words, the performance data derived from measurement programs must be applicable to the information that can be drawn from the conceptual studies. This may at first sight seem obvious. However, monitoring of quantities does not have a central role in normative project control practices compared to the monitoring of resource use such as man-hours and cost, and is thus not readily available. In the absence of quantity or weight data to correlate with resource use, the resource data are of little value to an estimator. Formats for collection of data must, accordingly, be set up specifically with this purpose in mind. In this light, the introductory statement seems somewhat less obvious.

Beyond this, the breakdown structure must be generic in order to have validity for as broad a range as possible of types of modification projects, all types of execution strategies and contact formats and over a lengthy time period. Such a breakdown structure is a prerequisite for a broad and representative base of data which can be used with any confidence.

The breakdown structure proposed by this study and already described in detail in the preceding sections, is deemed to have these qualities.

4.3.1 Synthetic estimating methods

In much of the reference literature (Clark, Lorenzoni, 1985; Granli, Hetland, Rolstadås, 1986; Leese, 1988; Rolstadås, 2001; Westney, 1985), reference is made to relational and factor estimating techniques based on extrapolations from past projects of the form COST =A*S^n where A is some constant dependent on the character of the facilities in question and S is some characteristic property such as size or capacity of the facility to be estimated. These techniques are intended for use in very early conceptual evaluations of greenfield projects.

There is accordingly some general expectation that methods of the above character also may be applied to estimating of early phase modification concepts. Normally, however, it is not a practical proposition to estimate modification concepts on the basis of capacity due to the highly diverse nature of the work, and which normally includes only parts of a facility or system and seldom whole facilities or systems. Estimating techniques have normally focused on tonnage by factor estimating of discipline weights, possibly split as module or integration work, on the basis of total equipment weights, which are the first quantifiable data available from a new concept evaluation. Analysis of experience data has focused these relationships. Cost per tonne or more detailed norms (mhr/tonne, cost/mhr, etc) may then be used to prepare estimates. Estimating at total project level of aggregation is not considered accurate enough, especially considering the very small additional amount of work required to work at discipline level. It is nevertheless of interest, in a general and in a quantitative benchmarking context, to investigate the cost-weight relationship of the above format.

To this end the relationships between 1) total cost and equipment weight, 2) total cost and total installed weight, 3) total cost per tonne and equipment weight and 4) total cost per tonne and total installed weight have been investigated, based on the selection of projects in the experience data portfolio. Note that the company management, logistics and marine operations costs are not included in the cost or the cost per tonne parameters. The results are presented in the Figures 4-1, 4-2, 4-3 and 4-4 below, respectively. The charts include trend curves from Excel trend analysis functions,

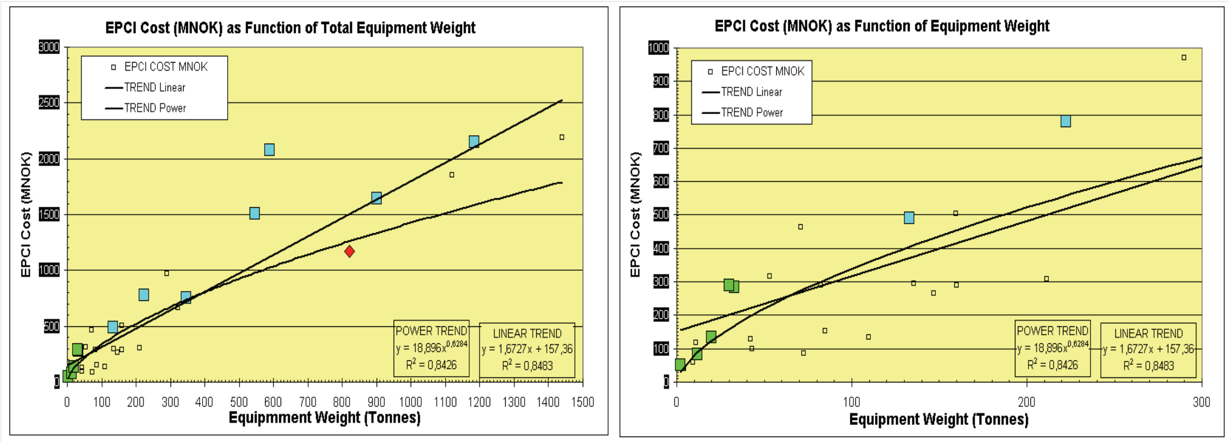

Figure 4-1: Total installation cost vs equipment weight

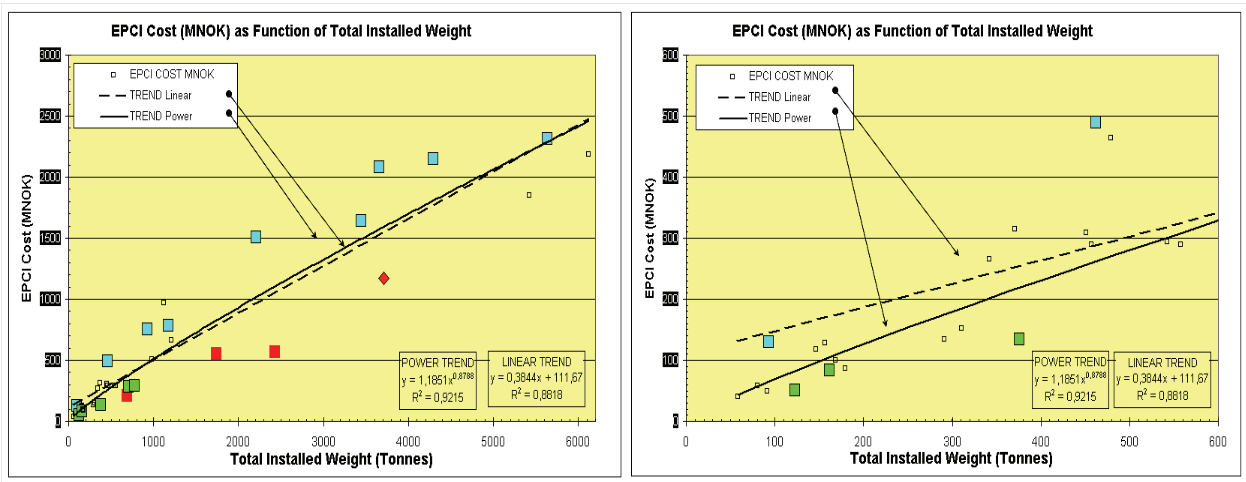

Figure 4-2: Total installation cost vs total installed weight

It is evident from the charts that the deviation from the trend functions is substantial both for the equipment relation and the total installed weight relation as well as for large and small projects. For the sake of clarity, note that the charts on the right expand the range of the small projects.

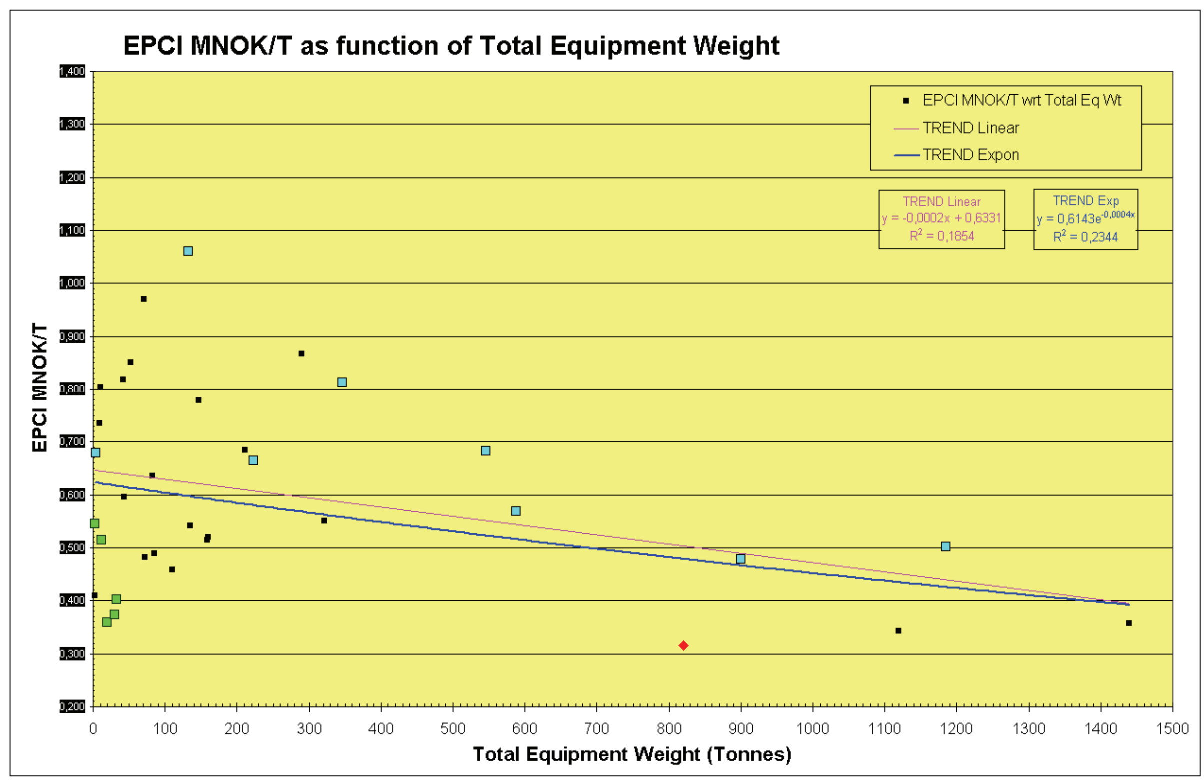

Figure 4-3: Total installation cost per tonne vs. equipment weight

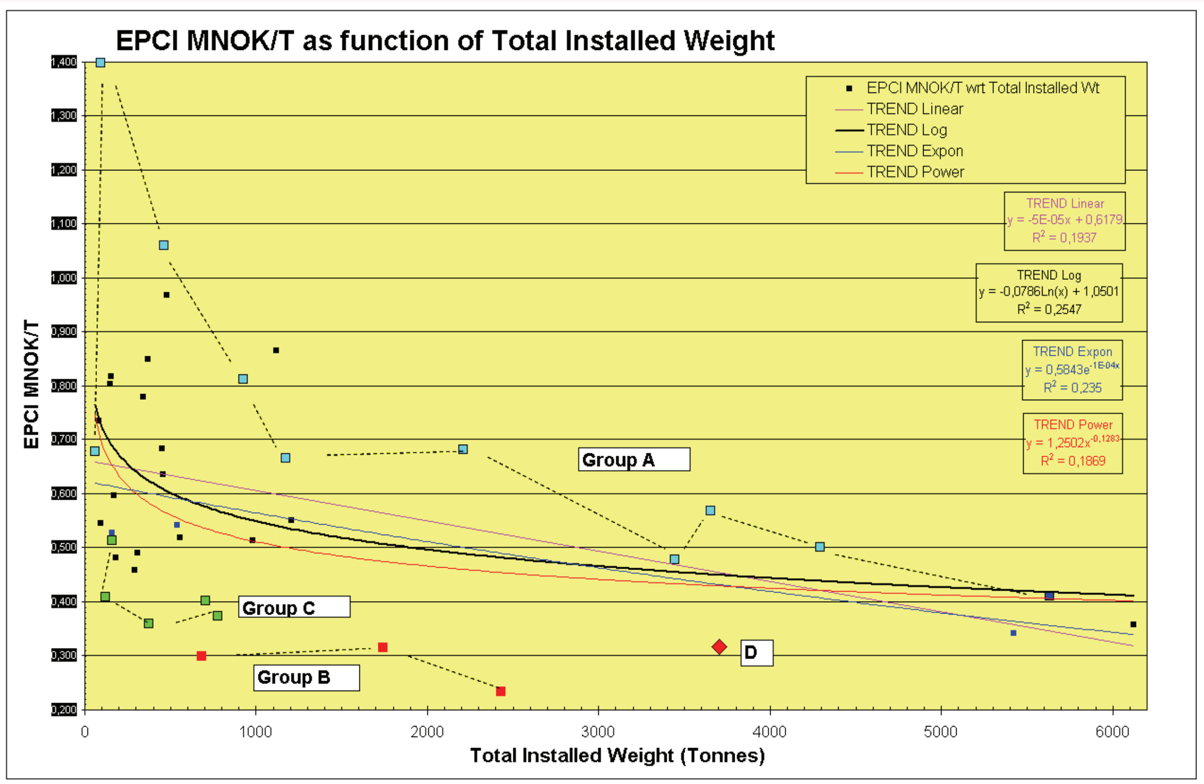

Figure 4-4: Total installation cost per tonne vs. total installed weight

As with the cost-weight charts, the data do not fit the trend functions particularly well, but in the cost per tonne cases it can also be seen that the trend functions exhibit a marked scale effect. The potential margin of error of estimates made on the above charts may be judged by the deviation of the reference data from the trend lines. As can be seen from the charts, the margin of error is best defined on the cost per tonne based charts and largest for the small projects.

The large deviations from the trend lines have various contributory causes, primarily the particular nature of the work (such as the relative content and character of each discipline) and the particular executional and organisational circumstances (such as the case study of chapter 3) affecting the execution of the work, sometimes both.

To illustrate the above for qualitative benchmarking purposes, it should be noted that most of the projects above the trend lines (labelled A) are projects that did not perform optimally for various reasons. In some of the cases, the concepts were immature requiring scope development in the detailed engineering phase and suboptimal work flow as a result. In some, suboptimal work flow was a consequence of schedule stress arising from external circumstances beyond the control of the project. In some suboptimal work flow was the consequence of internal dispositions in the project. In several cases, however, higher costs were simply a consequence of the discipline mix, but in others also associated with sub-discipline functional requirements, such as the use of high cost materials, or equipment of a special character. Similarly, the projects below the trend line (labelled B, C and D) have specific qualities. The C projects are all large diameter or simple straight run carbon steel piping with low valve content and low equipment content of unsophisticated character. The B projects are of normal complexity, but were all executed under an advantageous labour cost regime. The D project is not in fact a modification project at all, but a single topsides jacket-mounted module used as a calibration and benchmarking reference project for large module modification projects with low integration content. In addition, application of corrections for known properties of the individual cases may be considered. For example, the three A cases in the midrange from 2000 T to 4000 T, are higher than normal partly due to sub-optimal performance, but also partly due to high cost per tonne high-grade piping materials content compared to the others.

In view of the fact that equipment weights based on process studies are the first reliable data to emerge from early concept studies, it seems logical to attempt to estimate total costs directly in terms of equipment weights. The results of such an analysis are presented above in Figure 4-1. The picture that emerges is much the same as in the chart in Figure 4-2 based on total installed weights. The dispersion is of the same order of magnitude and increases for the smaller projects. In the light of the above the relationships appear unsuitable for all but very rough estimates, although they may be useful as a form of quick 'ball park' check on orders of magnitude, if the nature of the shortcomings are understood. Better quality estimates must be sought in the better project specific detail available from discipline and sub-discipline levels of definition. At the same time, it is evident that any estimate based on normative performance will be subject to a high degree of execution uncertainty.

It has been found more appropriate by most actors to model bulk weights on the basis of equipment weights using weight ratios of the type presented in Chapter 3.7.3, Figure 3.4. Estimates may be produced by direct application of discipline cost norms drawn from the charts of Figure 3-13, 3-14 and 3-15 and applied directly to the discipline weights, or even by the application of man-hour per tonne norms. The more detailed approach may provide a more correct estimate due to the fact that characteristics of the product, if known, can be taken into account when selecting norms at discipline level. In general however, estimates based on equipment definitions alone will be subject to the above degree of uncertainty.

4.3.2 Development Phase 1

The first studies to be performed in a conceptual development process of a satellite tie-in project, for instance, are process and utility studies, which provide some quantitative definition of the equipment requirements in the form of equipment lists with the weights of the individual items. These studies focus on the reservoir processing requirements against the process and utility capacity of the existing equipment on the platform, seeking to optimise the use of existing equipment and facilities. These equipment requirements are thus the first basis for defining an estimate which needs to include a lot more, namely the surrounding infrastructure which is not defined at this stage. Clark and Lorenzoni address this type of problem through measurement and normalisation of the piping, structural, civil, electrical and instrument infrastructure surrounding individual equipment items, such data being available from previous projects as a result of good and extensive ongoing performance measurement programs. While Clark and Lorenzoni may apply this approach, with an acceptable degree of accuracy, to reasonably standardised process plants, the congestion and layout constraints on offshore platforms, along with the highly variable nature of modification work, suggest the use of a simpler generalised approach, but which is principally similar. This generalised approach is the use of the historical weight data to provide typical ratios of equipment to bulk items as a basis for modelling the overall bulk requirements. Typical weight values for each discipline can be defined in similar fashion. Cost estimates may then be calculated using the appropriate parameters, namely the overall EPCI, or separate labour and material cost per tonne parameters at discipline level, as shown in Table 3-1 and in the charts in Figure 3-13, 3-14 and 3-15. An advantage of using discipline weights is the scope this gives to select norms from similar work based on qualitative information concerning the nature of the work. The variances associated with each item in the statistical material provide a basis for assessing the uncertainty range of the resulting estimate. Contractor overheads and project administration is included while Company costs are factor estimated at this stage.

A plot of three central weight ratios was shown previously in Figure 3-4, the equipment weight, the system bulk weight (piping, electrical and instrument bulk) and structural bulk, each with respect to total installed weight. A characteristic of the graphs is the arrangement by size, expressed as total installed weight, in order to highlight the effects of scale which were discussed in detail earlier. The uncertainty associated with weight variation, based on extreme weight ratios and median overall cost per tonne per discipline, lies typically within a range variation of -40/+60%. Bulk weights may be estimated from the curve in Figure 3-4 using the equipment weight trend line (labelled A) plotted against the right axis of the chart.

There is of course an additional component of uncertainty related to performance variance. The high uncertainty can be reduced in the first instance by selecting discipline material and labour cost per tonne norms based on size, using the trend lines shown on the graphs in Figure 3-13, 3-14 and 3-15. Alternatively, and particularly with respect to piping, one may use qualitative information regarding for example, the nature of the piping in terms of material quality, average size, and so on, to select parameters from known projects. This latter approach, however, requires insights into the nature of the individual projects in the portfolio, an overview which is not easy to maintain over time as the portfolio grows, nor easy to transfer to newcomers not familiar with the portfolio. As a last resort, in the absence of any definitive information regarding the sub-discipline nature of the work, medians or averaging may be used to define norms of performance for piping.

It should be noted that there are many types of modifications of which many do not have equipment content of any significance. Many projects find a high degree of equipment re-use by revamping equipment components. Such projects will normally not be able to develop any factor-based weight estimate of bulk quantities without doing development phase 2 type of work on which to base MTOs and weight estimates.

Estimates at this level provide the basis for sanctioning of further development.

4.3.3 Development Phase 2

The logical next step in a conceptual development process is to initiate layout studies to define and develop the platform-specific constraints regarding space requirements and infrastructure for the planned new installation. This naturally starts with equipment block layouts and the associated piping layouts, including a broad brush installation study to establish the need for major steelwork support structures as well as an evaluation of the capacity of the support frame. The result of these reviews will be layouts on which to base the measurement of quantities of bulk materials as input values for calculation of cost and man-hour estimates. In parallel, other documents, such as PIDs, are being developed that provide a basis for quantification of specific items, such as valves.

Since the layout work normally only includes the major elements and major pipe runs at this stage, many items within each discipline remain undefined. Indeed, some items will remain undefined until all detailed engineering is completed. Even then there are still elements of work that are encountered in the field. These undefined elements are usually defined provisionally by the addition of technical allowances at discipline level to cover for details that will only be specified at a later stage. The size of the allowances used is intended to provide an estimate of the expected weight at completion and they are based on experience within the weight estimating community. It must be said that many of these factors are drawn from experience with greenfield work and may not necessarily be applicable to modification work, especially that of a more extreme character.

Not all disciplines are subject to layout studies at this stage. Electrical and instrument bulk are often factor estimated based on piping or equipment weight, using weight ratios such as described above for the Development Phase 1 type estimates.

Cost and man-hour estimates may be built up on a more detailed analytic basis, using the man-hour per tonne type parameters in Table 3.1 applied to each work phase or product along with the appropriate man-hour rates. Materials cost may be calculated using the materials cost per tonne parameters. In such estimates the uncertainty in the bulk quantities is significantly reduced compared to earlier phases, but performance uncertainty remains and may be reduced by selecting norms in the same manner as described above. An additional possibility remains, however. Due to the definition inherent in the layouts, sub-discipline weight detailing can be used as a basis for calculating norms at discipline level by use of the type of sub-discipline norms of performance indicated in Figure 3.10 and 3.11 and typical of steelwork and piping.

Estimates for Project Administration and Preliminary/Facility costs will need to added, as well as the Company Management and Logistics and any Marine Operations required. But now man-hour estimates are available, the better to define the personnel logistics costs and need for flotel and the like. Company Management and Contractor Project Administration will still, however, need to be factor estimated using estimated man-hours or estimated labour cost as the basis, referring back to Figure 3-8.

Estimates at this level provide the basis for concept selection and sanction for further development.

4.3.4 Development Phase 3

The natural progression in concept development leads to detailing of layouts to include electrical and instrumentation bulk disciplines as well as further development of other engineering documentation and provides a firm basis for measurement of quantities for these disciplines. Cost and man-hour estimates are built up in the same way as described previously, but now on a wholly analytic basis.

Estimates at this level form the basis for sanction of project execution and evaluation of engineering or EPCI contracts prior to award. In circumstances where separate construction contracts are let these estimates often form an initial basis, subject to later update based on detailed engineering data, for evaluation of construction contracts prior to award.

During execution, estimates at this level of aggregation are suitable for owner estimates seeking overview, verification of commitment and updating budgets. Verification of contractor baselines and resource dispositions are an important element of this verification, but, in addition, provide a basis for management intervention in the event that should be required. This applies particularly during the period of detailed engineering while the concept is still subject to development. Detailed engineering has often exposed flaws in the concept evaluations performed in earlier phases, which may have adverse effects on the commitment frame of execution.

Highly detailed information from detailed engineering MTOs will need to be rolled up in accordance with the tabulations in Chapter 3.

4.3.5 Development Phase 4

Development phase 4 is the detailed engineering that defines the basis for execution. Contractor estimates are embedded in the detailed planning processes and are based on detail from MTOs using manuals similar to Page. It follows that these estimates will not be fully complete until completion of detailed engineering.

Since these estimates in aggregation form the control basis for the execution phase, it follows that higher aggregate estimates, such as the Phase 3 estimates described above, will be required to bridge the gap pending completion of the detailed planning basis.

Detail-based estimates cannot easily take into account special project-specific conditions of installation and method. This speaks for an additional verification role for high aggregate estimates that are based on historical performance, even after completion of the detailed planning basis.

4.3.6 Estimate classes

As outlined above, conceptual development proceeds through progressive stages of detailing often with several concepts being developed in parallel. It is characteristic of modification work that layout work starts much earlier in a development cycle than equivalent greenfield topsides development work. This is natural since the infrastructure already exists and constructability is a central consideration in modification work. It follows that MTO based quantities are available for estimating purposes much earlier in a development cycle and ought thereby to increase the quality of the estimates. However, there are many aspects of uncertainty in modification work that override this apparent advantage.

As described in earlier chapters, there is a great degree of variation in modification work, both as to the mix of disciplines and the sub-discipline character of the work. The major problem of the estimator is to select the right norm for estimating the man-hour needs to perform the work. It follows that sub-discipline norms cannot be used until the necessary sub-discipline detail is available. Until such time the best indicator is provided by taking the scale effects into account rather than using averages based on the whole array, which is the normative practice passed on from greenfield work. The effects of size may be seen as an aggregated effect of the sub-discipline content. However, in circumstances where sub-discipline detail is available this information may be used to override the norms taken from effects of scale trend lines. Even in cases where only a little information is available, it may be sufficient to permit a selection of norms from group characteristics directly. Piping is a challenge in this regard being affected by many variables such as installation method (welded/bolted), size (diameter), material type, valve content and the extent of insulation, to name the most important. But knowing for example, that the piping is mostly small diameter (information available from PFDs), high grade steel, and bolted construction would permit selection of norms from similar work, provided that this sort of information has been preserved in the performance data from previous projects, and with a better degree of accuracy than the use of averages.

Not all projects have equipment content on which to base factored estimates of bulk quantities. It follows that some form of layout work must be performed in order to provide a basis for quantification. Typical in this regard are some tie-ins that mix well streams directly without any form of separate processing and require little more than a riser and pigging equipment. It follows for such concepts that development phase 1 type relational estimates are not practical. Accordingly, the first reliable estimates can only be achieved in accordance with development phase 2 study requirements of piping layout and associated installation study.

From the above can be seen the manner in which the degree of detail in the technical studies defines the basis for estimating and a consistent expectation regarding the accuracy of the resulting estimate. This is the basis for defining estimate classes and is broadly coupled to the degree of layout definition. Returning to the question of what to measure in performance measurement processes, the above has described the way in which technical elements defined in study at progressive stages of development dictate what elements in close-out data need to be measured in order to provide a basis for estimating. The parameters in the array in Table 3-1, supplemented by sub-discipline weights and norms, provide a consistent basis for estimating at progressive degrees of detailing for all classes of estimates from concept until well into the construction phase.

While making the above statement, it should be mentioned that many Estimate Class gradation systems include an initial ''Development Phase 0'' type of estimate class which normally has no defined accuracy expectations. Such an estimate class may include a field development cost based on high order relational estimating, using high aggregation parameters such as the correlation of total installation costs and equipment weights discussed initially in this section 4.3.1 of this chapter.

4.3.7 Baseline updating, Earned Value analysis, and forecasting

In the introduction to this chapter, the discussion pointed to the estimating nature of the project control applications arising out of performance measurement processes. The efficient functioning of earned value analysis is dependent on the correct dimensioning of the control basis.

In much of the normative literature and in keeping with current practice in the industry, baseline updating is based, more or less exclusively, on the logging of the impact of change orders on the original scope of work. The underlying assumption here is presumably that the control estimate, which was established as the basis for sanctioning, will not change unless additional scope is introduced or the design basis is altered. This is all logical and natural in so far as the control estimate establishes the project's formal budget with regard to original scope of work. However, control estimates have a major function as a management tool primarily giving forecasts of negative trends, which require management action. For this purpose the forecasts need to include the effects of internal scope development with respect to the original control basis. This scope development classically takes the form of bulk material volume growth or increases in complexity, or both, or reductions, and impacts man-hour resources and material costs and ultimately threatens durations, milestones and overall efficiency. This is a natural consequence of concept development during detailed engineering, but does not represent additional scope of work. Traditional practice provides no basis in baseline adjustment for such internal concept growth since this internal growth is not addressed by change orders. A consequence of this is that many projects and contractors do not have routines for updating [24] their estimates after award of contract while detailed engineering progresses. This is anomalous since a lot of development can take place during detailed engineering, a major information blackout period, as emphasised by Clark and Lorenzoni, which may have consequences for both owner and contractor. Under normal circumstances these extra volumes will be defined as the detailed plans are developed in parallel with the progress of detailed engineering and the full extent will only be clear at the completion of detailed engineering.

Clark and Lorenzoni's proposed method for this important update of the 'definitive' estimate is based on BOQ updating taking place during detailed engineering. Clark and Lorenzoni propose the use of sampling of initial layout drawings and interpolating the results to provide a basis for comparison with the estimated quantities in the early definitive estimates. Reliable trend data can in this way be available as early as 20% completed detailed engineering, and backed up later using the 70% complete MTO. In reality , this is merely a continuation of the quantity based estimating process which started with the semi-detailed estimates where the bulk quantities are factored on the basis of physical properties of the equipment items and or aspects of the plant as a whole. The whole process is finalised in commodity reviews for each discipline at approx. 95% complete. The results form the basis for the QAB (Quantity Adjusted Budget) on which the planning and control of the construction phase is based even though the final QAB update will be after construction start due to overlap.

Unreliability of MTOs and weight estimates at the early stages of detailed engineering is often given as justification for not updating the definitive estimates until detailed engineering is completed. This is anomalous considering that MTOs are an essential basis for procurement processes that must be executed in parallel with the detail engineering. Continuous updating will be required as detailed engineering proceeds in order to support the material procurement processes. Thus a basis exists within the normative practices of project administration for estimate updating. All that is required is for the same information to be harnessed for project control purposes as a basis for estimate updates.

Onshore plants do not have the same weight and stability concerns as offshore platforms and accordingly lack the sophisticated weight estimating routines of the offshore industry. Onshore plant estimates are mostly based on BOQs, equivalent to the development phase 4 estimate discussed above. This is a more complicated process due to the lack of consistent metrics which facilitate aggregation. In the offshore oil and gas industry the above MTO/BOQ processes form the basis for technical weight estimating processes, which are also a normal part of the work. This provides a basis for estimate updating using weight based methods. It is clear that MTO and weight estimate updates will also pick up the extra work and changes introduced through VOs in a more accurate and effective fashion than poorly defined VO based estimates.

Not the least advantage arising from this estimating cycle is the feedback it provides on the correctness of the allocated engineering resources. Engineering work can also be measured in man-hours per tonne; it follows that quantity updates may also be used to re-estimate the engineering resources in an ongoing routine. Traditionally, engineering resource estimates are based on factors of installation man-hours or more or less subjective assumptions regarding the number of documents to be prepared. It follows from the above that weight updates

[24] A distinction must be made between updating of estimates on an overall basis and the preparation of the detailed planning basis which is an ongoing activity supplemented on an item by item basis as work is defined by the detailed engineering processes.

provide a basis for correction of the engineering resource estimates in a way that factor based estimates cannot match.

Forecasting practice based on earned value analysis will be of little value if the overall control basis is inaccurate, as emphasised by Harrison (Harrison, 1985). This approach extrapolates the performance deviation resulting from comparison of planned and actual costs (or man-hours) for a given quantity of work, as though it applied to all the work to be performed. It follows that the accuracy of the interpolation will depend on the accuracy of both the total scope estimate and the planned scope of work to cut-off. Clark and Lorenzoni point to an additional element of inaccuracy inherent in simple extrapolation which does not take into account the varying nature of the work over time. This problem is resolved by Harrison by limiting the number of cost centres and the size of work-packs subject to extrapolation. Clark and Lorenzoni focus discipline–wise on products and activities using historical production curves accompanied by detail planning prepared in the field offices. Overall performance is then aggregated in both cases by weighting in accordance with relative man-hour content. The scope of work to cut-off most likely will be defined accurately enough, and this sort of performance comparison is useful to gauge efficiency relative to the norm basis for estimating the work content of the task sheets or work-packs. But forecasting may be seriously underestimated due to the presence of undefined work in the overall scope, which will not be picked up by the procedure.

One might ask what the consequences are of the deficiencies in earned value analysis as a forecasting procedure? In the absence of signals regarding internal scope growth or man-hour growth due to complexity derived from verification estimates, the contractor will be dependant on the aggregated result of the completed job-cards, which are produced progressively as detailed engineering proceeds. Due to overlap between engineering and fabrication, this signal may arrive too late for effective corrective action. The managers' only recourse at this later point in time is to man up, but the remaining work will now have to be completed at a greater rate than previously assumed. This may incur overtime, flotel cost or non-optimal manning. It is evident that if the signals regarding too few man-hours totally could be received earlier, more efficient means of acceleration and avoidance of crashing may be possible with minimisation of schedule stress and other associated disruptive elements to work flow. Case studies suggest that a year of lead time may be acquired in this fashion.

Uncertainty associated with potential scope growth will exist at least as long as detailed engineering is in overlap with fabrication. A logical basis for updating would be found in the MTOs taken from the detailed engineering drawings at regular intervals as a basis for updated weight estimates consistent with the practise from concept development studies prior to project sanction. Such MTOs are in any event required for purposes of initiating material purchasing at early stages of detailed engineering, a process requiring regular updates as new detailed planning task sheets are prepared.

Modification projects are particularly subject to this sort of development due to the more diffuse interface between the modification scope and the rest of the facility and difficulties identifying complexity prior to detailed engineering. Greenfield work, both onshore and offshore, is also latently exposed due to the increased overlap between detailed engineering and the follow-on activities of procurement and fabrication prevalent in current execution strategies. The late initiation of detailed layout work in the development cycle, compared with modification work, may also play a part. One may argue that all the work to be done will ultimately be incorporated in the reference baseline by the end of detailed engineering when all the tasks have been documented. But management will have lost valuable lead time to plan effective compensatory action that may be required.

Prevalence of latent undefined volumes of work, if not identified, will also have general schedule impact such as delayed engineering causing delays in deliverables to the detriment of follow-on activities and thereby negatively effecting the orderly progression of the work, which can be very detrimental to performance.

VOs have other disadvantages that make them unsuitable for updating control estimates. This is due to the fact that VOs often take a long time to be approved since they are, strictly speaking, only instruments for contract administration and appropriation of additional funds. In addition they are normally poorly defined as estimates and hence of low accuracy. Finally, it is not effective to maintain separate monitoring of VO costs and quantities, as many do, in order to improve the basis for adjustments to the contract. In circumstances with EPCI reimbursable compensation combined with performance-based incentive mechanisms based on quantity updates, such as modification contracts often are, VO approval may be based on order of magnitude estimates in order to speed up approval without further VO handling. Contractual adjustments can be built into the incentive mechanisms which are adjustable in terms of the final quantities. In this way additions to scope, through VOs and internal development, can be followed up by the same routine, that of quantity monitoring at regular intervals during detailed engineering.

The type of weight-based scope verification routines described above, that pick up additions to the scope of work as well as concept growth elements, can easily be incorporated in the CCE updates without affecting the basis for the MCE adjustments, which can continue as before, being based on variation orders.

4.3.8 Network planning

The above discussion regarding the efficiency of the earned value analysis as a forecasting tool is also affected by another consideration, that of the network planning. The schedule forecasting based on earned value analysis relies on exact planning at task level, if the size of the tasks is such that inaccuracies arising from subjective progress reporting are to be avoided, in other words to ensure the correctness of the planned resource use which is the yardstick. A measure of the total scope cannot be achieved by these means until all the tasks have been documented and incorporated into the overall logic of the network, which will not be effectuated finally until the detailed engineering is completed. This will inevitably create a planning vacuum which has to be filled by interim activities, and a formidable task to update if the interim plans are very detailed (Bungard, 1988; Harrison, 1985; Nunn, 1986). The theory appears not to adequately address the fact that the detail network basis has to be developed while work is ongoing due to the overlap between engineering and construction.

Here again is an argument supporting control estimate updating in order to ensure that the interim assumptions reflect the full scope of work as well as possible while the detailed control basis is being developed.

A real life case may serve as an example of how these issues may appear in current practices. In the case in question, the contractor made up the difference between the defined work and the assumed total scope by including dummy activities in the plans. The dummies were dimensioned on the basis of the total man-hours in the contract (the owners estimate) minus the accumulated man-hours in the completed task sheets. The contractor refrained from estimating the volume of the dummy in real terms, or updating the overall estimate, in spite of indications that the quantities were increasing with respect to expectation. Note that the quantity growth was tracked by the owner not the contractor. The result was poor correlation between the owners estimates and the contractors forecasts. The contractor was finally forced by the owner to initiate a serious re-assessment of the total volume of work. The volume of work had, in fact, increased considerably due to large volumes of permanent, temporary and demolition work associated with the development of the installation concept, in addition to changes in the design basis. The completion milestones were achieved, but at the cost of the use of a flotel [25], very high offshore manning, extensive overtime, multi-shifting (with inevitable safety and efficiency impact) and the postponement of all non-project related work on the platform.

4.4 Conclusion

This chapter has directed attention to the project control applications of the performance measurement methods described in this thesis, mostly in the form of estimating applications aimed at constantly re-assessing the scope of work with respect to the resource framework for performing the work.

Even in the absence of re-estimation, comparison of contractor assumed norms of performance with normative levels of performance in the industry will highlight potential under-resourcing. This sort of basis of comparison can be established by applying the performance measurement procedures defined in Chapter 3.9 to the contractors forecast data. Such comparisons would not normally only function as indicators not able to pick up the discipline and sub-discipline variation and should accordingly be followed up with independent estimates.

This sort of comparison would be facilitated by the use of consistent breakdown structures in contract reporting formats which would limit the extra work that would otherwise be necessary in converting data from one format to another.

At the end of the day however, and especially in circumstances that disrupt the orderly progression of the work, levels of poor performance are sometimes experienced that are unexplainable in terms of growth, complexity or characteristics of the product. Some projects overrun on all functions, others only on some functions. Some projects do not overrun in spite of potential disturbances such as growth or conceptual re-engineering. Conversely, some projects overrun despite the absence of any such the pressures. Deeper investigation has uncovered organisational dispositions that, in some cases, may have precipitated the poor efficiency. In other cases no firm explanation is available. Such cases represent a dilemma to the estimator but must be taken into account in some manner or other, due to the high order of magnitude of such effects can have.

The next chapter, Chapter 5, addresses the risk situation which confronts modification projects and presents a risk model that adequately addresses the indeterminate risk picture described above, based on the analysis of performance data from some overrun projects.

The following chapter, Chapter 6, addresses the way in which performance measurement processes can support benchmarking processes aimed at identifying the qualitative nature of the indeterminate risks described above and the means of managing them.

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[25] The full capacity of a flotel can normally not be used while the platform is operational due to limited lifeboat capacity and manning densities constrained by general safety considerations, such that flotel hire to support extended periods of offshore work for modifications on operational platforms will be less efficient than the equivalent as applied to greenfield work.

5 COST RISK EVALUATION

APPLICATION OF PERFORMANCE MEASUREMENT PRINCIPLES IN THE COST RISK EVALUATION OF OFFSHORE MODIFICATION PROJECTS

5.1 Introduction

The performance measurement principles presented in this thesis can also form the basis for objective performance risk evaluation. This application of performance measurement principles in the development of a generic cost risk simulation model for modification work is the theme of this chapter.

Risk and uncertainty are aspects of management that all project management personnel are confronted with at regular intervals. Particularly the evaluation of cost estimate uncertainty is an area of expertise that is not particularly transparent, but still cannot comfortably be relegated to the domains of technical expertise. Understanding of the performance risk exposure is a central aspect of project management strategy, but performance expectations are very often based on subjective assumptions[26]. Risk quantification and qualification by use of performance measurement principles may provide documentation and better understanding of the nature and magnitude of risk exposure, leading to better understanding of the mitigation actions required to reduce risk.

The discourse includes, 1) the organisational and technical uncertainties inherent in capital cost estimates (CAPEX) for modification projects, 2) associated uncertainty assessment tools and procedures as applied in the context of modification projects in the oil and gas industry, 3) analysis of historical data from some known overrun projects, 4) a cost risk simulation model for modifications. The model, which has been developed as part of the work underpinning this thesis, uses inter-relation effects based on experience data from analysis of the development history of some under-performing projects. The discussion regarding the model itself is presented in Chapter 5.6.

The arguments are presented against a case background of a large and complex offshore modification project in a remote environment.

5.2 Risk evaluation

The range of norms in the performance data and weight content discipline ratios provides an alternative source of extreme value parameters for risk analyses based on quantitative results rather than relative subjective assumptions regarding risk maxima and minima. However, the range of variance in the performance data is due to the complexity variation attributable partly to the specific complexity and partly to circumstances of work in the individual project.

Measures of sub-discipline complexity provide a quantitative means of assessing whether measured performance is solely a consequence of complexity or whether there are anomalies present that indicate influence of other factors on performance that have to be taken into account. This approach may provide a basis for understanding the range of variances associated with normal performance due to complexity in comparison to the range of variances associated with disturbances to the orderly progression of the work that might arise, for instance, from concept immaturity.

In this chapter risk and uncertainty in modification projects and cost estimates is considered in detail in the context of developing a generic cost risk simulation model specific for

[26] Typically the prescribed levels of contingency associated with estimate classes are seldom documented but have their roots in historical experience. Likewise perceptions of the magnitude of risk are subjectively linked to bad experiences and the normative expectation associated with these prescribed levels of contingency.

modification work and where such considerations are taken into account. For all practical purposes, the range of uncertainty at early stages of development will need to include the technical uncertainty associated with concept as well as the uncertainty arising from other influences such as organisational, installation or market related issues, since the full range of uncertainties will need to be considered until at least the detailed engineering is well advanced. For this purpose the range of variance defined with respect to the trend lines in the effect of scale charts (Figure 3-13, 3-14 and 3-15) may be regarded as an adequate measure of the uncertainty of performance, provided a sufficiently broad range of projects is available in the portfolio. Similarly, the variance in the weight ratios of Figure 3-4 may provide a measure of the technical uncertainty of all early phase estimates.

5.3 Summary of the case background

The chapter is based on practical experience acquired as a representative with responsibility for topsides modifications cost in a partner operated project with regard to the quantification of risk in the sanction estimates.

In practice it was found that the results of the risk simulation by the operator did not seem to align with the 'common sense' expectations of the partners, who perceived the risk effects of a potentially poor performance to be underestimated. The source of the risk of under-performance was the contractual strategy put in place by the operator combined with complexity aspects of the concept itself, as well as conditions surrounding the installation circumstances. A consequence of the operator's low estimate of the potential cost impact was that the partners believed the operator would perhaps not take the risk potential seriously enough to introduce real mitigating activities. This, amongst other matters, delayed the sanction processes, which in turn is potentially aggravating to the orderly progression of the work, particularly in circumstances where the completion milestones remain unchanged.

A workshop was called with the express purpose of aligning stakeholders' expectations and achieving endorsement of the operator's estimates by:

- review of concept development status
- pooling of experience data from the partners on which to base the simulation
- common participation in the development of the model

The partners advised to radically reduce the complexity of the risk model (from about 250 to about 100 activities) and introduce interaction effects between core activities in order to establish a common platform of reference. However, the results of the exercise still failed to satisfy the partners' expectations.

In order to verify (order of magnitude) the low estimate internally, a simpler model (approx. 17 core activities) was constructed. Interaction effects were modelled using equations that coupled core activities and correlation factors derived from historical data from underperforming projects. Since the interaction effects are mainly relevant under conditions of stress, it was found appropriate to apply the equations asymmetrically in such a manner that the coupling effects were only activated in the event of over-run situations. This model gave results that were more in line with expectations, but they were still lower than historical data might suggest.

The essence of the problem appears to be that the expected values (medians or averages) derived from simulations do not align with the expectations as defined by experience. In the absence of a consistent historical data record, expectations are likely to align with worst case experiences. The ambition is to find a model that functions well enough when compared to experience and at the same time has a coherent theoretical base.

The contractor finally adjusted the model to include a separate prescribed contingency element to the deterministic base estimate in the simulation input data, thereby providing a contingency factor of 10-20% with respect to the base estimate in the simulation output. The size of the input factor is prescribed by the estimating class as described in the previous chapter. Simulations assumed independence. While this approach may provide an adequate contingency, the simulation contributes nothing to defining the nature, range and size of the uncertainties confronting the project, in order that appropriate mitigating action may be initiated.

5.4 The risk assessment process

As a generality it may be stated that the risky nature of oil and gas production suggests that oil companies' procedures for uncertainty management are likely to be 'state of the art'. Review of corporate governing documentation reveals a hierarchy of procedures, which includes prescribed levels of control and review, guidelines for best practices, predefined acceptance criteria, etc, which can be said to be generic to all oil companies. This does not mean that the practice of risk management always coincides with the formal requirements of the procedures.

Within the realm of project management, uncertainty management is a central management function to be applied continuously at all relevant levels in the organisation. With regard to estimates and in the assessment of contingency and/or reserves deemed necessary to cover the associated cost risks, all elements of risk and uncertainty have to be taken into account,. Different aspects of the work are normally handled by different domains of competency, which are all brought together in the commercial evaluations. By this is meant that, for example in the case of a satellite tie-in, the topsides modifications, the subsea infrastructure, the operating expenses and the drilling/workover costs respectively, will normally be estimated by appropriate competencies. All elements are brought together and analysed in several payback scenario evaluations, conducted by the commercial analysts, which in turn are governed by predefined acceptance criteria such as ROI or NPV and based on predefined assumptions regarding product price variations, currency exchange rates and the like. Each element will be based on the special technical nature and the latent uncertainties pertaining to performance of the specific concept. The specific nature of the uncertainties being evaluated is very diffuse at such an order of aggregation.

5.4.1 Technical uncertainty

Risk and uncertainty issues are addressed in the course of project development through the technical requirements for concept development work in the form of prescribed activities to be defined in the scope of work. Likewise, during the execution phase, risk and uncertainty issues are addressed through technical requirements for the detailed engineering. These requirements include for instance installation engineering, the preparation of detailed work procedures, safe job analysis processes, prescribed constraints and procedures for certain types of work as well as prescribed technical solutions and guidelines for certain types of potentially hazardous or pollutive activities. This means that the technical and operational elements of the work contributing to risk will normally be worked to an acceptable level of confidence based on technical acceptance criteria in the course of the engineering development work. The engineering development work is in turn a result of the guidelines identifying the elements that shall be included in the technical studies. Finally, the quality and consistency of the work is subject to review at all sanction milestones at all relevant [27] levels of technical and managerial competence.

5.4.2 Estimation requirements

The extent and content of the development work is coupled to the estimate class requirements that identify acceptable levels of accuracy and confidence and often prescribe recommended levels of contingency for each development stage. These class requirements and corresponding levels of accuracy and confidence are business requirements associated with sanction of further investment needed to reach a higher state of concept development, ultimately leading to full implementation, or, alternatively, stopping further investment. Normally these decisions to proceed or stop will be based on evaluations of the project payback, but may also on occasion be based on elements of unacceptable technical risk[28]. However, at the end of the day most elements of technical risk will have been converted into some form of physical installation and translated into cost elements. As mentioned previously, at each stage of development the concept will be subjected to review [29] in order to ensure compliance with procedures, completeness, quality, consistency with respect to acknowledged practice and alignment with corporate objectives and capacity. The estimator may to some extent rely on the fact of approval by technical review in accepting conformance to class requirements and the prescribed contingency levels. The prescribed contingency levels are deemed to include the risk associated with normal [30] concept development as well as organisational risk elements, which are inherently manageable. Radical changes in concept or the unmanageable risk associated with freak environmental conditions, extreme market fluctuations and political disturbances are not included. Risk elements of such a high order of magnitude will normally fall outside the mandate of the individual project. As an example, currency exchange rates may be preset for the purposes of capital cost estimating and project accounting and will not be the concern of the individual project.

There remains a requirement to perform a cost risk analysis in order to ensure that project specific issues are duly taken into account in the assessment of risk and that the evaluated risk lies within the range of the predefined acceptance criteria. This task is the responsibility of the cost engineer. A risk simulation performed on a base estimate using historical performance data will normally give a result well within the range of the recommended levels, which result may be reliable if the concept is appropriately mature and is not subject to disruptive disturbances. However, most operators have experience of overruns with modification [31] work and the recommended contingencies associated with each estimate class are aligned with this experience. Typically, predefined contingencies may add a non-specified monetary contingency to cover all elements of growth and complexity while others may add a quantity contingency to the base estimate in the form of a growth reserve in addition to a pure monetary reserve.

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[27] Geoscience/Reservoir , Drilling/Wells, HSE, Facilities, Procurement/Logistics, Project Management, Cost/Schedule, Operation/Maintenance, Commercial

[28] Such cases are handled separately by the technical disciplines in accordance with own procedures and acceptance criteria (such as FAR values or assessment of technical functionality) and is seldom subject to equivalent cost evaluations – in other words technical criteria are established independently of cost considerations; cost considerations will only feature in the overall acceptance criteria for the project as a whole. If the project itself is motivated by safety considerations, cost effective solutions may be sought within the same procedural approach but all solutions will initially be subject to technical acceptance criteria.

[29] Briefly, approvals are subject to peer review by product at discipline levels, multidiscipline reviews and corporate review at all decision gates followed up by internal project reviews at strategic approval points.

[30] 'Normal' here implies that radically different modification scenarios will be treated as separate cases.

[31] The same experience applies to grass-root projects especially in the wake of the NORSOK experiences, possibly of a lower order of magnitude (NOU, 1999:11).

Finally the estimate itself will be subject to review in the same fashion as the technical and planning reviews previously mentioned. Included in this review will be the basis for assessment of contingency and benchmarking of the concept with respect to historical data.

In the case in question, it is clear that there was poor alignment between the partners as to the nature of the additional elements beyond the median or average simulations of the risk analysis performed on the base estimate[32] . As previously mentioned, this was a consequence of the concept and execution complexity, the management philosophy and the contractual strategy put in place by the operator, but was inherently difficult to define and quantify in the estimates or in the risk analyses.

5.4.3 Benchmarking

BM is currently a requirement of the estimating procedure in many organisations. A form of quantitative benchmarking of estimates that can be supported by the performance measurement processes described in this thesis using the sort of background performance defined in the charts of chapter 4, typically Figures 4-1 to 4-4, but seldom as detailed as Figure 4-13, is fairly common practice. Benchmarking at too high levels of aggregation may not be meaningful, while too much detail clouds the issue.

An element of benchmarking is the range of variance defined by the reference data from previous projects and the risk that this represents for the project at hand. For this to be of any real value, a definition of the nature of the problems contributing to the variance is required in order to document appropriate levels of contingency and the nature of mitigating action required. This sort of qualitative information can only be provided by analysis of historical performances. Benchmarking may thus be considered as documentation of the link to historical data.

The range of variances defined by the reference data from previous projects may be used to define risk quantitatively in risk analysis models but only on a qualitatively general basis.

5.4.4 Performance uncertainty

One of the most observed sources of project overruns is the growth of quantities and complexity in the work to be performed, but this is inherently manageable given the right project control procedures and due awareness of the potential threat this might have on the orderly progression of the work. Modification projects are considered to be more susceptible to complexity growth than grass-root projects. This has its source in the nature of the work. In grass-root projects the full range of complexities will normally be included in the scope of work and accordingly be included in the historical norms of performance. Similar 'mixes' of work will be experienced from project to project and averaged norms may thus be used with confidence. Modification work may experience very differing complexities from project to project and the mix should be taken into account when establishing discipline norms. As mentioned previously, there are no routine project control practices that monitor the quantity/complexity issue as the project develops. These complexity issues, being defined in the course of detailed engineering, thus surface later in job-setting when it is far too late to manage in other ways than increasing manning levels, which may be impossible due to bedding limitations or other restraints.

Another organisational element that threatens the orderly progression of the work is that of poor coordination across the contractual interfaces where the consequences will also be underperformance, except here underperformance need not necessarily include a quantity growth element. In the same way as technical concept development is steered by 'best

[32] Current practice amongst the partners varied between use of median (50/50) estimates and expected value (average) estimates but all required an 80% confidence level.

practice’ procedures, planning and review procedures will normally direct the choice of contracting strategy in the individual project along lines that conform to company best practice. However, circumstances may dictate a sub-optimal contracting strategy with regard to interface issues. It is clear that problems associated with contractual interfaces will be aggravated in the presence of quantity/complexity growth. Both these issues are the domain of project management.

These issues are not easy to build into estimate uncertainty and there are no guidelines for quantifying contingencies. So there will always be residual elements of uncertainty associated with the individual project, which are inherently difficult to quantify. Performance measurement background data may provide a solution by resorting to the analysis of data from under-performing projects in order to identify interaction effects and orders of magnitude of deviation from median or average levels of performance. This is the approach that has been adopted here. Some may claim that underperformance arising from the issues defined above will be included in the variation in the norms of performance comprising the historical data. But these experience norms are normally derived in isolation of any interaction effects between succeeding activities that may be present in the historical data. Thus the interaction effects will not be activated unless correlation between activities is built into the simulation models.

Current project control practice does not have routines in place for monitoring the quantity and complexity development of the scope of work, which inherently reduces the manageability of the phenomenon and the predictability of outcomes. Not being part of the conventional wisdom, monitoring of the product characteristics as engineering proceeds is seldom seen as an option on the manager’s list of risk mitigation activities.

Given circumstances where a stakeholder has little real influence over the chosen contracting strategies or with the management practices put in place to monitor and identify and manage the problems that may arise, the basis for assessing contingencies is even more diffuse. In a conservative climate the investment acceptance criteria (NPV; ROI, etc) may result in projects failing to meet the acceptance criteria if the contingencies are unnecessarily high. But opting out of a major development project in a sector where the partner is co-owner is not a realistic course of action in most cases, without forfeiting benefits accruing from other activities in the same sector. Other issues relate to the role the project might have in relation to achieving corporate goals or business objectives, which may influence the motivation to commit to the project. In this regard the estimator may experience the same management arguing down the estimates and the contingency before sanction in order to gain approval and arguing them up again afterwards. As previously mentioned, delay in sanctioning is potentially detrimental to the project schedule if the completion milestones are retained unaltered, as is often the case. All these aspects constitute a real dilemma for the estimator and indicate the need for 1) a realistic basis for assessing and quantifying risk, 2) a sure identification of the nature of the risk that should be included in the projects mandate and 3) which risk elements should be relegated to other domains of responsibility and higher levels of management.

This then is the background for considering the assessment of uncertainty and the nature of the risk evaluation model presented in this chapter.

5.5 The nature of the project under review

5.5.1 Scope of work

The project for which the risk evaluation is to be done is a satellite tie-back to an FPSO at a remote location in waters off a developing country. The project scope consists of the subsea facilities and a major topsides revamp. The topsides modification is the subject of this case study and comprises 7 modules of various sizes, totally 3800 tonnes, and 1600 tonnes of associated infrastructure. It is one of the largest modification projects on record. The integration infrastructure comprises equipment items and piping, electrical, instrumentation and structural work. The structural work includes reinforcement of the support frame and several of the modules are closely interconnected requiring preconstruction of supporting structures as well as bracing and guides against existing structures. All this requires extensive welding beyond the duration limits of a conventional shutdown and must be performed prior to module installation.

5.5.2 Field support requirements

The support requirements comprise a flotel moored off the stern of the FPSO, which will also function as a laydown area and workshop, and a permanent fleet of crewboats, helicopter, a standby vessel/workboat and transport vessels. Due to the remote location all will be hired in for the duration of the offshore phase as will the flotel. The module installation will be by HLV. In addition smaller floating cranes will be required for purposes of mobilisation and demobilisation of temporary cranes required on board the FPSO as construction support. The smaller floating cranes will also be required to install an additional lifeboat and a purpose-built gangway system between the FPSO and the flotel prior to flotel mobilisation.

5.5.3 Contractual arrangements

The contractual arrangements consist of an engineering and procurement contract, responsible for all engineering design and procurement of long lead items, and a separate fabrication contract, although the fabrication contract also includes some tertiary design. The fabrication contract is responsible for module fabrication and installation of offshore infrastructure, as well as the subcontracted local content comprising two smaller modules and all infrastructure piping and structural materials. A special feature of the engineering contract is the split of the design between Europe and India, the Indian design team having responsibility for the design of the modules. The remaining contracts cover the flotel and the lifting operations, which include the HLV, the installation engineering and module transportation. Interface responsibility is in the hands of company's management team.

5.5.4 Management philosophy

The management philosophy identifies the operator's project team as responsible for overall coordination as well as for the detail planning and supervision of the infrastructure installation offshore and commissioning. Especially the latter poses a special challenge of interface coordination since modification projects require system-based planning worked backwards from the commissioning planning, through fabrication and procurement, and back to engineering. In addition limited space offshore places special demands on the planning systems with regard to maintaining a backup buffer of available work in the case of mishaps with pre-planned tasks, in order to maintain progress in the work.

5.5.5 National authority requirements

The national authority reserves the right to approve all contractors, both local and international. International contractors, who are already operative locally will naturally enjoy an advantage and it is advantageous to pre-qualify contractors and assess their strengths and weaknesses with respect to the intended scopes of work.

In addition the regional authorities have requirements regarding local content. This requires pro-action on the part of the operator to 1) insure that contractors that have local sanction are competent and appropriately equipped to perform the work and 2) identify work of a character and volume suited to local fabrication and gain sanction for the local content plan.

As previously mentioned, the local content includes two smaller less complex modules, mostly structural steel and piping, and fabrication of all the integration steelwork and piping spools. Finally, given a pre-knowledge of the bureaucracy tied to local customs handling, steps must be taken in the planning, such as adequate lead-time, to ensure smooth flow of raw materials into the yards and out again as prefabricata in line with the planned installation sequences. The orderly progression of the onshore prefabrication is crucial for the integration work.

5.5.6 Offshore installation

As previously mentioned the structural steelwork comprises support frame strengthening and the module substructures. This work requires welding and the man-hour volume is beyond the scope of a normal shutdown. Special work routines that make use of pressurised habitats, extensive temporary physical gas leakage barriers and monitoring devices combined with automatic welder shutdown devices have been designed and have received the sanction of the safety discipline. Nevertheless, the full extent of the work efficiency under such conditions will not be known until field experience is available. This activity is critical to the lift-in of the modules.

5.5.7 The challenge

It is clear that the size and complexity of the task combined with the constraints of locality are partly responsible for the contractual setup and management philosophy chosen by the contractor. This nevertheless poses a considerable managerial challenge and risk of underperformance as a consequence. The question remains how such a complex and diffuse risk picture should be priced into the estimates and whether it should take the form of contingency or reserve.

5.6 The relationship of the operator with the partners

The operator’s approach towards the partners has been very open on technical issues. Regular workshops and technical reviews in addition to the regular technical and commercial meetings were held. The operator was always available for clarification meetings with partners on an individual basis to address special problems and was actively interested in drawing on partners’ operational experience, views and contributions regarding technology.

Unfortunately, and in contrast, the operator was less open about the basis for the estimates and particularly rates, norms and quantities and study reports were not made available. This of course created greater uncertainty than necessary. Particularly, the lack of integration weight sub-discipline detail was problematic because this is a measure of complexity. In addition, the content of the reports gives a good idea of what has been addressed and consequently the completeness and maturity of the concept.

5.7 The basis for the cost risk simulation model

5.7.1 General assumption

The basic assumption underlying the cost risk simulation is that in principle all technical risk issues will either have been worked through to an acceptable technical conclusion in the course of the conceptual development and the review procedures put in place prior to all decision gates, or they will figure as unresolved issues on the risk management agenda. In the first instance these items will be a normal part of the scope of work and will be priced in conventional manner. What circumstances are applicable will largely depend on the stage of development and accordingly the purpose of the sanction. It is clear that there is a greater likelihood of unresolved technical risk elements at sanction points in earlier stages of development than at sanction for project execution.

Similarly, risk elements that are related to organisational aspects are likely to be unformulated at early stages of concept development. The residual uncertainty at sanction for execution thus normally comprises elements related to market and performance and any residual technical elements not picked up or clarified during the course of the development phases. However, these residual technical risk elements will normally be priced partly in the conventional manner and partly as part of the normal concept development uncertainty. Exceptionally, items on a risk register may be allocated a reserve, which is normally not included in the budgets.

In the case in question the residual uncertainty consisted of the following issues:

- concept maturity, particularly as it effected complexity development of the concept and the potential for quantity growth. The operator’s view is that the layout is frozen and internal reviews have not seen any need to comment this.
- the contractual split and potential for interface mal-coordination leading to underperformance
- the management philosophy and role and task split, particularly the role of the company project team vis-à-vis the engineering contractors and the main installation contractor
- the offshore installation circumstances with regard to productivity, particularly the hot work during the critical offshore module preparation phase
- the remote location and the coordination challenge associated with local content

The central characteristic of the above is that all elements are potentially interactive and in one form or another have the potential to disrupt the orderly progress of the work and undermine performance in ways that will only come to light as work progresses. They are inherently manageable, but require specific monitoring procedures to be established.

5.7.2 Historical data: Interaction effects in underperforming projects

Due to the inherent difficulties in quantifying the effects of organisational underperformance, historical data was used in order to find a basis for quantifying the magnitude and extent of the interrelation effects of underperformance. Three known underperforming projects were selected for analysis. The data from these projects are presented in Table 5-1 below. The results from these projects have been compared to median values drawn from all the projects in the historical data portfolio.

Case/Item	Eng	Prefab for Integration			Module	Integr	Total	Total
	All Disc	Piping	Steelwork	Total	All Disc	All Disc	EPCI	EPCI Lab
	Mhr/T	Mhr/T	Mhr/T	Mhr/T	Mhr/T	Mhr/T	MNOK/T	MNOK/T
CASE 1	**Large module project**							
Norms	241	201	127	156	226	286	0,542	0,369
Devn wrt Median All	123 %	114 %	109 %	108 %	142 %	147 %	108 %	113 %
Devn wrt Median All Mod	144 %	114 %	132 %	123 %	142 %	102 %	111 %	133 %
CASE 2	**Special atshore integration project**							
Norms	339	212	116	182	161	473	0,813	0,623
Devn wrt Median All	173 %	120 %	99 %	126 %	101 %	244 %	162 %	191 %
Devn wrt Median All Integr	148 %	146 %	87 %	126 %	--	270 %	161 %	180 %
CASE 3	**3a and 3b are two similar and overlapping phases of large pipe project by same contractor**							
CASE 3a	141	131	61	89	--	169	0,355	0,224
CASE 3b	124	53	104	75	--	137	0,336	0,208
Devn 3a wrt 3b	114 %	247 %	59 %	119 %	--	123 %	106 %	108 %
Median All	196	177	117	144	159	194	0,503	0,327
Med All 100% Integr	229	145	134	145	--	175	0,504	0,347
Median All Mod	167	177	96	127	159	281	0,489	0,278
Median Large Mod	131				144		0,340	0,191

Table 5-1: Interaction effects in underperforming projects

<u>Case 1</u> consisted of two modules, one large, as well as a large volume of integration work. The platform had not been prepared for future installations in the original design, The

contractor seriously underbid the resources required for piping engineering and accordingly undermanned consistently irrespective of the accumulative delay in engineering progress. The company management was not successful in ensuring adequate resourcing on the part of the contractor with the result that the project was in a permanent state of delay and associated stress. In addition the contractor split the scope at the module/integration interface between two sections of the same organisation, which were on opposite sides of the North Sea. Overall design responsibility was in Norway, while module design and fabrication, as well as fabrication for integration, was in the UK.

The data gathered here was useful since the project is organisationally [33] and conceptually similar to the case at hand as well as being conceptually similar to an earlier project which had performed optimally.

The results from this project have been compared to median values of all the modularised projects in the historical data portfolio. Here it can be observed that all major activities overran by the same order of magnitude with the exception of prefabrication, which had a slightly lower overrun.

Case 2 is primarily an integration project, but with a small module. The special character of the project is that the modification was performed on a semi brought atshore [34] for hull strengthening and increased buoyancy modifications. This was seen as an opportunity to perform a large topsides modification atshore, believing this would offer substantially reduced costs. The special challenge was the performance of a large scope during a short period of time in parallel with the hull strengthening, while the semi was atshore. This work required all materials to be ready for installation on the quayside at the start of the work. The problems resulted from the project sanction being delayed without an adjustment in the milestones, causing considerable stress in the project, especially with regard to engineering. The contractor opted for a sub-optimal [35] installation philosophy based on volume and site erection. This choice was consistent with the contractor's experience from atshore work on grass-root projects, instead of optimised prefabrication in combination with extensive field measurement, which characterises offshore modification work. In this context volume site erection represents a complexity increase. The installation philosophy was chosen as a result of time pressure. The result was a large volume of clashes and the associated engineering and fabrication rework in the field combined with disturbance to the orderly progression of the work and consequent drastic underperformance, amongst other factors.

From case 2 can be observed consistent overruns of all core activities of the same order of magnitude as case 1 with the exception of the integration work, which has considerably greater overrun. In this case there was a reduction in the overall installed weights compared to the original concept. The engineering overrun was largely related to field rework resulting from clashes. The installation overrun included a significant degree of rework due to clashes, but also a large component related to inefficiencies resulting from high manning densities, overtime and poor continuity in the orderly progression of the work due to the clashes.

Case 3 is an integration project consisting mainly of large bore pipe and steelwork. The scope was performed in two partly overlapping phases and consisted of similar work on the same platform by the same project organisation. The project did not overrun extensively, but the first phase experienced problems getting competent CAD personnel with the result that piping

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[33] Organisationally similar with regard to the separation of engineering responsibility for the modules but dissimilar with regard to the use of an overall EPC form of contract in the historical case. The potential for interface trouble is thus more severe regarding the case under review.

[34] Atshore means quayside as opposed to inshore (moored in a fjord) compared to offshore.

[35] Suboptimal with regard to manning densities and work routines in the field.

engineering was delayed. This in turn, created problems for procurement so that prefabrication of spools was effected and the offshore installation program had to be constantly re-planned. The surface protection could not be completed onshore and had to be completed offshore, resulting in more offshore man-hours than necessary and a longer overall project period. However, all project milestones were met.

Since similar problems were not encountered in the second phase of the work, the data provides an opportunity to compare the effects of the disturbance in the orderly progress of the work on performance in two highly similar projects. It can be observed that the orders of magnitude of the disturbances are similar for all activities with the exception of the prefabrication of piping in the first phase, which has a much greater overrun. It should be noted that the steelwork was of quite a different character in phase 2 compared to phase 1.

Conclusion from the analysis of historical data: The data presented in Table 5-1 above indicates that interaction effects may influence all core activities in a project and by the same order of magnitude. Further, it indicates that an order of magnitude of +50% with respect to median performance levels is not unusual. Individual activities may deviate considerably more or less than the average for all activities. Studies of other projects indicate that underperformance may be isolatable to conditions specific to a single work phase. Typically, efficiency offshore may be adversely influenced by poor and discontinuous work flow resulting from lack of beds.

Given the fact that case 2 and case 3 did not experience weight growth, the analysis indicates that a considerable part of the latent risk is organisationally grounded. This conclusion is underscored by the very different execution histories of the three projects in the historical analysis.

5.8 Cost estimate - Simulation of interaction effects

This section describes the cost risk simulation model for modification projects developed as part of the work underpinning this thesis. The model is based on conclusions derived from analysis of historical performance data collected as a consequence of the performance measurement practices presented in this thesis. The results of the analysis pointed to the presence of interaction effects between the main activities of a similar order of magnitude for all activities.

The interaction effects were simulated in two ways; by the use of deterministic sensitivity calculations of selected execution scenaria and by simulation using Crystal Ball. The calculation basis for the simulation and the sensitivity calculations are illustrated in Table 5-2 below.

5.8.1 The deterministic sensitivity calculations

The sensitivity calculations were performed to illustrate in a step-wise fashion the impact of interaction effects with respect to the predefined levels of contingency and in order to isolate the impact of specific scenaria. Referring to the columns Sens1 to 6, the values highlighted in dark yellow are the driver activities, the activities in light yellow are the affected activities. The effects of interaction were calculated by applying the Performance Norm factors shown in Table5-2, which represent the P10 and P90 values from the full array of historical data.

Basis for simulation											Sensitivity Calculations					
Class D; +/-20%; 80% Conf	Base	Sim1	Sim2	Sim3	Techn/Wt		Perf Norms		Rates/Prices		Sens1	Sens2	Sens3	Sens4	Sens5	Sens6
EPCI COSTS	MNOK 04	MNOK 04	MNOK 04	MNOK 04	P10	P90	P10	P90	P10	P90	Eng	Offsh Prod	Wt Grth	Compl	All	All + CO
Prelim/Facility	338	356	407	444					0,86	1,26	400	379	392	487	560	560
Man/Admin	217	246	273	298					0,92	1,36	257	243	252	313	360	360
Engineering	342	380	397	397			0,81	1,44	0,93	1,08	492	342	393	492	566	566
Proc - EQ	280	280	280	280					0,90	1,10	280	280	280	280	280	280
Proc - BULK	338	353	353	353	0,95	1,15			0,95	1,09	338	338	389	338	389	389
Prefab for Integration	88	90	94	109			0,81	1,44	0,82	1,05	88	88	101	126	145	145
Module Fabr/Ass + Comm	170	175	183	212			0,81	1,44	0,82	1,05	170	170	195	244	281	267
Offshore Integration	225	232	242	281			0,81	1,44	0,82	1,05	225	323	267	323	372	385
PT/LOG/OPs COSTS																
PT, Ins etc	361	361	361	361					0,95	1,05	361	361	361	361	361	361
Studies; Verifikations, etc	0			0					0,95	1,05	0	0	0	0	0	0
Base/Supply Boat Transport	106	111	111	128					0,95	1,15	106	122	122	122	122	122
Heli/Crewboat Transport	39	41	41	47					0,95	1,15	39	45	46	45	45	45
Accomodation	76	76	82	95					0,95	1,05	76	110	91	110	126	131
Platform Operator Costs	0			0					0,95	1,05	0	0	0	0	0	0
Heavy Lift Vessel	187	187	187	187					0,95	1,05	187	187	187	187	187	197
Flotel	443	431	431	496					0,81	1,15	443	509	443	509	509	509
TOTAL BASE ESTIMATE	3210	3320	3442	3688			TOTAL EPCI+PT/LOG/OPS				3462	3498	3520	3939	4304	4317
Prescribed Cont 20%	642						Cont = SensX-Base				252	287	309	729	1094	1106
TOTAL EXPECTED COST	3852	3320	3442	3688			%Cont = (SensX-Base)/Base				8 %	9 %	10 %	23 %	34 %	34 %

Table 5-2: Calculation basis for the simulation and sensitivity analysis

The following cases were modelled in the sensitivity calculations:

- Sens1 models a full engineering overrun alone, not including any interaction effects.
- Sens2 models a full integration overrun alone and the associated interaction effects on the offshore logistics costs.
- Sens3 models a weight increase assuming no disruptive effects on other activities.
- Sens 4 models a bulk complexity increase using the P90 performance norms without any associated weight increase and without any associated underperformance effects in other activities.
- Sens5 combines Sens 3 and 4 in a combined quantity/complexity increase.
- Sens6 applies the effects of an incomplete module fabrication to Sens5 by transferring 5% of the module fabrication man-hours offshore as carry-over .

For all cases, but which will have no effect in Sens1, logistics have been increased by 15% if offshore integration man-hours overrun the base estimate by more than 20%, assuming this will lead to an extension of the offshore period. This is due to the remote location. Since the whole spread is hired for the entire period, it is sensitive to a schedule overrun, but not volume variation. Sens4, 5 and 6 each represents combinations of several extreme conditions simultaneously. Such circumstances may intuitively be considered unlikely, but are not dissimilar to Case 1 in the interaction analysis shown in Table 5-1 above, noting that the P90 values in Table 5-2 are similar to the overrun factors in the analysis of the overrun interrelation effects. The difference between the simulated values and the base estimate is shown at the bottom of each sensitivity case with the percentage value related to the base estimate. Note that Sens4 has the same order of magnitude as the predefined contingency of 20% while Sens5 and 6 have the same order of magnitude (30%) as the Case 1 EPCI Lab (meaning Labour) overrun in Table 5-1. From this it may be concluded that the deterministic sensitivity calculations endorse the assumptions of interaction and the associated order of magnitude of overrun.

Regarding the likelihood of overrun effects of the above order of magnitude, it was the position adopted by the operator that a combination of worst case effects was extremely unlikely, and this conclusion was deemed to be supported by the results of the risk analysis performed by the operator.

5.8.2 The simulation model

The interaction effects that were exposed by the historical analysis and the results of the sensitivity analysis were used as a basis for constructing, testing and calibrating a simulation model using Crystal Ball. Three models with different degrees of interaction were constructed. The calculation basis and the results are presented in Table 5-2 above and Figure 5-1 below.

It was found that some of the interactive effects had to be modelled asymmetrically in order that the model gave results of the same order of magnitude as the sensitivity calculations Sens5 and Sens6. Such an approach can be supported by the following rationale: Individual activities may for internal reasons perform well or badly without influencing the succeeding activities as long as the deliverables are not delayed. Given a circumstance with delayed engineering, or poor interface coordination (for instance a poorly aligned plan basis), the engineering efficiency as well as the deliverables to the succeeding activities are likely to be affected, thus disturbing the orderly progress of the work. It is presumed that efficient engineering that delivers on time will not exercise a positive effect on performance of succeeding activities equivalent to the negative effect of non-delivery on time.

Of course interaction effects may arise between other activities such as prefabrication and offshore integration and independently of any other activities. Likewise module fabrication may result in carry-over offshore or delays entirely independently of other activities. Offshore activities may be adversely affected by poor work continuity due to a lack of beds. So far, engineering as the driver of the interaction effects is considered to be the most conservative position. Precedence for this view may be found in the analysis of overrun projects. But correlation effects are assumed to be progressive in the sense that a mild engineering disruption will be associated with a mild disturbance to the downstream activities.

The individual values were simulated in the columns Sim1, Sim2 and Sim3 using the Base estimate values as input along with the Technical/Wt values, the Performance Norm ratios and the Rate/Price ratios as shown in Table 5-2 above. The interrelation effects were modelled using correlation formulae linking the random values for each activity generated by the simulation in the following manner:

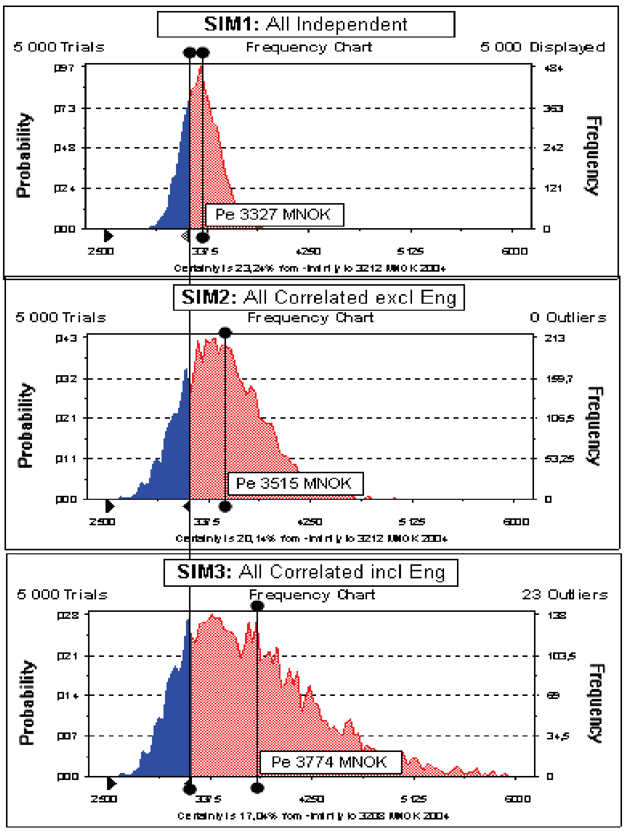
- <u>Bulk Quantity effects</u>: For correlation of effects of bulk quantity variation on the labour content the individual Engineering, Prefabrication for Integration, Module fabrication and Integration Offshore values were multiplied by the ratio (Bulk Sim)/(Bulk Base)
- For correlation of bulk quantity effects on offshore Base and Supply Boat costs the Base/Supply values were multiplied by the same ratio (Bulk Sim)/(Bulk Base)
- <u>Engineering underperformance effects</u>: For correlation of Engineering underperformance knock-on effects on the succeeding fabrication activities, Prefab for Integration, Module Fabrication and Offshore Integration, the individual values were multiplied by a the ratio (SimEng)/(Base Eng) applied for all values of (Sim Eng)/(Base Eng) greater than 1.
- <u>Offshore Productivity Effects</u>: For correlation of offshore productivity effects on offshore logistics costs the helicopter and accommodation values were multiplied by the ratio (Sim Offsh Integr)/(Base Offsh Integr)
- For correlation of offshore productivity effects on flotel hire costs, the flotel cost was multiplied by the P90 factor for all cases of (Sim Offshore Integration)/(Base Offshore Integration) greater than 1.2 assuming an extension of the hire period

Note that the engineering knock-on correlation effects and the offshore integration productivity effects on flotel hire are applied asymmetrically.

The range of the bulk quantity variation is also applied asymmetrically (-5/+15%) based on the assumption derived from the experience that bulk quantities seldom decrease. The range of the bulk quantity variance, +/-10%, is the prescribed level of uncertainty associated with a cost uncertainty range of +/-20%.

5.8.2.1 Results of cost simulation and conclusion

In order to highlight the effects of correlation, simulations were run for three cases that modelled increasing degrees of correlation, namely the Sim1, Sim2 and Sim3 cases that can be seen in Table 5-2 and the Figure 5-1 below. Sim1 has no correlation effects. Sim2 includes correlation between the bulk quantities and the engineering and fabrication labour, offshore productivity and logistics costs and effects of flotel extension due to schedule delay. Sim3 includes the engineering knock-on effects as well. A plot of the results of the simulations is shown in Figure 5-1 below. Note that the Base estimate and the respective Pe's (Expected Value) have been drawn in and labelled in Figure 5-1.



Parameter		Sim1	Sim2	Sim3
P10	MNOK	3126	3082	3098
Base	MNOK	3210	3210	3210
P50	MNOK	3322	3486	3678
Pe	MNOK	3327	3515	3774
REC Base + 20% Cont	MNOK	3852	3852	3852
P90	MNOK	3527	3974	4577
Std Dev	%	5 %	10 %	16 %
P10 wrt Pe	%	-6 %	-12 %	-18 %
P90 wrt Pe	%	6 %	13 %	21 %
Pe-Base (Cont)	MNOK	117	304	564
Pe wrt Base (Cont)	%	4 %	9 %	18 %
P90 wrt Base	%	10 %	24 %	43 %

Figure 5-1: Effects of correlation

It can be observed from the dispersion profiles in the figure that the range of the dispersion increases, the degree of asymmetry increases and the difference between the Pe and the base estimate increases with increasing degrees of correlation. Specifically the degree of asymmetry is coupled primarily to the assymetrical weight distributions and the asymmetrical engineering correlation effects, noting the marked incremental asymmetry in Sim2 and Sim3 with respect to Sim1.

On the basis of the above it may be concluded that the results of the simulation using the Sim3 model correspond best with the historical data. Note that the Sim3 Pe satisfies the acceptance criteria while the Sim3 P90 value corresponds well with historical data and the extreme cases Sens5 and Sens6. Sim3 is the result of modelling full interaction effects between all activities and better defines the real uncertainty than for example Sim1, in which all the activities are treated as independent. In effect, Sim1 permits several activities which are all dependent on the same source (volume of work defined in weight metrics), to vary out of phase with each other, causing considerable cancelling effects, as is evident from the results.

Specifically stated, given a weight increase one would expect both engineering and fabrication activities to increase synchronously, while the Sim1 model permits engineering, bulk material volumes and fabrication activities to fluctuate independently of each other, causing cancellation.

By comparison of the contingency elements in Sim2 compared to Sim3, it can be concluded that disruptive organisational effects have the same order of magnitude as the effects of weight growth alone. Specifically stated the Sim 2 models the effects of weight growth and complexity growth alone while Sim3 includes the effects of organisational disruption as well. The Sim3 contingency is twice that of Sim2.

The Sim3 Pe endorses the prescribed level of contingency (REC = Base +20%). On the other hand the Sim3 P90 value is well in excess of the prescribed contingency value. Since the Sim3 P90 value is seen to correspond well with the historical cases from Table 5-1 based on the norm variation, this must raise doubts whether the prescribed contingency is sufficient to compensate for the uncertainty associated with the circumstances of Sens5 and Sens6 for the case in question. However, the sensitivity cases Sens5 and Sens6 support the range of uncertainty defined by the model. It is also of relevance to note that the overrun analysis also indicates that individual activities may overrun to a much greater extent than the average, given the adverse integration conditions of Case 2 in Table 5-1, for instance. In order to provide illustration of the nature and magnitude of the generic risk elements incorporated in the model, these discrete deterministic sensitivity cases have been included as points on the dispersion profile frequency chart shown in the Figure 5-2 below.

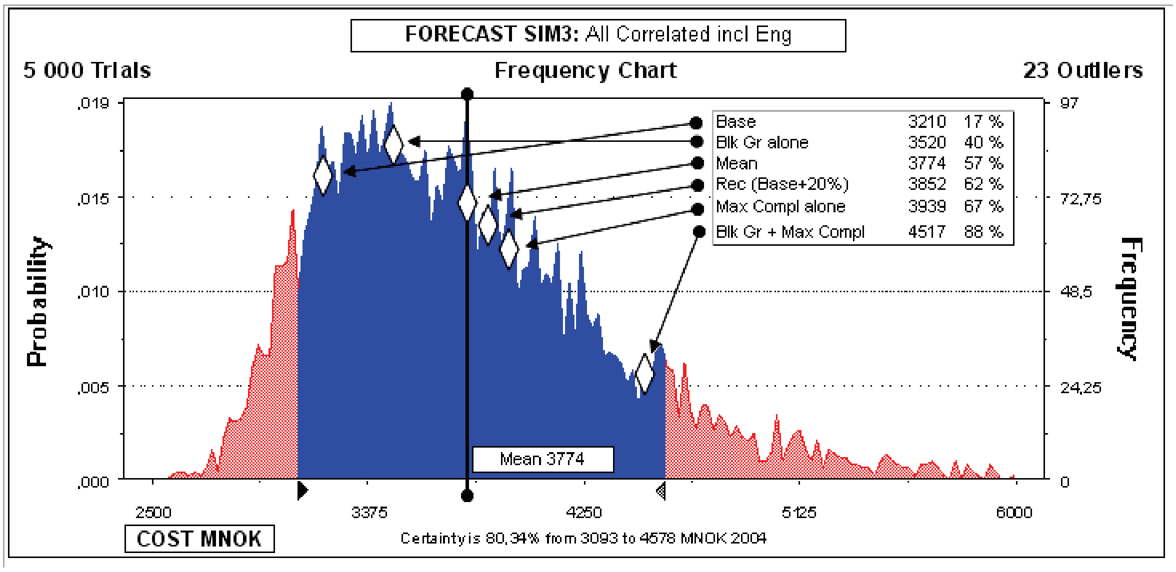


Figure 5-2: Dispersion profile including generic risk scenaria – Bulk and complexity growth

It may be concluded from the results that the model above is a better model than the model used by the operator referred to in the introduction, which gave results of the order of magnitude of Sim1.

One may see from this that the individual project has a real potential to exceed the limitations of the anticipated underperformance as defined by the prescribed contingency on the one hand and as defined by the simulated EV and the simulation dispersion on the other. This is particularly so under circumstances which lead to disruption of the orderly progress of engineering and precipitate underperformance in all follow-on activities.

The results of the correlated model endorsed the subjective suspicions of the partners that such scenaria are more common than the operator chose to acknowledge and that the real level of risk is significantly higher than that proposed by the operator.

How should the project respond to the risk picture defined by the above simulation? The extreme conditions of full correlation may be regarded as low probability high impact risks that should not be used to set contingency levels assuming that the conditions that precipitate such degrees of overrun are inherently manageable. However the simulation shows that the risk and potential impact of such scenaria are high enough to warrant the introduction of mitigating measures in the array of risk management procedures available to the project.

Further details regarding the premises for the model and adaptation for use in successive stages of development are discussed in Appendix 3.

5.9 Conclusion

The review has presented a tentative model for cost uncertainty simulation which provides improved quantitative modelling capability compared to the current procedure.

The basis for this model was validated by variance analysis of some under-performing projects in the historical data. This analysis pointed to a need and provided a basis for modelling correlation effects between succeeding activities in the simulation. Simulation results were found to coincide well with the historical data and endorse the order of magnitude of the recommended levels of contingency associated with estimate classes.

In order to illustrate the risk evaluation processes as they affect the cost estimating processes, the rationale was presented against a case background from a current project. The rationale demonstrates that a large part of the uncertainty arising out of the complexity is organisationally related and thus indeterminate. Benchmarking against historical data may contribute to reducing judgemental subjectivity regarding levels of contingency appropriate for the type of indeterminate uncertainties described in the case background and in the projects in the historical analysis.

Performance measurement principles can also be applied in a benchmarking context seeking specific explanations for underperformance and in so doing help to define the causal nature of the uncertainties, the better to understand appropriate mitigating action.[36] One such action that points itself out is the implementation of scope monitoring procedures in the standard array of project control tools, as presented in this thesis.

This benchmarking application of performance measurement principles is the theme of the next chapter.

[36] The type of review referred to is presented briefly in Chapter 3.9 and in the case studies presented in the Appendices 1 and 2.

6 BENCHMARKING OF PROJECTS

APPLICATION OF PERFORMANCE MEASUREMENT PRINCIPLES IN BENCHMARKING OF PROJECTS

6.1 Introduction

Considering that one of the objectives of this thesis is to promote the use of performance measurement as an improvement technique, it is appropriate to address the relationship that performance measurement has to the technique of benchmarking.

While performance measurement is recognised as an essential element pertinent to benchmarking success by most practitioners operative in the traditional industrial and manufacturing environments, performance measurement in absolute terms has not received the same recognition in project related theories and studies or in the realm of practical project benchmarking. The quantitative element of much project benchmarking is measured in relative terms or at high orders of aggregation. Much project benchmarking is entirely qualitative. This approach appears all-pervasive. In certain specific contexts in-depth performance measurement in absolute terms may greatly facilitate project benchmarking processes by providing insight into own performance and directing attention to areas of deviant (good/poor) performance that otherwise may escape attention, thereby directing the search for what to benchmark.

The benchmarking of projects takes place in an organisational context very different to the manufacturing industry in which the practice of benchmarking has its roots. This is due to the temporary nature of the project and often relatively autonomous position many projects enjoy with respect to the owner organisation.

The objectives of this chapter are to highlight the value in-depth performance measurement practices have in facilitating benchmarking of projects, to present documentation for this view through case studies, to explore the organisational context in which much project benchmarking takes place and finally, to present a generalised process model for benchmarking of projects which takes the above perspectives into account.

6.2 Background

The practice of BM is grounded in the work of industrial actors who sought improvement for their own products and practices by comparing own products, performance and manufacturing processes with that of the leading competitors. Great success by the innovator company led to the widespread adoption of the benchmarking technique by other companies. Systematic use extended the range of search areas for superior performance beyond the immediate arena of the competition to include similar industrial functions irrespective of the type of industry. Beyond the realm of products and manufacturing processes, it came to include service functions, business processes and even strategy. The experience generated by the practice of benchmarking has been documented in the literature by several of the pioneer actors themselves as a good practice foundation for other potential users, of which the foremost is Camp (Camp, 1989). Benchmarking today appears solidly established in industry, the business world and academic circles as a technique for improvement with great potential if used correctly. Benchmarking is the subject of much research and many publications from both academic and functional sources.

Projects, at least in the Norwegian sector of the North Sea offshore oil industry, less in traditional construction industry, have traditionally relied on quality assurance processes, ultimately the over-arching TQM approach, as a basis for improvement. This has its roots in the techniques of quality control based on statistical sampling as applied to mass production processes [37]. TQM extends the role of quality assurance from the domain of controlling organs and statistical sampling of production processes to include the involvement of every employee in the issues of quality and performance improvement in all the functions and processes in the organisation. These principles of pure quality control, as applied to manufacturing processes and products, have also been extended, in the guise of quality assurance, continuous improvement and TQM, to cover the more intangible products of project management and administration. These are engineering, estimating, planning, risk and uncertainty management, contractual and scope management, materials procurement processes, financial control and budgeting and the several other project management tasks which are intended to facilitate the timely and cost efficient execution of the project's task.

At times the same principles of quality assurance/TQM have been embodied in the core of control legislation, such as the offshore petroleum industry internal control legislation in Norway. The internal control legislation defines the duties and self-control obligations of industrial actors with respect to conservation of values, such as human safety, prevention of environment pollution and the economic value associated with the petroleum facilities installed offshore. This legislation has subsequently been extended to the process industry onshore and, more recently, to other onshore industry. From the above it is apparent that the TQM perspective is well entrenched in the oil and gas industry and without question ensures a greater reliability in the industrial production processes and special field operations that characterise the industry.

However, one might justly question that while the TQM approach has contributed to a greater uniformity of method and approach and ensured conformity of practice in the individual projects with respect to accepted best practices, has it in fact contributed to continuous improvement of project management processes [38]? Projects still overrun substantially from time to time, but also under-perform to a lesser degree on an everyday basis. These overruns are generally attributed to underestimation of quantities and complexity, or both, that precipitate disruptions in the orderly progress of the work, causing rework and inefficiency due to crashing. It is a well known and much debated (but not much researched ?) fact that experience transfer, meaning the ability to learn from the experiences of others, between projects is a difficult task fraught with obstacles. TQM appears not to have provided solutions to these recurrent problems.

A reason for this failure may be found precisely in the nature of the review routines employed in TQM practices which are generally of a single loop character despite ambitions regarding the learning potential in TQM practices expressed in much of the TQM literature (Morgan, 1997). Single loop routines seek non-conformances to established practices and are normally satisfied with responses that correct observed deviations. At generic level the review routines are guided by a set of rules as defined by standards documents, at project specific level the reviews are guided by the project's own internal procedures, which in turn are based on the generic standards documents. The review object, the project, has no requirement to proceed beyond the limits of best practice and TQM review has no mandate to demand responses that exceed the limits of best practice requirements.

It is appropriate to note the while much of the original practice underpinning the TQM perspective is based on the use of measurement and analysis [39], referring to Bisgaard (Bisgaard, 2000) and Kueng (Kueng, 2000) as well as others, TQM review procedures in the

[37] Defined in the works of Taylor, Shewhart, Deming, Juran, Feigenbaum, Ishikawa and others.

[38] Used in the sense of single loop corrective action compared to double loop learning processes as expounded by Argyris & Schøn. (Argyris, Schøn, 1996).

[39] Referring to Chapter 2 and the literature review (Bisgaard, 2000;Kueng, 2000)

oil and gas industry make little use of quantitative performance data, absolute or relative, as a basis for directing the focus of their review activities.

These constraints may have the result that TQM reviews are less responsive to the element of ‘surprise’ inherent in the search heuristic concept [40] of Nelson and Winter (Nelson ,Winter, 1982) to which TQM review processes may be exposed, making it difficult to jump the gap to double loop performance. In any event, the potential for projects to utilise the insights arising from such surprises is inhibited by the organisational context in which many projects operate, especially perhaps, the multi-project environment of project-based organisations.

Benchmarking theory, on the other hand, specifically promotes a mindset that seeks the learning and improvement potential inherent to double loop processes. And it is precisely learning by experience from others that is the raison d’etre of benchmarking. Thus, and inspired by the successes of benchmarking in manufacturing and other ongoing processes, academics and practitioners alike have addressed the issue of transferring the technique into the environment of projects (Dey, 2002; Emhjellen, 1998; Mohamed, 2002). This area of work is also the focus of several professional organisations offering benchmarking services [41].

Also in benchmarking of projects, as with TQM, there is a trend towards broadening the domains that contribute to overall project success, from the traditional execution phase to include also the conceptual phase (Andersen, Merna, 2002; Emhjellen, 1998). This, and recognising the large degree of commonality between different projects in different industries, also leads to a more qualitative perspective of the project on a generic basis that encompasses all types of projects in any industrial context (Miller, Lessard, 2000). But, the trend towards a largely qualitative approach in the interest of finding unified generalised theories may be detrimental to the development and use of traditional methods. Traditional methods are based on absolute forms of quantitative performance measurement and associated analysis applicable in very specific industrial contexts that characterise benchmarking in the manufacturing industry. This trend towards qualitative evaluations in benchmarking may be seen as analogous to the non-quantitative nature of the TQM review procedures[42] mentioned above. In this regard it may be observed that project benchmarking activities in the oil and gas industry largely limit the quantitative performance measurement to high levels of aggregation. Lack of in-depth measurement is not conducive to understanding and insight in own processes and levels of performance, otherwise regarded as a prerequisite of good benchmarking practice.

While not disregarding the legitimacy of the above-mentioned broad-based qualitative and generic perspectives on project management success or failure, it is project success or failure in an execution context that is the major concern of the majority of project practitioners and which receives the most focus in the popular and industry news media. In this context, methods, tools and techniques aimed at in-depth insights into the execution circumstances of specific types of projects in specific industrial contexts are of central importance.

[40] Control routines by one part of an organization may be the source of insights to another part of the organization – in a project context this becomes a question of the base organization’s perspective (long term/custodian of best practice) as opposed to the project perspective (short term/user of best practice).

[41] IMEC; IPA

[42] Referring to review procedures as distinct from general implementation practices, believing that TQM calls for implementation of best practice in the operating routines of projects – thus it is only in the context of reviews that insights leading to CI might arise. In spite of the expressed view that CI is an objective it normally lies outside the mandate of a project to be innovative beyond the range of its mandate.

6.3 The organisational context of project benchmarking

The benchmarking of projects takes place in a special organisational context that has implications for the way benchmarking activities are organised to an extent that may be definitive for success or failure.

The benchmarking rationale in general presumes that the process owner both initiates and implements the results of any particular benchmarking exercise. But the project is not the process owner. Transferring the traditional approach to projects implies that any given project benchmarks itself against some other project in its own or some external company and own or other industry and implements the results in its own routines. This means treating a project as a firm. But the time-limited cyclic nature of projects renders this approach impractical. Owing to the cyclic nature and schedule constraints that dictate the priorities of most projects, the results of benchmarking a project can only practically be implemented in new projects. But this again is practically difficult, since the project organisation will dissolve after completion of its task. Thus new practices can practically only be implemented if the same project organisation transfers intact over to a new project, which is seldom the case even within project – based organisations. Alternatively, BM results may be implemented in new projects through championship by empowered individuals. However, in environments with a well established base organisation, the implementation of new routines will normally require the sanction of the base organisation through the medium of best practice. In conformance with the TQM perspective, new routines will normally require implementation in the best practice which is defined by the process owner through the functioning of the base organisation. From this one may conclude that benchmarking practices in projects can most efficiently be executed, and results implemented, if performed under the auspices of the process owner and the base organisation, which are operative over a longer time-cycle than projects and can therefore bridge the gap between individual projects.

Since project performance can really only be judged in hindsight, the time-related issue also has a bearing on the basis of comparison for assessing performance. The standard sequence for setting up a benchmarking program, advocated by many practitioners in non-project based industry and services, is to seek proof of good performance before starting to measure the activities of the good performer. This approach is impractical in a project context. The conclusion follows from the fact that the majority of the key processes in the project life cycle will already have passed, and opportunities been lost, to observe and measure, before superior performance is confirmed. This time-related problem can be overcome by instituting some sort of generic measurement practice in several selected, or all, projects in a portfolio. The results from individual projects may then be highlighted against a background of general performance, based on the results of several projects, thereby providing a basis for isolating deviant (good or poor) performance as a starting point for qualitative review. Such an approach will solve all the problems outlined above, but presupposes an appropriate level of performance measurement in all projects.

The time-limited but cyclic nature of project work poses other problems regarding the direct transfer of the generalised routines developed originally for application to manufacturing processes. Due to the complex nature of project work with its many interactions that collectively impact the final outcome of the project, the whole project must be benchmarked. Measurement only at aggregate level will pose problems in identifying the specific practices leading to collective superior or inferior performance. This circumstance speaks for an in-depth measurement of performance that facilitates identification of the elements of the project organisation that are the superior performers, or the underperformers. Measurements may, in addition, need to be spaced out in time through the project life cycle, in order to highlight the development of the interaction effects between core processes. In contrast, the traditional benchmarking approach may select an activity, function or process to benchmark, in isolation from other activities, functions or processes, knowing that the process being benchmarked is an ongoing process with a definable and controllable routine where both the detail functioning and the relationships with the larger context are relatively stable over of time. Recycling of lessons learned is practically feasible and can be tested. This continuity is not available to the project benchmarker.

Based on the above rationale, this thesis has two main proposals regarding the use of benchmarking in projects:

1) A suitable background for performance comparison can be achieved using the set of performance measurement parameters outlined in preceding chapters. Thereafter, benchmarking techniques may be applied in order to identify the qualitative issues underlying good quantitative results along the lines of the case studies presented in Chapter 3.9 and Appendix 1 and 2.

2) A project-related theory of benchmarking will need to address the lack of routines aimed at bridging the gap between successive projects and the organisational relationships and mandate for experience transfer between projects. These are generally grounded in the concept of the project as a unique stand-alone entity, relatively independent of the base organisation and the process owner. It may be appropriate to redefine the concept of the project as simply a batch (or time-limited cycle in the long-term process) whereby stakeholders make repeated use of the project form of organisation to implement strategic investments. The shift in emphasis from the autonomous project entity to the multi-project organisational environment may be necessary to emphasize this different perspective on the issues of experience transfer between projects. It is the process owner (who is the project owner) who should have the active role in ensuring experience transfer from current projects to future projects. This concept, of the project seen as a batch in a longer term industrial context, applies equally to industries making capital investments as part of their business strategy (eg oil companies investing in capital plants), industries providing services (eg engineering and management consultants) and to specialist manufacturers (whole plants, sub-plants, individual items of equipment, shipbuilding, etc) providing bespoke products.

The above discourse has not always differentiated adequately between the benchmarking of on-going manufacturing processes compared to the benchmarking of time-limited processes inherent to the nature of projects. However, and echoing Mohamed (Mohammed, 1996) as mentioned Chapter 2, projects may be regarded as subordinate elements in organisations that do business through projects. Projects may thus be likened to large-scale purpose-built assembled products and as such are special cases of manufacturing, with a long cycle time [43]. This in turn suggests that there is no need to address projects specifically when setting up benchmarking process models beyond that of taking into account the special nature of the processes involved and the organisational dispositions within these organisations regarding the way projects are mandated and run. Each individual project is but a repetitive subroutine in a broader process that is more extensive over time and that incorporates whole projects as cycles of repetition. In this context benchmarking of projects in fact means to benchmark the skills of the overarching project owner organisation in utilising the project form of organisation as a method for managing capital investment processes or simply as a means of doing business, or both. This approach has special relevance for project-based industries performing work of a broadly similar nature, such as the design and construction of oil and

[43] Meaning that there are large sectors of the industry that operate on a bespoke basis, producing large and complex assembled products, rather than off-the-shelf products.

gas production facilities, and that wish to employ benchmarking techniques as improvement tools.

Contrary to the apparent general trend away from quantitative benchmarking in the manufacturing industry expressed in several papers and publications, the author is of the opinion that quantitative benchmarking is an essential element in any benchmarking process model intended for use in project-based industries that make extensive use of the project mode of organisation. This has particular relevance for oil and gas and other process industry that has the means readily available to measure performance on a generic basis, thereby facilitating comparison between projects and actors. This view has extensive support in the literature, but primarily in the context of manufacturing (Bisgaard, 2000; Camp, 1989; Feuer, Chaharbagi, 1995; Kueng, 2000; Mohamed, 1996; Spendolini, 1992).

This is then the traditional background in which benchmarking as an improvement technique in projects will also have to function. This theme is also elaborated elsewhere, in Chapter 2 and in Chapter 7. Chapter 2 is a general review of the professional press seeking relatable research while Chapter 7 is a review of literature and a discussion of the organisational theoretical perspectives pertaining to the themes of this dissertation.

6.4 A process model for benchmarking of projects

An approach to BM as a special function or tool of TQM, may be fruitful when applying the concepts of BM to projects rather than the apparent piecemeal approach that has characterised much benchmarking in manufacturing so far, as seen by some researchers (Carpinetti, de Melo, 2002; Underdown, Talluri, 2002; Yasin, 2002). This approach is applied holistically in the processes and structures that form the core of the proposed practical performance measurement applications that are defined as part of this thesis. Central to this approach are the following sequential BM process activities:

- an ongoing quantitative performance measurement of key activities, functions or processes in individual projects and correlation of results (provides a basis for understanding own processes and levels of performance)
- systematic quantitative comparison of forecast and final performance in individual projects in order to detect deviations with respect to norms of performance and project-specific goals (serves a purpose for project-specific project control purposes as well as evaluation and comparison of life-cycle development with other projects)
- systematic qualitative review (ongoing and final) of the project performance with respect to own goals and general norms of performance and with special focus on the deviant processes, activities or functions in order to establish the root cause of the observed deviations as a basis for improvement (internal benchmarking)
- use of findings in individual projects (seen against a background of general performance based on performance data from many projects) as a basis for selecting what to benchmark in in-depth functional and process benchmarking
- implementation of the findings in the best practice documents for use by current (where possible) and new projects
- extension of benchmarking effort as defined above to the external domain (performance measurement as a basis for review of partner operated projects and other actors in the same field)

An essential feature of the above model is the organisational dispositions regarding mandate for experience transfer and the roles and duties of the discrete projects. A primary feature is the need to promote an enduring practice of measurement, analysis and review as a basis for understanding own processes and performance and as a basis for experience transfer.

Responsibility for experience transfer should be allocated to an organisational entity that is continuous in time in order to bridge the gaps between discrete projects. In this way the responsibilities can be better aligned with the functional realities and goals of the organisational entities that are involved, respectively the discrete project and the base organisation, and ensure cooperative interplay.

The approach outlined above is considered to rest on the already extant general theory founded in TQM [44] (Bisgaard, 2000; Bendell, Bolton, Kelly, 1993; Carpinetto, de Melo, 2002; Mohamed, 1996; Ramabadron, Dean, Evans, 1997; Underdown, Talluri, 2002; Yasin, 2002), and specifically utilises the strengths of benchmarking processes for the purposes of establishing the qualitative root causes of good or poor performance through the processes of experience transfer.

Irrespective of the approach, be it BM, TQM, CI, what ever, there is a general consensus (Nelson,Winter,1982; Sørensen,1996; Utterback,1994) that research is essential in innovative organisations as a background to the routine processes utilised in routine tasks. In a more general context it may be said that research underpins the understanding of all science and science-based processes (Bisgaard, 2000; Kueng, 2000; Latour, 1997). In the context of this chapter this research takes the form of systematic collection and analysis of own performance and that of other actors in the same or similar fields of operation. The results of such a process are better insight and understanding of own processes and performance by providing theoretical insights that are anchored in experience. These insights can be continually tested and developed in the light of new data and may be translatable into methods, tools and formats and other forms that facilitate transfer of tacit knowledge in communities of practise by processes of organisational learning [45].

6.5 Types of benchmarking and characteristics of the benchmarking process model

Closer examination of the generally accepted types of benchmarking indicates that a slight re-alignment of perspective may be appropriate regarding benchmarking of projects.

Projects may best be compared by using 'internal' benchmarking processes. This is particularly suitable in the multi-project environment. Indeed there is hardly any point in benchmarking projects in organisations that seldom use the project form of organisation unless this is performed by stakeholders such as governmental authorities, project based organisations like EPC contractors and research-based organisations that have need of a wider view. This is due, as pointed out previously, to the time-limited nature of projects that makes it difficult to implement the results of benchmarking in the project under review. Thus the use of benchmarking as an improvement tool is only of practical value in a multi-project environment. The benchmarking approach proposed in this dissertation, that of routine identification and measurement of the core processes in the project life cycle on a

[44] As summarised by the Denning/Shewhart Plan-Do-Check-Act cycle.

[45] For instance the accepted norms and rules of thumb used in estimating are anchored in a background of specific experiences gleaned from specific projects which may not be known to the estimators (in other words the details in the data set from which the typical reference values are derived is not always known to the estimator). Given a problem the estimator must revert to first principles for which there is normally not enough time available. Previous practice, due to lack of systematic data collection, has been the ad hoc collection of experience data from current or recent works without any means of judging the rightness of performance levels – systematic collection and analysis of own and other relevant performance data in a form of continuous performance measurement and BM circumvents this problem by updating the database with projects known to the estimators and which they may have estimated themselves thus enhancing their ability to 'read' the data holistically. Additionally this speaks for the involvement of the estimators in the later life of 'their' projects by participation in the data collection and project review processes.

standardised basis (*performance benchmarking*), leads to identification of processes for review as a result of performance deviation. This may in turn kick off a process comparison with other projects (*process benchmarking*) especially with regard to deviations that are recurrent in several projects. For instance, specific activities or functions may be isolatable as suitable for specific process benchmarking along the lines of practise in the manufacturing and service industries. In such a case one might benefit by parallel review of the same function in several projects as a test of the application of the best practice guidelines by the project management.

Considering the independence and autonomy the project organisations enjoy and the varying nature of the project constraints that often require project specific project management approaches, one might justifiably argue that there are in addition '*competitive*' and '*functional*' elements in the benchmarking of projects using the proposed methods. Since the method provides a standardised set of performance parameters by which to measure performance for all the key processes for all projects, real competitive and functional benchmarking is facilitated, at least in the world of oil and gas offshore modification projects

But internal benchmarking processes have the same shortcomings as continuous improvement processes that rarely look beyond own organisation. Seeking world-class performance by benchmarking of projects in external organisations (e.g. seeking world class partners), the benchmarker is confronted with similar ambiguities. There is no reason why one excellent project should not form the basis of a world class benchmarking review. But the fact that excellence is usually not apparent until the project is complete poses problems for the benchmarker because the organisation will disappear. However, project outcomes can be circumstantial. Accordingly, an organisation's track record, established over several projects, is a better basis for judging capability. Thus world-class performance in projects can really only be judged against a portfolio of projects in the form of consistent good performance. The outcome of such reviews is likely to reflect the portfolio of good practice tools and techniques available to the managers, understanding of critical success factors and the climate of internal communication and experience transfer between projects in the organisation (dissemination of tacit knowledge in communities of practice). From this it must be clear that in the absence of good quantitative performance measurement data across a wide range of projects, it will be practically difficult to select good performers.

By good quantitative performance measurement data is meant absolute measures of actual performance as outlined in earlier chapters. The traditional relative measures of performance are certainly useful indicators for assessing performance at higher orders of aggregation, but are nevertheless deficient in identifying real efficiency. To elaborate, a cost under-run with respect to budget may simply be the result of generous budgeting. Under-run in such a context is not necessarily a sign of good practice. In contrast, an over-run project may, as a result of good management practices, have performed well with respect to the challenges inherent in the overrun context, but it will not be recognised as such if only the relative measures, to exclusion, are considered as selection criteria.

It must be stressed that this review must take a qualitative form. The quantitative format is absolutely essential in order to establish levels of actual performance against norms of performance, but the actual evaluation can only be judged in terms of the project-specific issues confronting the project manager. As a point of departure in a review process aimed at establishing the root cause of performance gaps, quantitative deviations and anomalies in the actual performance in relation to anticipated values point to areas of specific interest for qualitative review of the project-specific issues that gave rise to the deviations.

Finally, benchmarking of projects is a matter of benchmarking the performance of individual managers, the quality and completeness of the best practice portfolio, the ability to apply the available tools and techniques to the problems and challenges of the mandate and the ability to communicate experiences within the community of practice.

6.6 Conclusion

Review of reference literature has exposed limitations with regard to the benchmarking of projects. In the texts of this discussion alternative perspectives have been argued in the form of comments and in the form of an introductory summary. In general this perspective has the following elements:

- individual projects may viewed as a single repetitive cycle in a long term process for the implementation of capital investments that makes extensive use of the project form of organisation
- processes of quantitative performance measurement may facilitate the benchmarking of projects by identifying performance deviations as a point of departure for qualitative review regarding causal effects
- assessment of project success in terms of performance related to qualities of the product in absolute terms
- a set of 'generic' parameters for ongoing quantitative performance measurement with associated metrics as background for benchmarking (specific to modification projects)
- the process owner, and not the individual project must take the role of the benchmarker in a multi-project environment that uses the project form of organisation extensively
- experience transfer between projects is the responsibility of the process owner through the medium of best practice and not the individual project

The rationale has also demonstrated that the alternative approach presented here conforms to the general theory of benchmarking. Case studies have been included that demonstrate applications of the method in practice in Appendices 1 and 2. The case histories also demonstrate that the metrics and the parameter matrix are capable of identifying the locus of deviations, hence providing a focus for further investigation in a way that more aggregate metrics of performance and pure process benchmarking would not be able to achieve.

It has also been demonstrated in other chapters in this document that the metrics of quantitative performance measurement support other project administration activities in an holistic fashion thus ensuring synergies in the data collection processes.

7 PERFORMANCE MEASUREMENT AS AN INSTRUMENT OF EXPERIENCE TRANSFER AND ORGANISATIONAL LEARNING

AN ORGANISATION THEORETICAL PERSPECTIVE

7.1 Introduction

The recurrent schedule and budget overruns which are experienced with all types of construction projects, in spite of the routine nature of the work and the familiarity and experience of the participants both with one another and with the type of work, provides an arena for focus on methods for organisational learning. This chapter will explore, from an organisational theoretical perspective, the insights gained in attempts to promote performance measurement and benchmarking methods for project control and experience transfer in production facility modification work in the oil industry.

The project is seen by many as the modern form of organisation of work suitable for the realisation of major developments of unique one-off nature. Inspired by the success and achievements of such lofty ambitions as the 'man on the moon by the end of the decade' and 'the challenge of the North Sea', the project form of work has become synonymous with innovation and industrial creativity and has become the all-pervasive organisational form for almost any non-routine type of work.

Many industries employ the project organisational form for more mundane one-off tasks that are nevertheless sufficiently large, or complex, or unique as to warrant the use of the project type of organisation. Typical of this is the construction industry that for years employed the project form of organisation, but without capturing the public imagination in the same way as NASA's space program or the earlier days of the oil industry developments in the North Sea have done.

In my company, as an example, the project form of organisation is employed for all forms of construction work from the very smallest modifications (platform maintenance), through individual small, medium and large platform refitting projects combined at times with elements of new field developments, to very large new field developments that command a lot of attention in the national press and indeed national legislature.

The greater number of these projects is relatively mundane, constructing the same type of constructions, involving the same participants both in terms of individuals and companies and generally employing well-known industrial components and manufacturing processes. The central task is to co-ordinate the effort of the individual participants in new but often similar contexts, where the participants are experts in their respective fields. Indeed the greater part of the task is bringing to fruition the concepts conceived, designed and conceptually engineered during the early, primarily creative phases of the project. The work is often of a routine and repetitive, but also often highly skilled, nature. The constraints are generally not conducive to creativity and innovation, which may in fact be actively discouraged, unless the project is confronted with a crisis. Nevertheless, a practical, dynamic, action-oriented, innovative and creative image of the project persists compared to the theoretical, non-action-oriented image of the base organisations.

In spite of the repetitive and cyclic nature of the work, many industries that routinely employ the project form of work organisation often experience random but recurrent problems of schedule and budget overruns even in the more mundane areas of work. These random but recurrent overruns are associated by many with the lack of effective experience transfer between projects as a process of organisational learning from past good performance or mistakes toward improvement of performance in the longer term.

The intent of this chapter is to provide some insights and make some proposals pertaining to this problematic area of experience transfer on the basis of experiences gained with attempts to introduce performance measurement based methods to support project control processes and experience transfer in modification projects in the offshore oil industry.

These experiences and proposals may also be applicable in other areas of project work such as process plant modifications and greenfield oil and gas developments both onshore and offshore.

7.2 Considerations concerning criteria for success

"On time within budget to prescribed quality". This is a relative form of goal-setting that is consistent with the concept of the project as a unique one-off event and is legitimate in the short term of the individual project life cycle. However, in industries that repeatedly use the project form of organisation, the individual project can be seen as a batch in a longer-term multi-project multi-cycle work process. In such a context the levels of production performance in hard terms are of interest as a means to test the efficiency of production and administration methods, as well as contractual strategies, with a view to improvement of performance. The criteria for judging the success of a project gains a new dimension which is more in line with conventional production processes.

The random but recurrent cost and schedule overruns mentioned in the introduction are generally associated with initial under-estimation of the quantities of materials embodied in the works, compounded by the complexity [46] of the work itself, the methods required for installation, the physical constraints of the location of the work and the constraints of the schedule. Particular circumstances may change the relative influence of these variables, where the recognition of and coping with changing circumstances constitutes the main task of the management and the project control functions in the project organisation. This is valid not only with respect to differences of character from project to project (batch-to-batch), but also with respect to changing circumstances within the individual project as it progresses through its life cycle.

Central to this task is to monitor the status of the work with respect to the committed goals. This information constitutes the knowledge basis for control and corrective action by the project management. Experience has shown that the monitoring activities often 'miss' the quantity and complexity changes that occur during the process of concept development and which are recurrent features of overruns. Yet project management is in general slow to adopt alternative methods, such as the performance measurement based project control and benchmarking techniques put forward in this thesis, which have the capability of closing this important knowledge gap. This is in spite of the fact that 'experience transfer' is one of the foremost icons of project management, to which extensive lip service is offered.

This thesis proposes that this phenomenon is rooted in the concept of the project as a unique one-off event where comparison with other projects is deemed of little relevance and that indeed the normative monitoring methods themselves reflect this 'relative-to-itself' control philosophy.

[46] By complexity is meant a more work-hour demanding process as exemplified by the difference in work-hour content between the fabrication and installation of long lengths of straight run piping compared to piping with many bends and short runs of straight pipe.

An odd aspect of the normative perspective is the very uniformity and lack of differentiation in approach irrespective of the special properties of the task at hand. This is inconsistent with the image of uniqueness, especially as regards the ability of the project control methods to isolate the unique aspects of the work so that they may be handled as 'uniquely' as circumstances require.

7.3 The nature of the performance measurement method

The introduction proposes the use of performance measurement techniques to support project control processes both in the short term of the individual project life cycle and in the longer multi-project multi-cycle perspective.

Any measurement system of production efficiency with aspirations to support long-term processes of experience transfer and improvement of project management methods will need to include a qualitative dimension that explicates the hard quantitative measurements of production efficiency. Qualitative methods are however inadequate in themselves. This qualitative/quantitative [47] interplay has the character of benchmarking processes and may be applied internally in the organisation or externally for comparison with external actors.

Both the quantitative and qualitative aspects of benchmarking presuppose the correct identification of the core processes involved in the project life cycle. The greater the complexity of the work, the more challenging the selection of performance parameters sufficient to encompass and highlight the character of the individual project within a framework of generalised applicability to modification work. For information purposes, refer to the table of parameters proposed as suitable for the measurement of most modifications, Table 3-1). The table provides a practical example of the nature of the core processes and hard quantitative forms of production measurement featuring in this discussion.

Central to the proposed benchmarking methods is to measure the development of the concept of each project in terms of the quantities of materials embodied in the works as well as to correlate with planned and actual resource use throughout the project lifecycle. Broken down into core processes and content, these material and resource data constitute a description of both the quantities and the complexity of the work to be performed. Comparison with previous work of similar nature, or possibly interpolation, provides a basis for adjusting the commitment frame (work-hours, cost, time) to changed circumstances. Review of the qualitative aspects of previous work can provide insights as to choice of method and approach to problems of a similar nature. A central point to be made is that the quantitative comparisons provide a pointer to areas of work where qualitative experiences of others may be of relevance. Benchmarking processes are seen as a form of search heuristic [48] with capability of exposing incipient problems before they manifest themselves in other forms (such as schedule stress, delays or excessive resource use) at a later time in the execution cycle of the project, thereby giving project management a longer response time for corrective action before problems become critical.

This approach is supportive of both project control processes specific to an individual project in the short term and experience transfer between projects and the long-term cyclic perspective. In this context estimating is seen as a specialist form of experience transfer as well as a specific form of project control tool.

[47] For the sake of clarity: *quantitative* means the use of numbers to measure performance such as work-hours per tonne while *qualitative* is descriptive in nature, defining circumstances that may have a bearing on the size of the numbers which were calculated from quantitative data.

[48] A heuristic is any principle or device that contributes to the reduction in the average search for a solution

7.4 Experience with implementation

In the preceding introductory descriptions it has been suggested that the conservatism of project administration with respect to changing practice is organisationally grounded and reflected in the modus operandi of the project organisation and endorsed by its greater organisational environment. At the same time, however, the project administration is committed to support the 'icons' of management theory as embodied in corporate goals, such as continuous improvement, experience transfer and organisational learning. This is a potentially conflicting situation.

Through the example of own observations and experiences over several years with implementation of data gathering routines and benchmarking techniques, there are indications of logical discontinuities, deficient 'system' understanding and poor cross-functional coordination on the part of the several actors concerned. This chapter presents a selection of rational anomalies drawn from experiences related to the author's own attempts to gather data and promote benchmarking methods. This theme is very subject-specific and therefore the discussion must of necessity be technically quite detailed at times in order to expose the nature of the anomalies which are embedded in the logic of the work processes under scrutiny. Explanatory footnotes have been provided where found necessary.

In the succeeding sections, and in justification of the methods proposed here, these constraints to organisational learning will be reviewed in the light of the work of several researchers in the field of organisational studies.

7.4.1 Anomalies of behaviour encountered in projects

<u>Anomaly 1 – concerning comparability</u>

Among many modification project practitioners, a view prevails that modification work is too complex and variable to permit meaningful comparison at high orders of aggregation, commonly expressed as '*… comparing apples to pears*….' for instance. This view refers typically to parameters such as NOK/barrel or NOK/tonne, which are used to compare capital investment efficiency between companies, also being used to compare performance between projects. This view is legitimate. Anomalous to that view, it is also commonly held that a simplified set of performance parameters, such as that shown in the Table 3-1, and the principles for data structuring that underpin these parameters are too complex for practical use and too demanding with regard to data collection in terms of work-hours. This opinion is often compounded by the view that *'.... the work will cost what that sort of work costs*….' implying that the results cannot be significantly influenced. This view is depreciative of the role of project control overall and resistive to any forms of measurement of production efficiency.

<u>Anomaly 2 – concerning sufficiency of method despite past failures</u>

Amongst protagonists of project control as a discipline, on the other hand, the standard accepted methods of control are considered to be adequate project control tools in spite of repeated occasions of resource and schedule overrun that must be construable as failure or, at least, insufficiency of method. The method functions through the establishment of relative forms of resource measurement based on the results of detailed engineering through the preparation of detail level task sheets [49], which form part of the detailed planning effort. Control is based on the comparison of actual and planned man-hours with earned man-hours, all work having been converted to planned man-hours, which is the relative basis for comparing status. The planned work-hour accumulations, if deviant from the original

[49] Task sheets are documents detailing the materials, technical documents, fabrication methods and installation procedures, and work-hour estimates related to a specific piece of work and containing sufficient information to support the work in the field.

assumptions, tell nothing of the reasons for the deviation, which may for example be quantity or complexity. The detailed basis for the work has the consequence that the overall fabrication resource requirement cannot be tested quantitatively until the full results of detail engineering are completed. If deviations to the committed values are present, a long period of planning will have been lost and particularly the opportunity to change elements of the design. This view was once aptly rephrased as *'.... once we've done the detailed engineering, we normally have a good handle on the scope….'*. At this stage the average project may have run about 50% of its allotted course and committed about 50% of its budget, due allowance being made for early material purchases. In fact, the overall engineering resource requirement will normally not be tested quantitatively at all by the standard approach, the consequence being that engineering effort can only be influenced by hindsight of failed performance. This is unfortunate in view of the criticality of timely engineering activity for successful project execution.

It may be added that the successful completion of projects that do not experience growth is not necessarily a result of the sufficiency of the monitoring systems. This is borne out by the fact that examination in hard terms of the final results of some projects which were generally considered to be a success, has at times revealed poor levels of performance. The opposite has also been experienced, namely that projects that were judged to have been difficult, were found to have performed well in the final result. But failure to predict the outcome in cases where growth does occur, is most likely to be a failure of method.

There are, of course, situations other than growth that create problems for management, but uncertainty regarding the man-hour frame is a recurrent dilemma. These different types of situation have been addressed in the texts of the previous chapters and in the case studies of Appendix 1 and 2.

Anomaly 3 – concerning the accuracy of cost and work-hour estimates based on weight estimates

The above perspective is mirrored in the objection brought to bear by many contractors, and through them by the owner's personnel, that there is an inadequate technical basis for making the weight reports, which are central to the benchmarking process, until the detailed engineering process is complete. This promotes doubt concerning the accuracy of the estimates that can be made from this source. Overlooked, however, is the fact that MTOs, for the purposes of initiating material purchases, must be, and are, prepared well before completion of the detailed engineering. Similarly structural analysis requires definition of the structural loadings embodied in the new installations. Both processes are based on preliminary quantity take-offs requiring iteration as detail engineering proceeds.

If the above argument were true, weight estimates stemming from the technical basis of earlier studies would be even more prone to inaccuracy. Weight estimates are of course the basis of the project conceptual study estimates, made in an earlier phase of the development cycle, and often by the same contractor. These conceptual study estimates are the basis of the owner's commitment and the master control estimate defining the project's cost, schedule and work-hour goals, which are fundamental to the monitoring effort. By the above argument, the control foundation of the entire project is based on an inadequate premise.

The discontinuity of insight and method implied by these arguments is often attributed to the differences in attitude resulting from organisational separation. The people as well as the organisation doing the conceptual engineering in the contractor's organisation are not the same people and organisation doing the project detailed engineering and fabrication, which provides an argument in support of the need for experience transfer.

Anomaly 4 – concerning cross-functional alignment of common processes

From the above it is evident that the weight reporting requirements seen from a technical point of view are different to the requirements of weight reporting seen in a project control and procurement point of view. Technical personnel often make issue with the degree of detail required. Typically, being small items, the electrical and instrument materials have little impact on the structural loadings and are therefore often neglected. The same applies to small valves and small bore piping. However, the installation of these small weights is highly work-hour demanding and accurate estimation is impossible in the absence of precision in defining the quantities involved. Clearly, a higher degree of precision is required to provide weight data intended for project control purposes and estimating. Again, the presence of such anomalies between different functions in the same organisation supports the argument for experience transfer.

Anomaly 5 – more concerning the accuracy of estimates

Regarding the accuracy of estimates derived from weight reports, it is of interest to note that as part of the standard budget control effort, the scope of the committed contracts is normally adjusted for additions to the contractual scope of work. These additions are normally very poorly defined and the estimates are correspondingly of low accuracy. The net result is normally inflation in the contract incentive mechanisms (target cost for example) due to the large risk content included in the additions. However, the budget coverage of the total labour scope is not verified in the update processes by monitoring growth of quantities of materials. Paradoxically, better quality estimates of the development of the total scope based on total material quantities that can be defined from the ongoing detailed engineering by the weight estimating specialists in the contractor organisation, are considered superfluous to the standard methods.

Anomaly 6 – more concerning sufficiency of method despite past failures

Experienced personnel, both base and project, resort to essentially three arguments when attempting to account for the overrun deviations and identify action to remedy the problem: firstly, deficient estimating practices, calling for improvement of methods, secondly, poor concept definition, calling for better quality engineering in early-phase work, and thirdly, additions to scope which are not included in the project budgets, calling for better change control.

This evokes the response on the part of many actors (normally non-estimators) that the estimating practices are good enough given that the concept is well enough defined in the form of the input to the estimates. In short, if the weights are right then the estimate is usually right. The argument has the intent of calling for more front-end engineering, but has the effect of diminishing the estimating perspectives brought to bear on the problem such as the monitoring of the concept development (weight development) itself in a format suitable for estimating. The alternative is seen as simply to do more engineering, but for this there is no guarantee as to the quality of the work performed. Unfortunately, and paradoxically, the effect of this argument, while implicitly consistent with the monitoring principle of control, does not endorse the use of weight estimating skills as a technical discipline for the purpose of improving the quality of the periodic updates. In the performance measurement approach proposed here this potential concept deficiency is recognised as a recurrent problem related to quality of the study work, complexity of concept, and so on, for which there is no certain remedy and for which reason it is deemed prudent to institute control mechanisms as part of the standard package of project control tools. The techniques also provide a basis for coping with the quantity and complexity changes embodied in the third argument above.

Anomaly 7 – concerning 'explaining away' the lack of response to improvement proposals

There is normally no lack of agreement amongst project managers regarding the need for experience data from completed projects in the light of the uncertainty associated with quality and maturity of the concept, which it is their task to build.

Yet the same managers often display a consistent reluctance to institute routines that monitor the development of the concept. Examples of the reasoning for not adopting such practices are:

- project control and engineering resources should have priority to work on the periodic cost and schedule adjustment
- updating of weight estimates will disturb the work of engineering at a critical stage
- the costs of performing the work are too high
- the requested data will be part of the close-out report

The terminal point endorses the point made earlier that comparison with other projects is often seen as having little relevance to the work at hand. Of no avail the argument that updated weight estimates provide a better basis to support the periodic updates. Of no avail the fact that engineering personnel must in any event give their timely input in the form of materials estimates in order to support the procurement of materials program or cause fabrication delay. Reduction of the number of weight estimate updates will only have a marginal effect since the task is normally part of the agreed scope of work, at least for the purposes of providing MTOs and supporting structural analyses. Overlooked are the added synergy values achieved by extending the use and range of application of work which must be carried out anyway.

Anomaly 8 – concerning the help potential of experience data

Many managers do not support the gathering of experience data, simply not believing in its potential. Justification for this attitude is that in the past the custodians of experience data have not been able to offer any help when problems arose. This is a self-predictive loop reflecting on the poor quality of data, which follows as a consequence of the scepticism and corresponding lack of support for data gathering in the first instance. The view is understandable though, since the efforts to accumulate performance data have generally been sporadic in the past, based on individual effort and as such are not organisational in nature.

It must be added that initially the problem of non-support was related to the collection of close-out data with the express purpose of accumulating insight into the actual performance achievements as a basis for improving estimate quality. In such circumstances the solution suggested was to include the reporting requirements in the contracts, thereby binding both the company's and the contractor's project organisations. However, the reporting requirements have subsequently been incorporated in the contracts as part of the periodic updates, but the data collection situation has remained substantially the same.

All in all then, it would seem that, in general, not much credence is placed on the value of experience transfer from other work. Evidently, each project is seen as a unique isolated event where experience from other work is deemed to be without relevance. Alternatively, the effort required to establish comparability is too complex and presumed not value-additive. However, even though the literature often portrays the project as a unique working environment especially suited to the production of one-offs, in the oil industry projects are by no means unique. Projects are in fact a standard method of working involving specialist personnel of whom many seldom or never work in any other environment. The nature of the work is cyclic, but involves the same basic procedures and well-known industrial processes, especially during the execution phase. Under such circumstances there ought to be room for a greater degree of systematic measurement of production performance in order to accumulate data from project work seen as a cyclic process and the systematic use of the type of quantitative/qualitative analysis outlined here as a basis for cross-project experience exchange and improved project control.

Unfortunately, just as the method of working is standardised, a basic set of problems is also repeatedly encountered, either alone or, in extreme cases, all together. The problems very often have a character stemming from the underestimation of the quantities of materials and complexity of the work such as:

- delayed engineering documents
- late ordering, pressed delivery lead time, late delivery and often increased acceleration cost of materials
- tight delivery lead time for prefabricata offshore
- incorrect prefabricata resulting in clashes and rework
- low materials buffer offshore with resultant waiting time or inefficient sequencing of work operations
- increased offshore bed requirements

And so on, which may be due to undermanning, due in turn to unseen underestimated volumes or changed complexity, which can appear in many different guises not immediately relatable to underestimation. Times of stress often compound the situation and are not conducive to encouraging the increased insights that comparative performance measurement based analyses can provide.

This thesis contends that these sporadic but recurrent failures can often be traced back to inadequate project control practices arising from misconceptions of project uniqueness, in turn aggravated by the type of fatalism or project control method conservatism mentioned above, and compounded by a poor ability to learn from past experience.

7.4.2 Anomalies of behaviour stemming from the project environment

So far only the anomalies arising out of the attitudes of the project personnel have been described, but there are several anomalies influencing project attitudes stemming from the organisational environment in which the projects operate.

It is not to be denied that the pace and pressure of project work, compounded by the short-term goals and constraints of contractual incentive mechanisms, are not conducive to the introduction of new methods. All project organisations operate in an organisational context of several actors, all with differing spheres of interest that exercise pressure on the project. The organisational context consists of the project and some sort of base organisation that is usually the repository of the theoretical method basis for the planning and administrative processes and methods to be used by the project organisation. The organisational context usually also includes the operator's line organisation that commissions the works (on behalf of the asset owners) and the contractor's line organisation that is responsible for the empowerment of the contractor's project organisation. In the peripheries, but not without influence, are the license partners and their line and base organisations, and the authorities. All parties have a financial stake in the project and accordingly an interest in project performance. Of these it is the base organisations, rather than the projects, that are the natural locus of longer-term multi-project performance monitoring and analysis aimed at improvement, being as they are the repositories of *best practice*. This sort of activity is not part of the natural task of the project in view of the limited life-span and the nature of the project's mandate. But there are generally no such programs in the base organisations [50]. It would seem that the base organisations, as well as the projects, bear some measure of responsibility for the enduring inconsistencies and discontinuities described above.

The dialogue with these base organisations has similarities with the dialogue with project teams as discussed previously. The base organisations may indeed be the source of some of the arguments, bearing in mind that the base organisations are the repositories of *best practice*, and noting that benchmarking has currently only a superficial role as a project control tool in a post-project context. Of course, there may be aspects of entrenched interests within the base organisations where new methods come into conflict with established ones, which have not been drawn into the discussions so far. Similarly, there are actors within project teams that are not necessarily interested in encouraging a greater degree of insight into project performance, both during execution and after completion and especially in cases of overrun.

Another aspect that complicates the issue as far as projects are concerned, is the lack of a standard format for the recording and reporting of data. Projects are often subject to requests for data and reports of different nature from various outside actors. These requests are often experienced as disruptive to the ongoing effort of 'getting on with the job' and are therefore resisted. A greater overall utility in the practice of project control could be achieved were a common format to be adopted for all the project control activities that are applied at various stages of the project life cycle. All too often are the structures of compensation formats in contracts, project control reporting and prognostication and budgeting/accounting formulated differently from project to project and indeed within the same project, based arbitrarily on the narrow interests which accord with the prevailing philosophy of the particular profession or person having responsibility for formulating the documents. The essential comparability of data, which is the essence of the methods presented in this paper, is thus made unduly difficult. The differences are often to all appearances small, but may nevertheless be significant enough to cause uncertainty and force tedious conversion of format. The lack of consistency in these reporting structures is a manifestation of poor cross-functional alignment between different departments in the base organisations.

An odd aspect of the normative perspective to project management is the very uniformity and lack of differentiation in approach irrespective of the type of work and special properties of the task at hand. This is inconsistent with the image of uniqueness, especially as regards the ability of the project control methods to isolate the unique aspects of the work so that they may be identified and handled by management as 'uniquely' as circumstances might require. Review of the literature has not revealed exactly how, or by what methods, this capability to handle uniqueness is to be achieved, neither in the form of general principles of method nor in particular routines aimed at specific types of work.

In the face of conflicting standards and formats, and the resulting duplication of effort in conforming to reporting requirements, and not recognising an own utility in the recycling practices embodied in a benchmarking approach, the project's motivation to contribute data and align its own methods is undermined, and thereby the whole cycle in the longer term. The situation is compounded by unclear philosophy, lack of endorsement embodied in *best practice* and the fact that improvement of method is alien to the project's modus operandi, being inconsistent with the temporary nature of the organisation and its task, which is to build.

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[50] The base organisations have various types of review processes, but for the time being benchmarking methods have only been conceded a peripheral role in the procedures of *best practice,* but only in applications with a high order of aggregation which have little relation to the detailed processes of project control.

Thus it behoves organisational units outside the project to provide the necessary coordination between functional units and across contractual boundaries. This is to ensure good alignment between the parameters and formats of the general performance data, and the monitoring interests of the project and the other actors operating in the project environment. In addition, they will also have to provide the incentives that are obviously necessary to encourage the adoption of improved work methods in the administration of projects.

The intent of this section has been to provide evidence, through the example of own observations and experiences with implementation over several years, of logical discontinuities, poor system understanding and poor cross-functional coordination on the part of the several actors concerned.

In the succeeding sections these constraints to organisational learning and justification of the methods proposed here will be reviewed in the light of the work of several researchers in the field of organisational studies.

7.5 Congruence with organisation theory

The task at hand is then to explore the reasons underlying recurrent cost and schedule overruns and poor ability to transfer and translate this experience into insights and preventative routines to improve project performance in the longer term. The reason for these overruns is often underestimation of the quantities of materials embodied in the product coupled with poor routines for monitoring these parameters as the design work proceeds. The proposed remedy is the implementation of routine cycles of performance measurement in the form of an internal benchmarking practice utilising the parameter set presented in Table 3-1, which is based on the core processes pertaining to modification work. This measurement program should furthermore be performed as part of the periodic review of the project's resource basis with respect to the amount and nature of the work to be done and should include measurement of the properties of the product in the form of weight estimates. Finally the project history of performance, as defined in terms of the sanction estimates, periodic updates and the final result, should form the basis of a quantitative/qualitative close-out review with the intent to gather relevant experiences regarding methods, procedure and actual production efficiency for use in later projects. To facilitate this process, interaction by representatives of the base organisation with the project team should be routinised, preferably in the context of the periodic updates, in order that the representatives gain insight into the nature of the problems confronted by the project. This is inter-action is important since the base organisation is the repository of the recommended methods taken into use by the projects.

In the following sections the following central aspects of this proposal will be explored in the light of research performed by organisational theorists:

- the measurement of production efficiency and properties of the concept
- the normative approach to project control
- ambiguity or clarity?
- routinisation of practise
- data gathering
- method of measurement
- organisational learning and experience transfer
- the constraints of governance networks
- more about the relative method of monitoring: information technology

7.5.1 Measurement of production efficiency and properties of the concept

In the introduction the nature of the work was described as routine and repetitive employing well-known industrial techniques and suggesting a likeness to a batch process of manufacturing, albeit on a large scale both physically and in time. This was in contrast to the prevailing image of the one-off nature of the project, which promotes the view that performance comparison is invalid due to the unique nature of each project.

The central issue here is to find means to better monitor and predict the outcome of projects. The wider context of this control is to minimise the capital cost outlay of process improvements, which is what modification projects essentially are about, also, in addition, to increase the utilisation of existing infrastructure such as tie-backs of satellite fields. This is the core competence of the modification practitioner; to use the mechanical industry in petroleum related engineering and fabrication as a tool to produce cost-effective improvements in the oil and gas production process.

James M Utterback has studied the dynamics of industrial development in a wide range of industries (ref Utterback: *Mastering the Dynamics of Innovation, 1994)* particularly the '*role of innovation in industrial competition*' and '*the relationship between product and process innovation in the cycle of industry development with special attention to the differences between assembled products and non-assembled products*'. The terms *assembled* and *non-assembled* relate in the context of this paper to modification projects and oil and gas production respectively. Utterback concludes that '*leadership in incremental improvement requires persistence in measuring product and process performance and in seeking improvement from any source*'.

In the Abernathy-Utterback model of the dynamics of innovation, the major area for improvement of *non-assembled* production lies in process improvement rather than product innovation and particularly so in mature industries with a sophisticated production apparatus. Oil and gas production fits neatly into this generalisation. There are, however, also other mechanisms driving the need to improve and modify, primarily the changing functional requirements as a reservoir is depleted, but also the effective utilisation of existing infrastructure. Suffice to say that the general characteristic of continuous process modifications in the findings of Utterback is that they are costly. Thus it is appropriate for the modification practitioner to pursue methods that minimise the capital cost of these improvements.

The project can of course be seen simply as a construction phase in a longer process that starts with a perceived need for infra-structural development and ends in a modification of the production systems. In this wider context process innovation, in the sense of improvement of production processes or extended utilisation of existing infrastructure, is indeed a major concern and has a great bearing on the economic survival of the company. It should be noted that this aspect of company behaviour can be said to be in tune with the Abernathy-Utterback model, should one judge by the considerable effort and resources spent internally and externally on continuous efforts to achieve production improvement. These extend to research sponsorship and even the establishment of independent industries that develop the technologies resulting from that research. The production efficiency is monitored over time and the effort is observed to bear fruit in the form of lower production costs.

It has been commented earlier that the construction phase does not enjoy the same dynamic focus on improvement of method as do the production units of the organisation, although the findings of Utterback apply equally to *assembled* products as *non-assembled* products. This is borne out by previous observations regarding both the lack of routine for performance measurement and the lack of support for performance measurement processes, since it is only by virtue of an independent and objective measurement that any form of continuous evaluation can be sustained.

The theory of Utterbach does not translate completely, however, when applied to the construction phase of the process improvement. The nature of the work has been likened to batch processes of *assembled-product* type, potentially on a grand scale. This type of work does not fit well within the Abernathy-Utterback model. The model is based on the manufacture of specific products such as automobiles, which pass through an industrial development cycle where the competitive advantage is characterised by high product diversity in an innovative (*fluid)* phase succeeded by convergence *(transition phase)* to one more-or-less standard (*specific phase*) design constituting a *dominant technology*. The manufacturing processes in the early *fluid phase* are general-purpose, relying on a large component of skill on the part of the workers, and are entrepreneurial in nature. At later phases the manufacturing processes become progressively purpose-built and automated, centred around a specific product or product range [51]. The fluid phase fits best with the type of work dealt with in this chapter, but the work has no product diversity similar to that of the model. In fact the product is a purpose-built design to fit specific functional requirements (such as a process plant), which by its very nature cannot rely on highly automated forms of production. The competitive advantage lies in knowledge (technical and organisational) of the industrial sub-components and the techniques for engineering, fabricating and assembling them into the final product in the most cost-effective manner. It is this knowledge that constitutes the skill base of the project personnel as individuals and the project team as an organisation.

This is not to deny that technically innovative products are incorporated in the work scope of projects, but rather to say that product development and innovation in the form of individual components will have taken place in other sectors of industry and is not the concern of the project. Similarly the development of the specific concept will have taken place in earlier phases of the project where the essential technological character of the specific concept will have been defined in the form of functional criteria, a basic architecture and construction philosophy. By and large then, in spite of the final project being purpose-built and of a rather unique nature, the component materials will be well known products of industry, taking the form of standardised whole- and half fabricata. Similarly, the methods of fabrication are well-known, of a general purpose nature and highly skilled, but nevertheless routine.

This implies a focus in an improvement context on both product (as a whole) and process since the dynamic relationship between product and process is not likely to shift dramatically over time as it does with specific product manufacture. Industries of this type will locate in the Abernathy-Utterback model somewhere in the region of *fluid* to *transitional* phase. Thus, in order to optimise construction time and costs and consistent with Utterback's general statement regarding competitive advantage, there ought to be a company focus on the methods and processes employed in the managing of capital projects. One might expect some form of objective performance measurement testing the efficacy of the methods and techniques involved - not so however - there are substantially no measurement routines in place looking beyond the life cycle of the individual project. This is the primary reason for proposing internal benchmarking practices as an essential element towards satisfying Utterbach's criteria for establishing a climate of reflection and innovation essential to organisational success in the long term.

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[51] The closest analogous type of industry is that of shipbuilding, where some yards have developed an almost production-line method of manufacture. But experience has shown that highly complex purpose-built production vessels do not fit easily into conventional ship building processes.

7.5.2 The normative approach to project control

So far the discussion has promoted the use of performance measurement based benchmarking techniques as an aid to experience transfer and organisational learning in a project environment. The techniques constitute specifically a project control method improvement aimed at reducing overruns, but have also a general relevance for other activities and tools employed in the administration of projects. Benchmarking techniques are a combination of qualitative and quantitative analysis of project performance, hard production measurement preceding soft qualitative analysis in order to identify method and practice anomalies causing good or poor performance. Central to the benchmarking concept is the comparison of performance with other projects. The contrast here is the view of the project as one-off unique type of work to which it is inappropriate to apply experience from previous work of similar character. The latter view is normative and is reflected in the general nature of the project's modus operandi with respect to the task at hand, in interaction with the other actors in the operational environment and particularly in the relative nature of the control methods which are employed to monitor the task.

The following definition of a project is found in the *Guide to the Project Management Body of Knowledge* published by the PMI Standards Committee (PMI, 1996) - '*a project is a temporary endeavour undertaken to create a unique product or service*'. The characteristics that are normative to the project in this definition, and which have a bearing on this discussion, are the <u>temporary</u> nature of the organisation, which is disbanded when the project's objectives have been achieved, and the specific nature of the project's objectives, to create a <u>unique</u> product or service, which is '*different in some distinguishing way from all similar products or services*'. This applies to all types of work in all sectors of industry. The project modus operandi that emerges from this is that of '*progressive elaboration of product characteristics*' combined with '*careful coordination with project scope definition*'. When properly defined '*the scope of the project should remain constant even while product characteristics are progressively elaborated*'.

In contrast to the quoted defintion, the suggestion of this thesis is that in organisations that regularly use the project form of organisation there are similarities from job to job which resemble batch production rather than totally unique events. These similarities encompass the elaboration and control processes, the materials, the fabrication processes, the actors and the personnel manning the project teams. This nuance is referred to as *management by project* in the PMI Guide. Organisations conforming to this model often have an organisational structure consisting of highly autonomous project teams backed by service departments (base organisation) and project management systems aligned with financial systems often designed for accounting, tracking and reporting on multiple simultaneous projects. In this context it would seem that the similarities between individual projects exceed the uniqueness. This circumstance is conducive to the use of production measurement metrics that are similar to ongoing production processes and the use of the comparative functionality of benchmarking techniques in support of the project management task. The normative approach of relative goals can be supplemented by absolute hard production measurement goals consistent with the characteristics of the product. But a prerequisite for this is the capability of mapping the product characteristics in appropriate metrics.

7.5.3 Ambiguity or clarity as project execution strategy

The above is an argument to play down the uniqueness aspect of the project in the interests of comparability with similar work for the purposes of reducing uncertainty. In contrast, Sahlin-Andersens case-study (ref. Chap 4 in Brunsson and Olsen, Organising Organisations, 1998) of the Stockholm Globe suggests circumstances whereby playing up the uniqueness of the project may be an appropriate strategy for the realisation of projects. This strategy is coined the ambiguity strategy as opposed to the clarity strategy of normative project management and suggests that stressing the opportunities present in an extraordinary situation can attract interest and achieve commitment also in the absence of a committed frame. The pursuit of an ambiguity strategy has a price, however, which is potentially losing control of the outcome of the project.

In contrast, pursuit of the clarity strategy is said to play down the uniqueness of the project in the interests of minimising complexity and ambiguity in order to foster an image of a purposeful organisation pursuing a programd plan of action, i.e. play down risk. The project's goals are to be established as early as possible and are assumed thereafter to remain the same. Opportunity for new actors to pursue their own special interest is lost in such a scenario because the normative project strategy is geared to avoid changes. In the ambiguity strategy, however, the frames of commitment will have to be established at some point in time, if for no other purpose than establishing a financial basis for the detailed engineering and construction activities. The project will be forced to move to a clarifying strategy for no other reason than to maintain a flow of funds. Sahlin-Andersen says that '*the clarity model tends to ignore that many complexities and ambiguities cannot be solved*' emphasizing that '*ambiguity and complexity cannot be organised away but have to be handled*' quoting March and Olsen (1976), Brunsson (1989) and Sahlin-Andersen (1986) in support.

From the point of view of this dissertation, there need be no contradiction between the clarifying strategy and living with change if appropriate methods are adopted in the control strategy for mapping the effect of changes in the product characteristics. It is the normative assumption of no changes to the frame of commitment that is the constraint, prompting a behavioural response that shuns change. All projects will be subject to a degree of concept uncertainty. Uncertainty will inevitably be experienced with respect to potential changes to the nature of the product as a consequence of the process of progressive elaboration irrespective of the existence of programmed changes or not. All projects will have some degree of uniqueness – it is in the processes of progressive elaboration that the degree of uniqueness is defined (clarified) and appropriate action taken to accommodate any 'special'qualities the project may have in the execution plans. Ambiguity is an aspect of this uncertainty regarding the need for and the nature of decisions that have to be made in order to create a program for completion. Projects pursuing an ambiguity strategy for purposes of maintaining a window of opportunity should most certainly implement monitoring methods that are capable of mapping the characteristics of the product on an ongoing basis in order to minimise the risk of loss of control.

With regard to maintaining windows of opportunity, one of the observations stemming from the case study in Appendix 2 is that the approval processes preceding sanction of execution may on occasion drag out while individual stakeholders are pursuing their internal interests. In the case in question, these delays were not accompanied by adjustment of the milestones. It is presumed that the resulting schedule pressure was in large measure responsible for the final poor outcome.

Modification projects in the oil industry are known to be especially subject to growth and change. Eide's study of changes in modification work (Eide, 1998) emphasises that change is inevitable and often beneficial and that the handling of changes should be built into the control strategy. Change is anathema to the project managers in her study. She maintains that the most important constraint is the belief that the commitment frame is sacrosanct and that the presence of changes in a project is synonymous with failure, whether beneficial for the final result or not. This is a judgement based exclusively on performance relative to the original frame of commitment. A control strategy that maintains flexibility with respect to the original plans will be able to maintain a 'window of opportunity' for the project management to cope with situations that arise as the process of progressive elaboration defines ever more precisely the nature of the product and the correctness (or otherwise) of the original plan.

This dissertation has suggested that the modus operandi of the normative project organisation is determined by the concept of uniqueness of the project, playing up uniqueness rather than playing it down. In contradiction to Sahlin-Andersen's view, comparison with other work is not a part of the normative control strategy. As pointed out in the section on experiences with implementation in this chapter, many modification practitioners do not believe that comparisons can be made between projects for the simple reason that the projects are too different, they reject comparison at high degrees of aggregation as being non-representative and they reject comparison of individual functions as being too complex. The normative methods of control are relative to the established plan. Projects do not pursue performance goals based on any relation to external standards of production efficiency and such methods are absent from the general body of knowledge. This points to the (mis)conception of each project as being unique.

In contrast, or rather in spite of the perceived uniqueness of the individual project, one can in fact observe that all projects are managed in much the same way. This is a consequence of the established project management body of knowledge espoused by the community of practice. But as previously mentioned, the explicit means of handling uniqueness is neither addressed in principle, nor specifically, in the established body of knowledge.

7.5.4 Routinisation of practise as the project modus operandi

In their work *An Evolutionary Theory of Economic Change* (Nelson, Winter, 1982), Nelson and Winter present an alternative theory of the capabilities and behaviour of business firms operating in a market environment when confronted with phenomena of economic change stemming from changed market conditions, economic growth and competition through innovation.

According to Nelson and Winter, an organisation's knowledge base is embodied in the skills of the individuals comprising that organisation as co-ordinated in the routines of the organisation. Nelson and Winter maintain that this model has relevance for organisations performing work with a high frequency of repetition on a daily basis. Most projects are involved in production by design, which in the case of modification projects may be seen as purpose-built large-scale assembled products, and naturally have a long cycle of repetition. Does this mean that routines as a repository of an organisation's knowledge have no relevance for project work? On the contrary, since all projects are managed in much the same way, one may argue that routinisation is a significant element of project's modus operandi especially in project based organisations, whereby a team may be mobilised and become functional in a short space of time. However, at the same time this very routinisation has significant responsibility for the behaviour of the community of practice and thereby the individual project and accordingly is a contributory cause to the difficulties associated with the adoption of new methods and experience transfer.

Nelson and Winter specifically limit the applicability of their models to organisations performing repetitive routines with high regularity, although acknowledging that the notion of routine behaviour does have application even with respect to the highly sophisticated and complex creative or problem-solving activities performed by engineers, scientists and management. The project is in this context much of a one-off having generally a low repeatability of routine. This low repeatability needs to be compensated by a higher degree of coordination of effort, supported by written procedures of practice (or *blueprints* [52]) . But the

[52] Blueprint: in this context seen as a formal procedure describing the essential elements for performing a task

functions concerning project control do have a highly repetitive cycle varying from weekly and monthly to bi-annually and of course the indeterminate length of the project life cycle from one to five or more years. In any event project personnel will normally experience several project life cycles and within each phase of the work many repetitions of the same activities in the handling of detail - accordingly, the general precepts of routinisation of skills can be regarded as applicable.

Of perhaps greater interest, seen in the context of the batch nature of the project life cycle, is the way the setting up of new project teams can be paralleled with the setting up of new plants. In establishing a project team, aspects of *replication* [53] are of importance, the normal focus being to establish a working organisation from a new set of personnel as quickly as possible, which implies a focus on experienced personnel of whom can be expected the routinisation of the necessary skills and competencies. Organisational shake-down, often taking the form of team-building seminars, is a front-end activity in which a central aspect is the establishment of procedures of practice, domains of responsibility and interface definitions. All these find their parallels in Nelson and Winter in the form of for example *truce* [54], *control* [55] and *optimisation* [56]. The long cycle of routine repetition and associated rustiness of routine is accommodated by the establishment of procedures to assist the memories of the individuals and the organisation. The procedures are generally of an outline character and in no way substitute for experience derived from 'having done' that lies in previous practice. This previous practice, however, involves the tacit knowledge of individuals acquired in practice and often involves deviant routines only broadly conforming to the recommended procedures of practice.

So, it may be concluded that the theories of Nelson and Winter are applicable in the project work context and can be used to explore the anomalies of behaviour and constraints to organisational learning already pointed to in the chapter *Experiences with implementation*. In this the nature of the project's task and mandate is central, as is the way this is reflected in the organisational focus and in the interrelation and overlap of individual tasks and skills. The following key issues may be deduced:

- procedures of practice (*best practice*) are needed to underpin the practice of project administration due to the long repetition cycle of the work seen as a whole
- the project focus for the purposes of establishing functioning organisational routine quickly and efficiently at the start of a project relies on using skilled and experienced personnel routinised to project work and in the practice of their own skills
- the setting up of new project teams is essentially *replicative* in nature and is implicitly inhibitive of debate concerning method leading in turn to copy-and-paste methods of establishing work procedures
- project work involves a wide range of skills beyond the knowledge base of individuals, and organisational failure to meet its goals does not necessarily imply individual performance failure, practise being anchored in *best practice* procedures and endorsed by internal control
- the project has no responsibility for *best practice,* which is located in the base organisation

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53 Replication: the process of creating a new organisation in a new location, say a new plant, to perform the same task as an existing organisation

54 Truce: the tacit understanding between individuals in an organisation controlling performance of duties and the interface between functions; the rules of behaviour in organisational culture

55 Control: the process of ensuring conformance to a routine through *monitoring, (re)selection* or *adaptation*

56 Optimisation: the processes and routines employed in decision making with the intent to maximise the outcome of an activity

- the concept of *best practice* has the aura of closure over it as long as there are no arenas or procedures questioning and debating method involving project performance
- project autonomy and lack of dialogue between the base organisation and the project promotes different cultures within the community of practice, i.e. between the project and the base organisation, due to the fact that project personnel work more or less continuously in projects and that their relation to the base organisations is often that of a personnel pool
- the basis for decision making, or exercise of choice, is routinised in the procedures; the main function of management is coordination of effort
- the knowledge base for coordinative action by management lies in the tacit knowledge of the skilled individuals who perform the complex technical tasks involved in progressive elaboration of the product and constitutes a challenge of oversight to management and project control functions

Thus the project modus operandi endures as a consequence of *replication,* being transferred more or less intact from project to project in a way congruent with the batch nature of the task and part of an ongoing long-term multi-cycle industrial practice. This can be done only because there is great similarity between the batches and therefore in the way of performing the tasks.

Of central concern in most discussions of organisational structure is the way in which the work methods may influence the effects of bounded rationality (March, Simon, 1958) [57] in the decision making processes. Nelson and Winter reflect that for organisations like the project, which rely extensively and more than most on the knowledge base of highly skilled individuals, much of the problem lies in '…*reconciling an exhaustive account of the details with a coherent view of the whole. Much more severe limits on the articulation of organisational knowledge arise from the same cause, because although attending to details is something that can be shared and decentralised, the task of achieving a coherent view of the whole is not. Similarly, improvisation of a coordinated response from a system requires a centralised control of the system. Organisations are poor at improvising coordinated responses to novel situations; an individual lacking skills appropriate to the situation may respond awkwardly; an organisation lacking appropriate routines may not respond at all'.*

Nelson and Winter suggest that one way in which the routine functioning of an organisation can contribute to innovation is that useful questions arise out of anomalies relating to prevailing routines (ref. Chapter 3-9 and the Case Studies in the Appendix). Applied to a project environment, this means that anomalies will be experienced perhaps once in a project lifetime, providing no opportunity or perhaps even need to resolve the anomaly for the purposes of meeting the project's objectives. Action taken to handle problems may provide the basis for an alternative routine, but will in any event only be testable in terms of the final result. The central anomaly by which all projects are tested in terms of the normative routines, that of non-conformance to the prescribed commitment frame, will normally only be testable in terms of the final result. However, at this point many of the participants, whose detailed knowledge of the concept and the work processes may provide the insights necessary to resolve the issue, may already have demobilised. It is possible to conceive that continuity may be assured through the experiences of individuals mobilising into new projects, but this is highly unlikely for the reasons outlined in the above.

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[57] The term *bounded rationality* reflects the deficiencies in the knowledge on which decisions are based. The concept reflects upon the presumed rational basis for optimal decision making presuming real choice of alternatives arising out of full knowledge of the situation at hand. This concept is attributed to March and Simon. They comment in the preface to the second edition that the concept of *bounded rationality* has become '*the received doctrine'* and *' more or less standard in modern theories of decision making* ', and is thus a central concept to the theories of the working of organisations.

It follows then that the continuity will only be assured in some other organisational context with a longer horizon, and with a mandate to implement changes in the recommended procedures, which serve as guidelines for the routines brought into new projects. The natural locus of this continuity is the base organisations, which are the repositories of *best practice*, and to which the projects are expected to conform. Nelson and Winter see this as a typical pattern where a crisis or exception condition in one part of an organisation is part of the routine content of jobs of other personnel. Problem solving efforts that are initiated with the existing routines as a target, may lead to innovation instead. On the strength of these observations, it is not unreasonable to conclude that the base organisation should have a shared responsibility to recycle experience gained in resolving anomalies in the work routines. Any routine intended to promote dialogue, experience transfer and organisational learning ought ideally to actively involve both the base organisation for continuity, method responsibility and analysis and the project team as a practitioner of method in the face of the reality of active project work.

Nelson and Winter advocate application of the theory of heuristic search to issues of improvement and innovation, suggesting that also these activities have routine nature. In a similar manner, the processes of benchmarking and performance review may be appropriate to the analysis of anomalies of performance, hopefully leading to insights that may provide the basis for reflective dialogue and improvement.

7.5.5 Data gathering

The data gathering and codification processes that underpin all science, as described by Latour in his book *Science in Action* (Latour,1987), may be seen as analogous to continual internal benchmarking processes based on reduction of product complexity to a set of generally applicable parameters representing the core production processes and central characteristics of the modification product. The test is the applicability of past experiences to current and future work of similar nature. In accordance with Latour, the data gathering and codification processes are understood to include engineering, technology, the administration sciences (project management), law (the contractual arrangement), economics, and so on.

The accumulation of experience data is a demanding process. Numerous proposals for cataloguing the results of experience using database technology have in fact been launched, but few have survived. This failure is possibly due to the sheer complexity of the task of cataloguing qualitative data in a way that is meaningful to others. Eide points to other studies [58] concluding that '*experience is tacit knowledge and questioning whether experience can be handled using information technology'* and further noting a general preference for '*informal and adaptable communication patterns when exchanging information rather than formal documents, reports and computer archives'* and *'informal channels and participatory approaches addressing tacit knowledge were clearly preferred to formalisation and information processing focusing on explicit knowledge'*.

Given these conclusions one may consider the following questions relating to the compilation of an experience database. What criteria will be used to decide which experiences are to be stored? How will the experiences be categorised – in terms of problem descriptions or solutions? Who will perform the storage and extraction tasks? In what format will the experiences be recorded - qualitative/descriptive or quantitative formats? Perhaps most important; how will the experiences be translated into practice - project start-up seminars, teambuilding séances, or brainstorming sessions? Perhaps a primary consideration is the fact

[58] Sørensen,T, 1996: *Experience as tacit knowledge: A method for learning in organisations. Established by investigating practice in Statoil's drilling department from a knowledge perspective.* Doctoral Thesis NTNU; Wulff, IA, 1997b: *User Involvement in Engineering Design:* Trial lecture for the Doctoral Degree. NTNU; Aase, K, 1997: *Experience Transfer in Norwegian Oil and Gas Industry. Approaches and Organisational Mechanisms* Doctoral, Thesis NTNU.

that the experiences most likely will become dissociated from the context in which they occurred. Shall one merely include all close-out reports in a data-base relying on search engines to dig out information of relevance? Any Internet user will understand the frustrating and time-consuming difficulty of finding anything useful in unstructured information. Without structure - chaos?

To Latour certain aspects concerning data gathering are essential in order to prevent a chaos of information, or perhaps more precisely to create information out of the data. Firstly, the data are gathered back to a central location or repository where they were correlated with similar information from other sources, then analysed and codified in a format that was easy to understand and use by others. Secondly, there is consensus regarding the basis for codification i.e. that the code was understood, endorsed and used. Thirdly, the users 'out there' are committed to sending back the data of their experiences because they understood the value and purpose of the information generated by analysis of these data. This codified information and the insights provided by correlation and analysis can then be made available to users/others providing foresight as a basis for rational action when confronted with situations that would otherwise be completely unknown. In other words, this foreknowledge provides a basis for planning.

When applied to the world of projects, a control philosophy that treats every new project as completely unique, cuts off the foresight potential embodied in knowledge of similar work. Personnel working close to the complexity of one project over time, see only that project and do not have the advantage (or perspective ?) of seeing the results of many projects of similar nature. Their foresight is limited to own experience or the tacit collective experiences of colleagues in the *community of practice*, communicated in *story-telling* over the lunch tables, or by other informal means (Brown, DuGuid, 1991[59]). By the same token the control method that does not monitor the properties of the product progressively in order to improve the knowledge of that product, will not be able to update the basis for planning in the light of new information.

In the Latour analogy the base organisation is seen as the repository of the methods of monitoring and the data and is responsible for the correlation, analysis and codification of project performance data with respect to a preconceived structure (ref. Table 3-1, Table of Performance Measurement Parameters).

The basis for deciding which experiences are relevant to transfer lies in the context of the anomalies arising out of comparison of the hard facts of performance and the nature of the qualitative explanations for deviations of performance. In the short term of the project, anomalies provide a basis for re-alignment of the plans. In the longer term deviations of performance and associated qualitative analyses provide a basis for re-alignment of the recommended codes of practice in the light of relevant experiences from the world of practice.

Over time this form of dialogue ought to lead to convergence between the formal procedures (*best practice*/*espoused theory*) and actual practices of individuals and projects (*theories-in-action*[60]), relating to the terminology used by Argyris and Schøn.

Judging by experiences outlined in the chapter *Experiences with implementation,* achieving consensus may not be the easiest of tasks. This dissertation is a contribution to that debate.

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[59] The terms 'communities of practice' and 'story-telling' apply to groups of people performing the same sort of work and sharing a common 'insider' understanding and modes of communication with respect to problem-solving.

[60] *Espoused theory* is the theory of action which is advanced to explain or justify a given pattern of activity. *Theory-in-action* is the theory of action which is implicit in the performance of that pattern of activity.

7.5.6 Method of measurement

The control strategy adopted by the project may be regarded as a consequence of the perception of the project as unique. The work by Latour, which was discussed in the previous chapter, also provides an interesting perspective on the significance of the methods of measurement used in the control strategies adopted by projects. It is thus interesting to relate the concepts drawn from the work of Latour to the nature of the normative method of measuring (monitoring) the control status of the project.

Latour is concerned with the concept of metrology [61] whereby appropriate forms of measurement bring together significant features of the physical world being measured. To borrow Latour's metaphor, the cartographer's coordinate pair uniquely describes the locus of one point on the globe; several points taken from distinct features in the terrain transpose into a picture of the physical world, a map, which can be studied in advance. A ship can set a course to any destination, and use navigational skills built on the same premise as the map, to check its absolute location with respect to the map at regular intervals, make due correction to its course to avoid dangers and reach its destination by adjusting its speed and the bearing of its course. Co-ordinate pairs are an appropriate metrology for tying together maps and methods of navigation. This is of course not to say that some form of look-out was no longer necessary after the introduction of navigation skills, since the quality of the maps leave a lot to be desired, requiring ongoing cartography until this day. This is the nature of science in action.

An appropriate metrology applied to modification work ties together the physical properties of the product and the resources required to perform the work. Knowledge of achieved production efficiencies from performing similar tasks provides a basis for checking the frame of commitment with respect to the properties of the product at regular intervals as progressive elaboration proceeds. What is needed is a process for monitoring the properties of the product as progressive elaboration proceeds. The normative method, however, has no specific metrology relating properties of the product and the resources required to perform the work. The properties of the product are all translated into work-hours and into money in detail planning processes deeply embedded in work planning routines. Status is transposed once more into a unit-less number calculated from work-hours planned relative to work-hours used, money planned relative to money used. At the start of the project relations between the physical properties of the product and required resources have indeed been used to establish the work-hours and the money in the plan. But thereafter status checking relies on a one-dimensional 'relative to the plan' metrology based on a single common unit of measure and unit-less numbers (percentages). Should the planned resource use at some future point in time not comply with expectations, the number of work-hours will be adjusted, not on the basis of the status of the properties of the product, at source so to speak, but on the basis of a trend.[62] Time is needed for a trend to develop - while the trend develops, action time is lost. Measurement of performance data linked to properties of the product provides the project with the means of continually testing the validity of its pre-planned course of action.

[61] Metrology: *Science; system of weights and measures.* (The Concise Oxford Dictionary, 1952)

[62] By analogy, even if it had a good map, without recourse to navigation skills the ship would have no means of checking whether it was still on the preset course and would have to resort to trending, by measuring its speed through the water and calculate progress along the preset path with respect to its expected speed. Likewise the project that does not measure the status of the properties of the product as progressive elaboration proceeds, has no means of knowing whether the expected number of work-hours is the correct amount needed to perform the work. Performance data linked to properties of the product provides the project with the means of continually testing the validity of its pre-planned course of action.

An inappropriate metrology is a consequence of the perception of the project as unique (comparison not relevant), but the situation is perhaps aggravated by the lack of guidelines concerning alternative methods for updating the commitment frame in the general body of knowledge. Consequently, there has developed a *theory-in-action* type of practice in the industry wherein the monitoring of the properties of the product as a project control tool, (i.e. a basis for estimating/verifying the commitment frame) by means of weight estimating techniques, is discontinued after award of contract in favour of the approach described above, that of linkage to the detail planning task sheets. The consequence is that the knowledge regarding deviations in the properties of the product will remain hidden until the weight basis is updated some time after the completion of detailed engineering, or the quantities of work-hours defined by the detailed planning processes mentioned above begin to emerge. Unfortunately, these detailed planning processes are also dependent on the completion of the detailed engineering processes. By this time the project will often have completed about a third of its cycle and will be well into the production phase of transposing paper (design) into hardware.

The effect of an appropriate metrology in the comparison of anomaly processes can be illustrated by referring briefly to the case study in the Appendix 1. The significant non-correlation between the cost and the weight curve in Figure 9-1 indicates that something was wrong with the target cost (TC) or the commitment frame (Study). The anomaly is apparent already at award of contract, indicating that the basis for corrective action was available at that time. Later baselines deepen the anomaly, the weight apparently going down while the cost estimate is rising. Comparison with similar work would have indicated the likelihood of an underestimated TC. The same phenomena are apparent in Figure 9-2, showing a non-correlation between engineering and integration work-hour development and the weight development, again indicating that something was wrong. This is already apparent at the time of the first periodic update, BL1, as manifested by the anomaly of the work-hour estimate increase while weight decreases. Comparison with similar work would have indicated that the piping engineering work-hours were severely underestimated in the TC. Information for adequate corrective action was available in the system. The continuous increase in the estimate of engineering work-hours is the consequence of the imprecision of the method of trending – too little, too late. The alternative was to estimate the engineering work-hour needs on the basis of the weight data in the concept and norms of production based on experience, and then make adjustments based on weight monitoring of the detail engineering. This would have resulted in an estimate of the same order of magnitude as the final result. That this was obviously not done is indicated by the continuously rising curve. That the weight monitoring was not updated during the detail engineering is apparent from the large discontinuity between the TC and third periodic update, BL3. Hence, it may be assumed that considerations of weight anomalies were not made available in the knowledge basis for action by the project management.

These anomalies and the linkage between weight and cost/work-hours are made very clear by the metrology used in the presentation. By contrast the presentation formats of the normative approach would normally only show two aggregation curves of planned and actual work-hour development, but without a weight correlation. The essential linkage, and the corresponding course of action, is not made evident to the viewer.

7.5.7 Organisational learning and experience transfer

The discussion in the preceding section extends logically into the theories of organisational learning expounded by Argyris and Schøn in the two works *The Reflective Practitioner* (Schøn, 1983) and *Organisational Learning II* (Argyris and Schøn, 1996).

The normative control strategy of the project relies on a form of instrumental learning whereby anomaly comparison leads to some form of corrective action (feedback) in order to restore the status to the expected, in other words, return to plan. This form of organisational learning is termed *single-loop learning* [63] in the theories of Argyris and Schøn and would be the normal mode of operation in the project. In the section *Methods of measurement* above, it has been argued that the methods employed in performing these control activities are deficient and that the concern is to find a means that will lead to correction of the method itself, that which is termed *double-loop learning* [64] in the theories of Argyris and Schøn. To this end the introduction of routines of internal benchmarking applied in a multi-project multi-cycle context has been proposed. The benchmarking method can be applied in *single loop* processes within the individual project as part of a control strategy, which uses anomaly comparison, norms of production and ongoing measurement of the properties of the products as a basis for prediction and corrective action.Use of the recommended metrology would further enhance the learning potential of the *single loop* through the inclusion of measures of efficiency in the control data, which is a precept of the Argyris and Schøn theory (ref. *Organisational Learning II*).

The experiences thus accumulated could then be the subject of a post project de-briefing (close-out review), which would use performance anomalies in the final outcome as a point of departure for reviewing the concept development and the projected performance history. From the debriefing, reflection on the methods employed in the control strategy leads to the possibility of *double-loop learning*. [65]

Organisational learning can, logically, only take place in an organisation that has continuity over time. Thus, a de-briefing of this nature may simultaneously form a convenient bridge from the limited life-span of the project to the more continuous base organisational unit as a repository of experience data and the *best practice* routines. This transfer is essential in order to implement any *double-loop* conclusions arising from the review into the recommended procedures (*best practice*). Experience exchange becomes a dual responsibility shared between base organisation and project. By placing the responsibility for the routine in the base organisation, continuity is assured. By using an analysis based on a fixed set of performance parameters as an objective starting point (*performance anomalies*), a focus for a dialogue is provided. In the absence of a routine the project, left to itself, has no guideline such as the relation of the anomaly to cost, quality, or recurrent problems in other projects, for judging relevant issues, as well as no experience (*routine*) for conducting such a search process. One can, in theory, visualise an experience transfer directly between projects, which is in fact one of the project start-up routines mentioned in the section *Routinisation of practise*. But there are obvious practical limitations, the most central being that the maintenance and development of a body of experience data is not consistent with the mandate of the project.

A central concern of Argyris and Schøn is the relative roles of practitioners and academic researchers and the interplay between them. Argyris and Schøn recognise the knowledge base of the practitioner and the potential for organisational learning latent in the processes of instrumental learning mentioned above combined with the reflections of practitioners on the anomalies of experience in the daily work situation. Recognising also that participation encourages ownership, they recommend collaboration on research between researchers and practitioners. These principles may be mirrored in interplay between the non-continuous project and the continuous base organisation leading in time to the convergence between

[63] Single loop learning: a process leading to correction of deviations to accepted norms of performance
[64] Double loop learning: a process leading to a change in the norms of performance by virtue of changes in the routines
[65] Analogous to the element of *surprise* stimulating enquiry as described by Nelson and Winter

theories-in-action and *espoused theory* (the recommended 'best' practice). In the same way participation may contribute to reducing *interaction effects* [66] resulting from enquiry into the causality underlying performance anomalies, particularly if the anomaly is negative.

In the researcher/practitioner context the role of the author is that of a practitioner seeking a practical outcome from the results of reflection of several years of work with estimating, project control, contracting and quality assurance auditing. The results of this reflection are the practical methods for experience transfer, integrated with project control and estimating techniques which simultaneously provide a basis for structured dialogue potentially leading to *double loop learning*, which have been presented and justified using the works of several researchers in organisation theory. There are however, according to Argyris and Schøn, different *stopping rules* [67] for practitioners whose enquiry is seen as naturally coming to a close when intended results have been achieved that are good enough. To this it may be replied that the benchmarking concept is not a closed rule, but an open-ended procedure intended to promote reflective dialogue between practitioners as part of the organisation's *learning system* [68] and that this may continue independently of formal research involvement [69]. The data structure that has been put forward (the core processes in modification projects) is only a point of departure. The *behavioural world* [70] of the organisation is the major constraint, some aspects of which have been described in the section *Experience with implementation.*

There are clear parallels between the perspectives of Nelson and Winter (routines of search heuristics) and the reflective practice of Schøn. In *The Reflective Practitioner* Schøn concludes that organisations wishing to promote organisational learning will have to institutionalise *reflection in action* [71] and stimulate constructive dialogue in order to ventilate dilemmas of practice. At the same time he is well aware of the conflicts that arise as a result of inquiry because of the potential threat to the stable system of rules and procedures constituting the framework within which an organisation operates. This stable system of rules and procedures is similar to what Nelson and Winter call *truce*. Schøn has no recipe for such an organisation beyond defining the essential characteristics that the organisation will need in order to convert the inherent tension in productive inquiry into fruitful dialogue. To use Schøn's own words: '*To the extent that an institution seeks to accommodate to the reflection-in-action of its (professional) members, it must meet several conditions. In contrast to the normal bureaucratic emphasis on uniform procedures, objective measures of performance, and centre/periphery systems of control, a reflective institution must place a high priority on flexible procedures, differentiated responses, qualitative appreciation of complex processes, and decentralised responsibility for judgement and action. In contrast to the normal bureaucratic emphasis on technical rationality* [72]*, a reflective institution must make a place for attention to conflicting values and purposes. But these extraordinary conditions are also necessary for significant organisational learning*.' (Schøn, 1983).

[66] Interaction effects: the (normally) defensive responses provoked by inquiry into an individuals domain of performance

[67] Stopping rules: In contrast to the practitioner, who would stop once having achieved a satisfactory result of the inquiry, the academic researcher would continue to research as long as there remained alternative hypotheses to explore

[68] Learning system: the collection of activities and routines used for problem solving and organisational development

[69] This is not to diminish the potential for further fruitful academic research inherent in this situation.

[70] Behavioural world: the organisation's cultural attitude to the processes of inquiry associated with the process of organisational learning

[71] The concept of reflection in action acknowledges that professional practice, in order to solve the complex and indeterminate problems that arise in the world of practice, is dependant on the insights, competencies and skills that are acquired through practice and that extend beyond the constraints of technical rationality.

[72] The concept of technical rationality presumes that professional practice is founded on the application of standardised methods, rules and procedures contained in a formal body of knowledge which is established, maintained and extended through processes of formal research.

Several of these characteristics will be found in the corporate organisational vision of many companies. The extent to which the corporate vision is successful may exercise influence on those aspects of the *behavioural world* that the participants bring to inquiry. That discussion is outside the range of this thesis.

7.5.8 The constraints of governance networks

Returning to the theme concerning the conservatism of practice, projects exist in a wider context (*network*) consisting of many actors with varying degrees of inter-dependence on each other. All these actors, in support of their own interests, exercise influence in some or other manner on the way things are done. Not all of these are supportive of innovation referring in general to the work of Brunsson and Olsen in *Organising Organisations,* Chapter 2, *Networks as Governance Structures* (Brunsson, Olsen; 1998)

So far the discussion has not differentiated strictly between the central actors in the project, such as the company's project team and the contractor, precisely because of the high degree of interaction and mutual dependency between them. All parties are participants in the same community of practise and are thereby adherents of the same *espoused theories* and practice much the same *theories in action*. This includes also formal representatives of professional practice such as the industrial standards committees, certifying institutions and consultant organisations selling good practice review services. Although these latter parties may not endorse deviant *theories in action*, they nevertheless have a vested interest in maintaining the status quo, unless perhaps innovative practice stems from their activities.

The contractor is a central actor in the project whose behaviour with regard to innovative methods, will not be significantly different from that of the company since both are party to the same ultimate set of goals. The contractor's focus will be on the use of established methods and routines, in order to save work-hours, and will tend to use the contract and the threats to the project's goals to resist any efforts to introduce new methods that may have been incorporated in the terms of contract. The contractor has the added incentive of a relatively much greater and more immediate economic risk than the owner, without necessarily having a share of the gains. Besides, as previously mentioned (ref. anomaly 5 concerning the accuracy of estimates), the contractors will most often benefit from the existing routines for adjusting the contract value to accommodate change and therefore have conceivably little interest in contributing to the control which early warning provides to the company. As Eide has pointed out, it is a well-known consequence of competitive tendering, that contractors rely on changes to correct the economic balance, something that is freely admitted by the contractors themselves. As a counter to this strategy, the company is definitively in need of the more reliable estimates, insight and early warning promised by the proposed method improvement, the better to handle the strategy of the contractor.

For similar reasons, contractors have little interest in contributing to programs of performance measurement. One might expect, however, that contractors would maintain internal programs of performance measurement in order to maintain a competitive advantage in the industry, but this does not seem to be the case. Another reason would be for the purpose of maintaining good control over the project with a view to minimising their economic exposure and the better to exploit the change potential. It would, however, seem that the contractors more often position themselves in relation to the different demands made by the client companies through new forms of contract rather than pursuing independent own programs aimed at improvement of internal work processes. In this way methods of improvement initiated by companies may come to diffuse through the industry as a community of practise. This tendency to conformity will at the same time offer resistance to change as a result of previously established practice.

The owners of a venture, including the project operator, are generally motivated by risk aversion balanced by strong pressures to reduce costs. The initial tendency is to challenge the realism of estimates, believing that estimates are generally low in order to gain project approval. Subsequently they may exert pressure to reduce budgets based on elements such as contract value at award of contract, or on intensive technical reviews aimed at cutting contingency reserves, usually prematurely. In order to handle this sort of seesaw situation, the project team will be in need of the insight and estimate confidence mentioned above in order to ensure adequate budget coverage of the work scope. The inherent risk aversion of the venture owners, however, normally leads them to seek certainty in uncertainty by promoting the use of well-known practices of project control and discouraging experimentation of method. But they are often protagonists of technical innovation in order to save money.

An interesting aside concerns the extent to which many oil companies have ceased to maintain in-house estimating competence and capacity, preferring to out-source this activity. This has an inherent logic for small companies with a limited number of projects. It would seem that a large portfolio of modification work is a prerequisite for the above-recommended methods to have full effect.

In order to be accepted, the proposed methods will need to have an objectivity that overcomes all the resistive elements described above. Benchmarking is a generally well-known and respected concept. The proposed methods modify, extend and supplement but do not replace existing routines. A criterion for innovative success is the combination and refinement of existing routines as components of new routines. These are described as '*new contexts of information flows*' and '*genuinely innovative*' by Nelson and Winter quoting Schumpeter.

This dissertation attempts to demonstrate that the proposed methods conform to this criterion.

7.5.9 More about the relative method of monitoring – information technology

The relative method of monitoring has already been discussed extensively in the preceding chapters. However, there are aspects reflecting on the extent to which modern data systems inhibit insights into the working of systems in a way that may be inherently conservative of method. This may be commented briefly by drawing on the work of Adler and Winograd**,** *Usability: Turning Technologies into Tools* specifically Chapter 7 by Brown and Duguid, *Enacting Design for the Workplace* (Adler, Winograd, 1992).

The general *organisational opacity* [73] resulting from the high degree of task specialisation in the inner workings of the progressive elaboration processes has previously been described in other terms in the previous chapters.

Brown and Duguid point to the modern tendency to automate espoused practice that has a tendency to hide the fundamentals of the task relationships comprising the system, or even to incorporate several functions within the system logic. The already remote activities of the detail planners become more remote by virtue of the fact that the task of input data logging is often placed in the hands of system operators, or even more extensively automated directly from the planning formats of the detail planners, rather than the users of the output. This in turn requires deeper insights and very convincing processes of inquiry on the part of practitioners who may be stimulated to question anomalies of performance or propose changes of routine.

The systems are generally supplied and supported by an external agent and accordingly can acquire an own inertia, being often a considerable investment for the company and

[73] The term *organisational opacity* has been borrowed from Brown and Duguid as the inverse of 'Organisational transparency' which is aimed at relating, through processes of work, the individual worksite and the work done there to the workings of the organisation as a whole.

representing long-term vested interests on the part of the support group. For the purposes of this discussion it is sufficient to point to the possible conservatory effects of data systems once introduced, without discussing the issue in further detail, apart from pointing to the extra demands on transparency in such systems, should one wish to promote reflection-in-action as a desirable component of the organisational learning system.

7.6 Summary in conclusion

The thread in the argument runs through the concept of uniqueness. The essence of the argument laid out in this chapter is that the concept is misconceived as to its very unique uniqueness. Consequently the methods used for monitoring a project are aligned with the commitment frame as reference, i.e. relative to itself rather than to the development of the technical properties of the product and norms of industrial performance by comparison to similar work. The result is that the project management is to a large degree deprived of the advantages that experience from previous projects can provide, thereby limiting its perspective and knowledge base for rational decision making. For the same reason project management is not particularly motivated to contribute to data gathering through which experience can be passed on to later projects. Indeed the project's methods do not prescribe any method for consistent use of experience data, even though it is one of the icons of project management. In addition it is argued that the verifications of the commitment frame resulting from the normative methods arrive too late to be of any real use and that they are essentially inaccurate as corrective techniques, being based on trending rather than hard measurement.

This does not mean that there is a direct causal link between the definitions of uniqueness contained in the normative literature and the concept of uniqueness prevailing in the community of practice. Rather that it is the concept of uniqueness common to the community of practice, which is expressed in the definitions embodied in the normative literature, although of course the normative literature over the course of time gains status and becomes a reference through newcomers to the community of practice.

In contrast to the concept of uniqueness, this dissertation has redefined the project as a batch or a cycle in a multi-project community of practice. The true nature of the project is a purpose-designed and purpose-built large assembled product consisting of more-or-less standard industrial subcomponents employing skill-intensive, but more-or-less standard industrial methods of fabrication to which more-or-less standard measurement processes of production efficiency can be applied. This approach would foster practices of data gathering in one project for the purposes of experience transfer to the community and hence to succeeding projects in a manner consistent with industrial engineering practices in general. By these means the improvement of production efficiency over time may be included as performance targets in addition to the existing goals of cost, time and quality.

The project, with its limited life and focused objectives, is not a suitable locus for the analysis and interpretation of experience data with respect to the standardised procedures of project management, for which a longer-term perspective is required. This task is the natural task of the supportive base organisation, which is also the repository of the standard procedures. Fruitful interplay between project and base organisation may be found by employing benchmarking techniques based on hard measurement of production efficiency to support processes of experience transfer of a more qualitative nature. An essential part of this process will be to find an appropriate form of codification of the experience data which all participants understand and which is easy to apply in the ongoing control work in the individual project. A proposal for this codification is presented in Table 3-1. The processes of experience transfer are also conducive to dialogues of inquiry based on the stimulus of anomalies of performance, ultimately leading to revisions of methods, if required.

This dissertation has attempted to demonstrate that the explanations and the proposed methods expounded here are congruent with the theories, conclusions and recommendations arising from organisational research.

The proof of the pudding is in the eating. To this end case studies have been provided as practical example in order to demonstrate the type of anomalies brought out by the application of the benchmarking method proposed here - anomalies which highlight the occasions for management action taken from analysis of factual project historical data. The Benchmarking Case Study Summaries in Chapter 3.9 and the Appendices 1 and 2 should be sufficient to illustrate in what manner such an analysis can set the agenda for a close-out performance review on an objective basis.

Finally, it remains to be said that there is of course no guarantee that the methods proposed here will result in fewer overruns. At best they provide a means to better insights into the technical nature of the work and a better knowledge basis on which to base decisions for action.

7.6.1 Toward a modified theory of project management

From the list of anomalies observed in the project environment, outlined in the sub-chapter *Experiences with implementation,* there emerges a picture of a community of practice which appears to lack a common understanding of the workings of the system among the various groups of experts contributing to the process of progressive elaboration. This statement also applies among the elements outside the project which affect its working environment. At the same time combination of specialisation and routinisation inherent in the skilled nature of project work, is inherently conservative of method.

So far the reason for the conservatism of method is also attributed to the concept of the uniqueness of each project. So far the review of methods has not revealed how this uniqueness is actually handled in the work methods. All one finds is standardisation and uniformity typified by the metrology of the project control, which is one-dimensional. The subject is not handled specifically in the normative literature of project management. An answer may be that the treatment of detail (and ultimately special or unique detail) is embedded in the processes of detail planning where elements of uniqueness can be planned in a consistent fashion using conventional routines, along with all the other more or less special items that are a consequence of a purpose-built assembled-product. By implication, while there may be elements of uniqueness in the work scope of the project, this does not make the project unique from all other projects. In fact, as previously mentioned, the special items will normally already have been adequately defined in the earlier phases, so as to make them suitable for industrial production by the standard means employed by projects, perhaps requiring a bit of special attention and coordination. This being so, one may conclude that the fact of the matter supports the argument that the community of practice may benefit by redefining its concept of the nature of the work.

In general all the details aggregate into normal well-understood products of industry and can be manufactured by well-understood processes of production. The failure situation regarding project control arises out of the metrology and methods that abstain from monitoring the development of the product as progressive elaboration proceeds and lack of a suitable metrology with which to draw together the aggregations of detail in a manner that gives meaningful insights and knowledge to the management as a basis for action. The normative method aggregates in one step from the rich detail of the detailed planning basis into total uniformity. While the management can handle special items by qualitative focus, as exemplified by preparation of lists of long lead items and other critical deliveries, or risk registers, for special follow-up, the volume work can only be handled in aggregation. The methods of project control lack functionality to perceive and quantify in adequate intermediate aggregations the effects of changes in bulk quantities and volume of work. As long as this special relationship between the handling of detail in a purpose-built production process and appropriate methods to provide management insights as basis for action is not adequately addressed in the normative project management literature, the misconception of uniqueness will persist and relativistic methods of project control will persist. Projects are generally not unique, they are only a bit special, or more precisely perhaps, they only occasionally have some really special bits.

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9 APPENDIX 1: Case 1 Performance Review

This is a brief benchmarking review of a project performance history. The purpose is to investigate the cost and man-hour development in the light of the concept development history seen in terms of weight development. This review should be read in conjunction with the review of Chapter 3-9: Some results of quantitative and qualitative performance review.

It is important to note that weight monitoring was not part of the project control effort. The correlation of weight with cost and man-hours used in this review has been undertaken expressly for the purposes of demonstrating the advantages of the recommended practice.

DEVELOPMENT SUMMARY

The concept comprised the installation of gas compression equipment on a GBS type platform. The central issue of the concept development history is the circumstances pertaining to the size of the modules and the installation complexity. The initial study indicated considerable complexity related to the installation requirements. For various reasons the project was postponed for one year. This year was used to place further studies with selected contractors that were to underpin a new tender round. The result was the TC shown in Figure 9-1. This was deemed at the time to represent a potential saving of the order of 500 MNOK overall, due to a better module solution.

The subsequent concept development history is summarised in the weight line shown in Figure 9-1, the module and integration weight columns in Figure 9-2 and the detailed discipline development charts of Figure 9-3. It is immediately of interest to note the large increase occurring at BL3 followed by a decline. It is suggested that the weight reports were subject to the first major update since contract award at this time.

It is evident that both module weight and integration weight increase with respect to the Study and the TC. The module weight increase is primarily 200 tonne steelwork. The integration weight increase is 145 tonnes steelwork, 146 tonnes piping and 175 tonnes equipment. Some of the equipment was moved out of the module, conceivably giving rise to some of the extra steelwork and piping.

Additional equipment in the form of pumps and compressor revamps was added to the scope. Note that neither the Study nor the TC includes this additional scope of work, which will have added additional bulk weight and equipment internals weight to the installation scope.

The project cost and weight history is summarised in Figure 9-1 below, showing labour and materials cost as columns and aggregate weight development as a line (W1). The immediate impression is that the TC was grossly underestimated while the Study estimate had the correct order of magnitude and lay within the anticipated limits of accuracy. The TC, however, being a contractually committed target cost, would normally be more sensitive to later additions to the scope, the tender situation not allowing for inclusion of risk contingency. But it is interesting to note that the labour cost estimates increase with respect to the TC, while the estimated weight is actually decreasing between the award of contract and the BL2, and again between BL3 and the end. The rate of increase per BL is steady from the start (TC), peaking at BL4. There is no clear change in the cost estimate corresponding to the marked weight increase at BL3. In contrast, the material growth rate is much higher initially, flattening off by BL3.

From the high initial materials cost growth rate can be deduced that both the weight development, and accordingly the labour cost and man-hour base, should have been higher at BL1 and BL2 than the Figure 9-1 shows. Simulated labour cost and weight development based on the materials cost development profile, this being the most reliable considering procurement requirements, have been included on the chart to illustrate this effect.

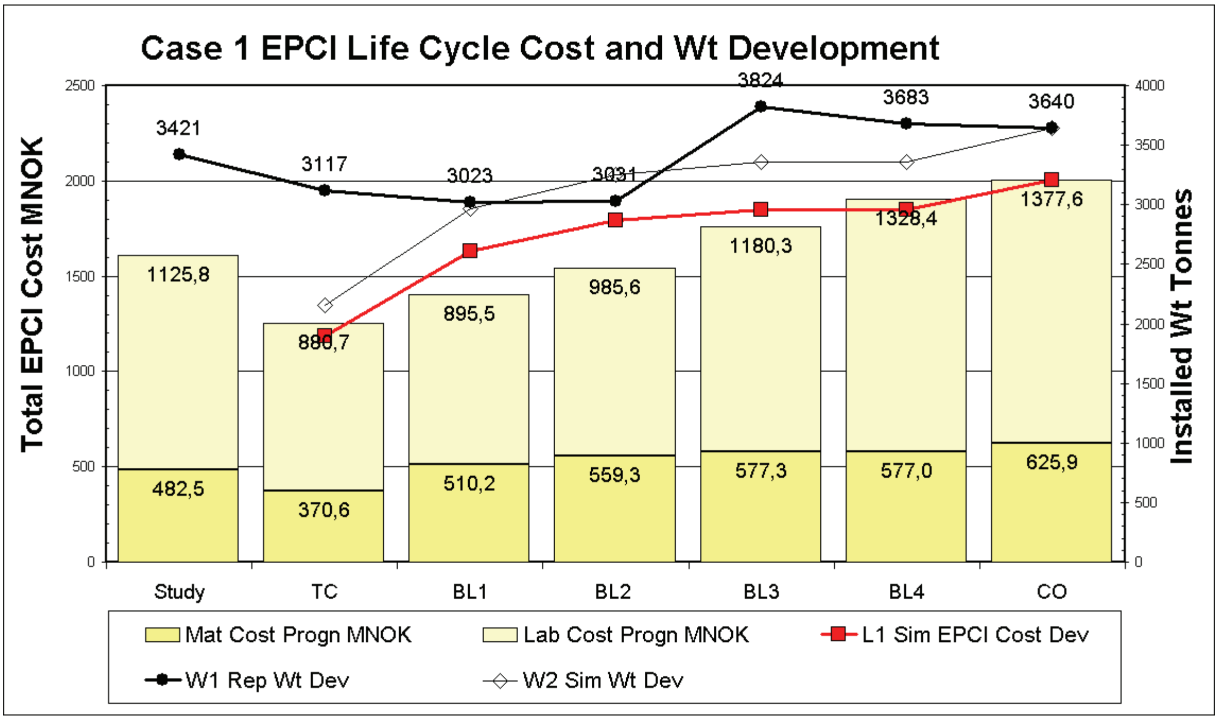

Figure 9-1: Case 1 EPCI weight and cost life-cycle development

It can be noted that the inflation corrected cost difference between the Study and the final result is only 10 % while the difference between the TC and the final result is 45 %. The corresponding weight growth is 6% contra 17%, noting that neither the Study nor the TC estimate have been corrected for the effects of work added to the original concept, although the TC should include an updated modular concept as result of pre-tender studies.

The conclusion to be drawn from the lack of correspondence between the labour cost and weight development and the materials cost growth, is that weight monitoring and weight based verification estimating was not used in the forecasting of labour cost and man-hours. Had this technique been used, the cost and man-hour estimates would have been higher at BL1 and BL2 giving earlier warning, by the order of 12 months, of the impending cost and man-hour overruns with respect to the TC. The extra planning horizon would have been located during, rather than after, the detailed engineering period, thus providing greater efficacy to any corrective action that might have been taken. The final results may have been more cost effective as a result. A general comparison of the final performance with comparative reference work can be seen in Figure 9-3.

Review of the change register indicates that the sum of approved changes corresponds in large measure to the increase in the TC. This translates into a cost per tonne of 1,18 MNOK/tonne for the added work compared to 0,44 MNOK/tonne in the original target cost (TC). This fact alone raises questions of relevance to the contracting philosophy and control strategy.

The labour cost development pattern is mirrored in the aggregate man-hour and weight development charts of Figure 9-2 below. In Figure 9-2 the man-hour estimates and the production efficiencies for engineering, prefabrication, module building and integration have been correlated with weight development in the plots. The plots for engineering man-hours should be read against the combined module and integration weight while the prefabrication and integration should be read against the integration weight alone. Likewise, the module fabrication should be read against the module weight alone.

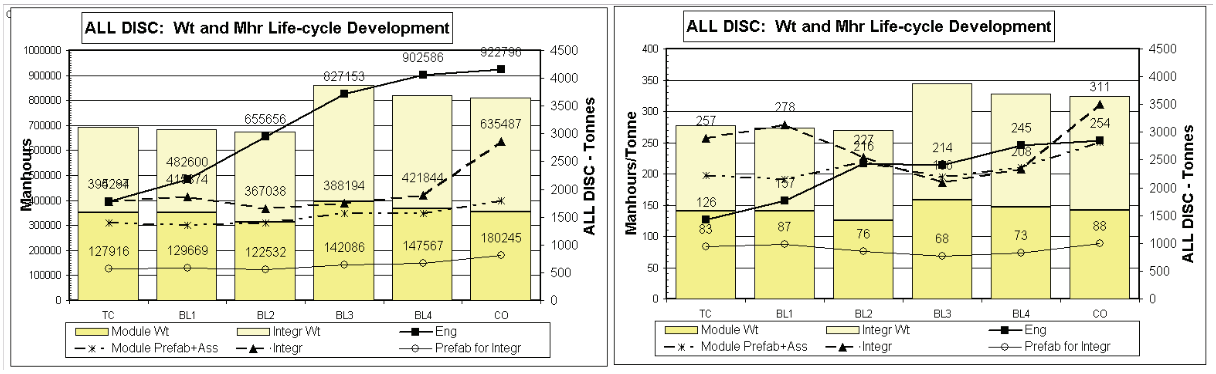

Figure 9-2: Overall man-hour and weight development

From the charts it can be observed the large and steady increase of the engineering man-hour forecasts from a low starting value. In contrast the integration man-hours dip with respect to the weight profile at the start of the offshore period in the period from BL2 to BL4 before increasing abruptly in the period BL4/CO. Both bear little relationship to the weight development profile. One may ask what led the contractor to believe that the engineering performance would be so much better than general levels of performance in the industry? What was the reason for lowering the integration man-hour forecast in circumstances where the weight was actually increasing?

The discipline breakdown of these aggregate man-hour effects and impact in each discipline can be seen in Figure 9-4.

Discipline Man-hour and Weight Development

For this comparison the disciplines will be reviewed individually, simultaneously throwing light onto the labour cost development and weight development for the individual disciplines.

<u>Steelwork</u>

The forecast engineering, integration and module fabrication man-hours increase steadily in rather loose correspondence with the weight development, but the corresponding production efficiencies (man-hours per tonne) do not at all fluctuate in correspondence with the weight changes. Particularly, the offshore integration man-hour/tonne is seen to decrease from the initial TC value, only to rebound, in a seesaw fashion, to a similar but higher level at the end. This may be related to the large volume (289 tonnes) of support frame reinforcement and stiffening, all of which is high man-hour per tonne welded construction performed during shutdown. Judging by the large increase in man-hours and man-hour per tonne from BL4 to BL5, this underestimation must have been discovered in the field.

It is difficult to conceive of the basis for the man-hour estimates, especially considering the large changes in the man-hour per tonne norm for the integration activities. This is particularly notable considering that the mhr/tonne performance level at the TC is almost the same as the final value. Did the contractor reason to assume that the complexity of the work changed as much as the variation in man-hour per tonne would seem to imply? Simple weight adjustments would have given early warning by BL3, conceivably also by BL2, if the weight basis had been updated. Sub-discipline complexity monitoring would have provided additional measures of the work complexity.

<u>Piping</u>

The piping discipline shows no weight growth to speak of, but in contrast a steady increase in engineering man-hours, culminating in a 200% man-hour growth. The final level is in the high range. The integration man-hour estimates fluctuate considerably in a way that bears no relation to the piping weight development, increasing dramatically in the period from BL to BL5 to a high final level, considerably higher than the TC level. Note that the dip in the period BL3/BL4 indicates a too low resource level at the start of the offshore phase. The weight variations can be partly related to the fact that the instrument valves are not consistently placed in the piping discipline, but vary from BL to BL.

Close-out reviews have reported possible knock-on effects of delayed engineering such as delays in finalising layout, late definition of basis of procurement, cost aggravating accelerated delivery requirements, pressure on prefabrication for offshore integration, delayed start-up of offshore integration activities and concentration of offshore bed requirements, as well as poor integration efficiency. The reviews did not, however, couple these observations specifically to the low manning of piping engineering or the low man-hour/tonne basis for the man-hour estimates. Noting the extremely low level of the piping engineering man-hour/tonne value in the TC, it may be asked if the contractor had reason to believe that they would be able to achieve a level of performance so much better than normal industry levels of performance? What was the occasion to lower the forecast resource level in the period BL3/BL4, for which there is no associated weight reduction ?

Instrument

As previously mentioned the instrument valves have not been consistently placed within the piping discipline. Having a large weight relative to the instrument bulk weights, it is clear that there can be no realistic comparison of weight and man-hour development. There is also reason to believe that the instrument cable has been included in the electrical discipline, thereby further complicating the issue.

It is sufficient to point to the steady growth of engineering man-hours, the low starting norm, the peak at BL4 and the final growth of ca 280%, all coupled with a highly erratic material development profile, to question the basis for forecasting.

The scope included weightless control room upgrading not suitable for weight estimating, but final levels are consistent with this.

Electrical

The electrical discipline is subject to weight growth in the module. The engineering man-hours grow steadily in accordance with the weight growth, with the exception of BL4 and BL5. Module fabrication man-hours grow in a likewise manner.

Note that the integration man-hour forecasts do not correspond with the integration weight development.

Equipment

The equipment weight and engineering man-hour growth reflects the added scope of work, but the integration resource forecasts do not follow the weight development profile.

Conclusion man-hour review

The engineering growth endured throughout the project, starting at initial levels that were low by comparison with equivalent work, implying a general underestimating of the engineering resource requirements. This had observable effects on the orderly progression of the work. A large part of the integration growth occurred between BL4 and BL5. This implies an undervaluing of complexity that was most likely discovered as a result of underperformance in the field.

If proper weight monitoring routines and reference data had been used, engineering could have been adequately resourced from the start. The greater part of the cost and man-hour increase would have been identified by BL3, perhaps even BL2. The piping and steelwork fabrication resource dip would not have come about and the project offshore work would have been properly resourced from the start.

OVERALL CONCLUSION

The review conducted here has indicated that the project may have achieved an earlier warning regarding the overrun potential if weight monitoring and weight based estimating methods had been followed in accordance with the best practice recommendations for modification works.

This early warning, being detail weight related, would have identified the locus of the potential problems, facilitating management intervention.

The fact that the materials estimates were updated quickly, and largely within BL2, indicates that there must have existed an MTO basis good enough for an updated weight estimate of reasonable accuracy. The actual estimating practices are not known, but may be questioned for no other reason than the weight inconsistencies in the baseline data, which indicate lack of good order.

It is difficult to understand why the piping engineering man-hour estimates were not fully corrected at BL1, since modification project performance data pointing to the likelihood of a significant man-hour overrun with respect to the MB, were available. This must have resulted in under-manning and poor progress afflicting the project throughout. This observation is borne out by interviews with personnel who were evidently aware of this deficiency in the TC. Similarly, interviews have indicated the presence of problems with material ordering, prefabrication, clashes and misfits offshore and late start on piping offshore, all of which may be attributed to knock-on effects of poor quality engineering. The extent of the problems is not known. Similar effects may have been experienced with other disciplines regarding engineering growth effects.

Finally, the growth in steelwork for both the module (temporary) and in integration (structural strengthening) indicates that there may have been deficiencies in the concept underlying the TC, which were not apparent during the tender evaluation. It is similarly difficult to understand why the integration man-hour forecasts for steelwork did not maintain the same mhr/tonne performance level as the TC, in view of the fact the final value is very close to the TC value and that the total weight and sub-discipline content are very similar at BL3 and at close-out.

The result was that the project suffered the consequences of delays and disturbances to the normal progress of the work brought about by poor engineering progress, particularly on the piping discipline, the final cost being higher than that of comparable types of work judged in terms of performance efficiency (cost per tonne; work-hours per tonne). The project achieved its schedule deadline, but at a cost.

Judging in the clear light of hindsight it is apparent that sufficient information was available in the contractor’s registers to provide better estimates of the final cost already at the time of the award of contract. Quantity monitoring during detailed engineering could have reduced the information deficiencies resulting from scope development. That information was somehow not brought sufficiently to management attention by the monitoring processes of the normative control strategy. In any event the deficiency in engineering work-hours was known at least qualitatively. This knowledge should have resulted in determined action on the part of the project management, ensuring that adequate resources to support the engineering program were provided in spite of the low level of the TC, and, in particular, the piping engineering. The lack of significant action indicates that the severity of the anomaly was not known.

There are several other aspects it may be fruitful to question, for example, the contract strategy (fixed target cost with profit sharing incentive mechanism designed to minimise cost), or the strategy of the contractor seen in the light of the final result and the development of the concept from the early commitment to the final product. Note that the contractor was paid a positive profit share in spite of the low TC, implying that the difference between the initial and final target cost (TC) must have been made up of approved adjustments to the contract.

The juxtaposition of significant parameters of performance in the formats presented here clarifies significant resource relationships, which would otherwise be embedded in detail registers, in a manner that supports management insight and response.

Comparative Performance Summary

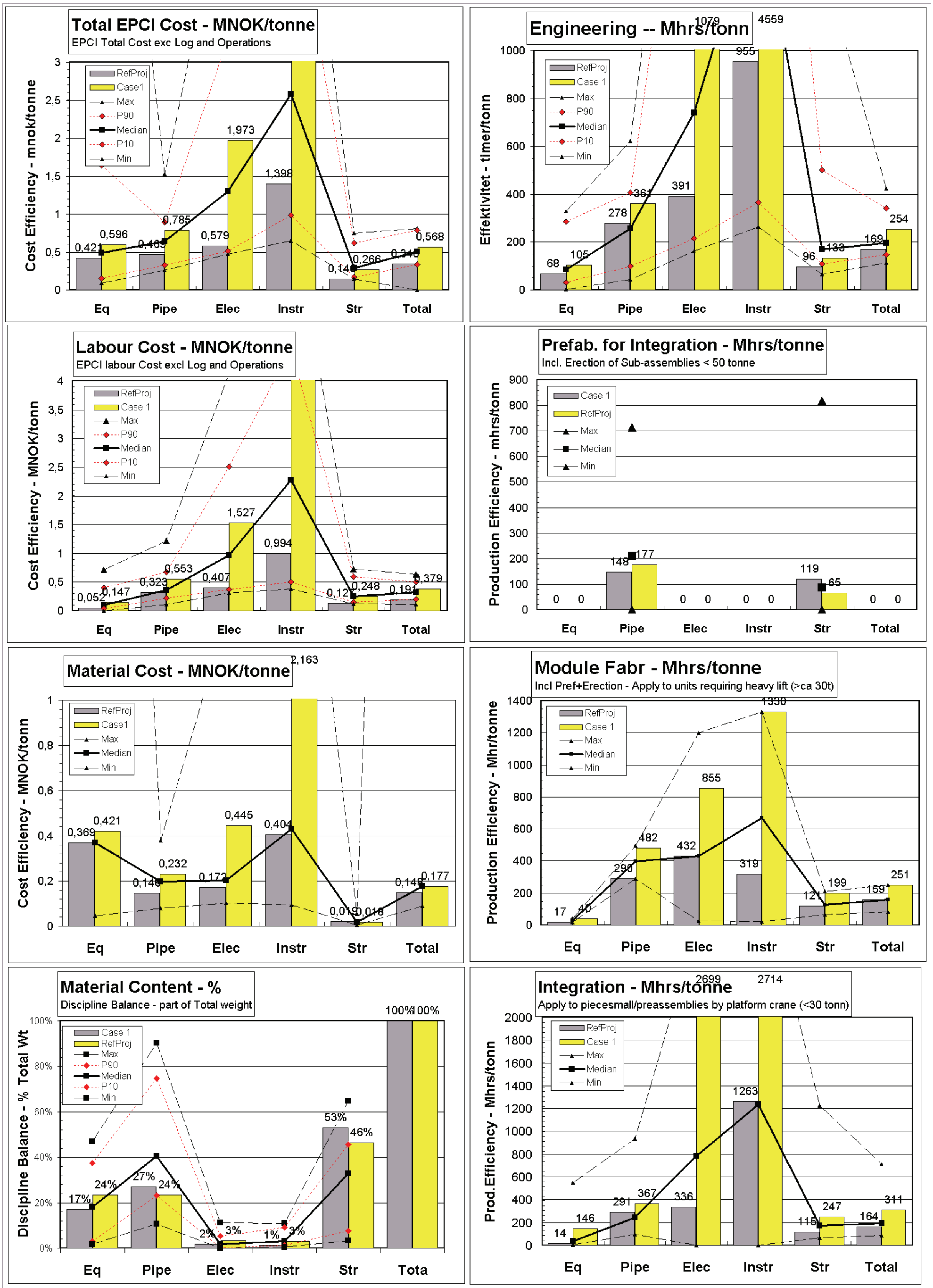

Figure 9-3: Case 1 core parameter comparative performance summary

Discipline Weight, Man-hour and Norm Development Summaries

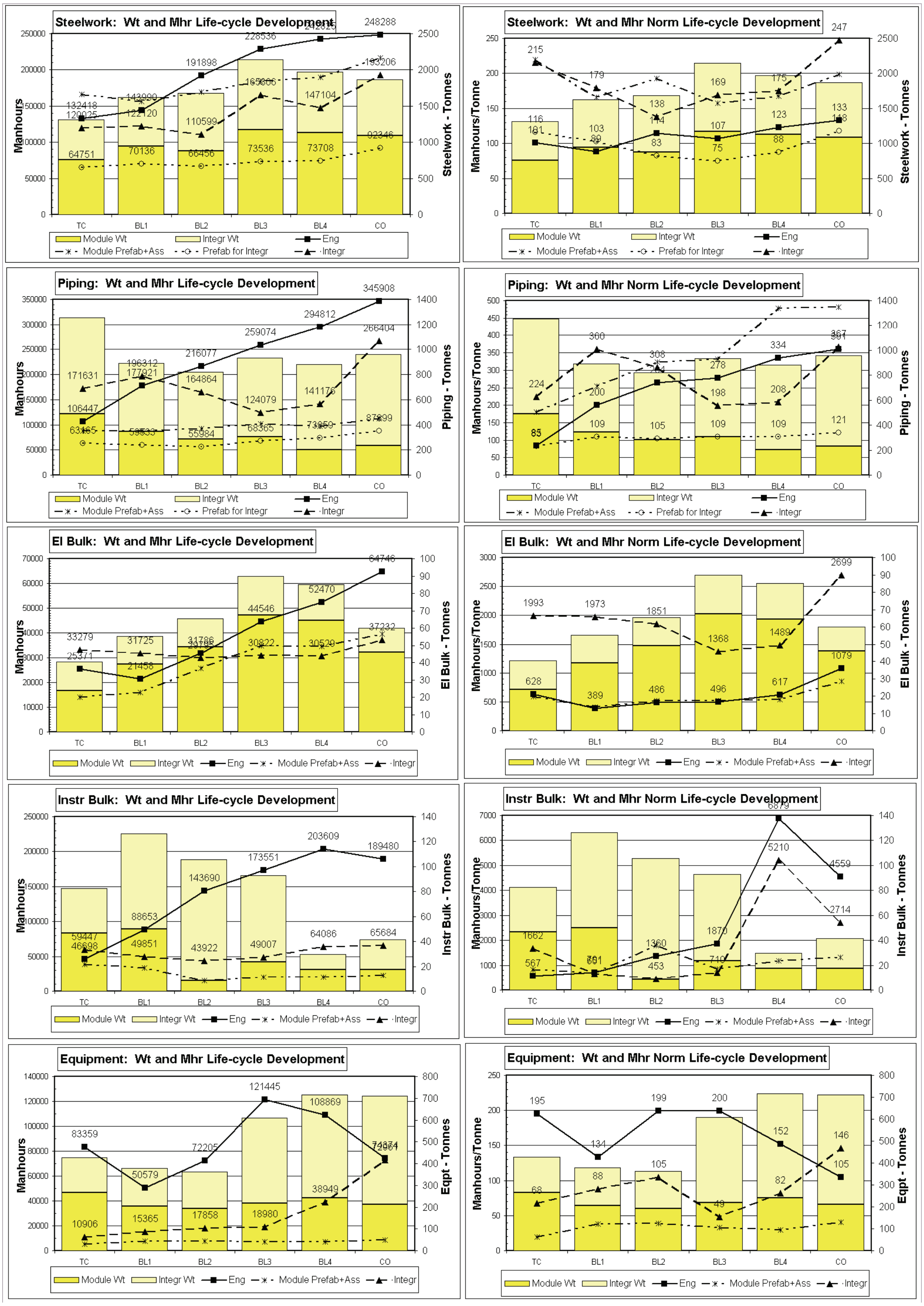

Figure 9-4: Case 1 discipline weight, man-hour and norm development summary

10 APPENDIX 2: Case 2 Performance Review

INTRODUCTION

The purpose of the analysis is to quantify the project's results measured in terms of efficiency, compare to performance data from other modification work, evaluate whether the results are consistent with the character and complexity of the work and, if relevant, consider reasons for deviation.

SUMMARY

The basis for the project is the retrofit of a production semi to treat the condensate stream from a neighbouring satellite field. The project was special in that the retrofit was planned as part of an atshore hull maintenance period, believing this would provide more beneficial circumstances than a modification offshore. The short period of time atshore would, however, pose special circumstances in view of the large volume of materials to be installed in a short period of time.

The project was subject to extensive man-hour overruns. The overruns can be attributed in a small part to under-dimensioned resources, but in a major part to extensive field rework as a result of extensive clashes. Both these effects are considered to have their roots in incomplete engineering as a result of front-end schedule stress. Market conditions at the time (high activity) and the timing of the atshore phase (summer holiday necessitated use of non-familiar imported labour) are contributory factors.

The concept development resulted in a reduced material cost stemming from reduced piping and steelwork weight, but increased electro and instrument work combined with optimisation of the equipment costs through the use of revamping rather than new equipment. Piping complexity marginally changed towards a greater content of high grade steel, which in itself contributes some part of the man-hour growth since extensive welding was employed. In other respects the concept may be regarded as mature, having gone through several study rounds in the hands of the same contractor.

The following additional contributory factors were cited by project personal in the course of informal interviews:

- a tight schedule for front end engineering, procurement and prefabrication
- the tight schedule excluded the possibility for field survey in advance of prefabrication resulting in extensive collisions (particularly piping), rework and disturbances to the orderly progress of the work. The specific volume of rework man-hours is not known.
- the EPCI contractor's construction partner lacked experience with modifications being more familiar with greenfield work
- The contractor's risk aversion, along with strong performance related incentives, hindered the contractor from utilising the company's experience regarding traditional methods for modification work
- field erection methods for steelwork were chosen rather than optimal prefabrication of steelwork as used in traditional modification work, possibly as a consequence of the schedule pressure. While reducing the criticality of the front-end engineering regarding coordination of detailed engineering, installation planning and prefabrication lead time, this had the effect of increasing fabrication resource pressure in the atshore phase.
- deficiencies in the control methods or errors in the MTO/weight estimates resulted in under-dimensioning of the man-hour needs
- no specific unforeseen elements of work were identified

EPCI Cost and weight development

The cost and weight development is summarised in the chart Figure 10-1 below. Each position represents a discrete development stage, the Study, completed prior to the bid stage, the Bid, the provisional target cost (PTC), the final target cost (FTC), the BL prior to start of the offshore phase and the close-out (CO).

The most notable feature is a marked increase in the labour costs associated with an overall decrease in weight and materials costs. The weight development can be seen to decrease overall by approx. 10%, consisting of 140 T equipment, 64 T piping and 40 T increase in elektro bulk. The sudden drop in the weight basis is related to an excessive risk allowance deemed necessary by the contractor, but later dropped. Details regarding weight development can be seen in the discipline weight and man-hour development charts in Figure 10-3 at the end of this Appendix.

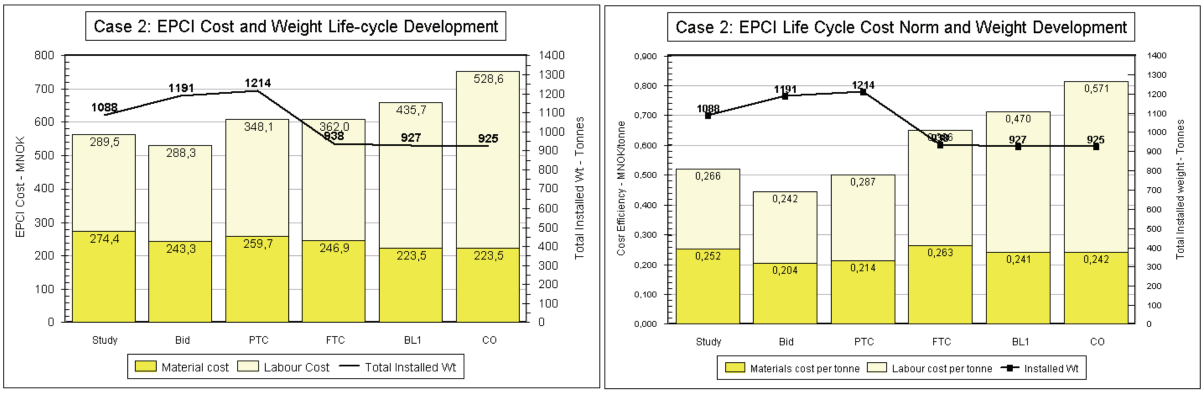

Figure 10-1: Case 2 EPCI weight and cost life-cycle development

<u>Material costs</u>

The material cost level is consistent with the nature of the work, evaluated on a basis of the overall discipline mix and the sub-discipline character of the work. The materials cost is marked by:

- below average steelwork content (low cost per tonne)
- below average piping content but high cost per tonne due to high content of high grade steels (60%) and high valve content (50%)
- high equipment and electro content at high cost per tonne

In total the cost per tonne is 0.248 mnok/tonne compared to a normative median value of 0.42 mnok/tonne. As can be observed on the chart, the material cost per tonne was marginally reduced overall, in spite of changes within the disciplines.

<u>Labour Cost Development</u>

As can be observed on the chart, the labour cost and the labour cost per tonne increases progressively from left to right across the chart. As previously stated this is largely due to the large overruns applicable to engineering and the atshore installation. As judged by the comparative performance charts of Figure 10-3, the final resource levels are well over comparable work.

The high costs are partly a consequence of the high hourly rates that were in turn a consequence of the market situation (high activity) and corresponding shortage of qualified personnel. The industry was also subject to risk aversion at the time due to large overruns in many greenfield projects at the time as consequence of NORSOK. The hourly rate included an extra profit element, which may have tended to cancel the incentive elements in the contract aimed at optimising man-hour resources. This extra labour cost comprises approx. 13% extra cost compared to the market rates of the period.

Man-hour and Weight development

The overall man-hour and weight development shown in the chart below, Figure 10-2, mirrors the labour cost development seen above. Corresponding discipline weight and man-hour detail charts can be seen in Figure 10-4.

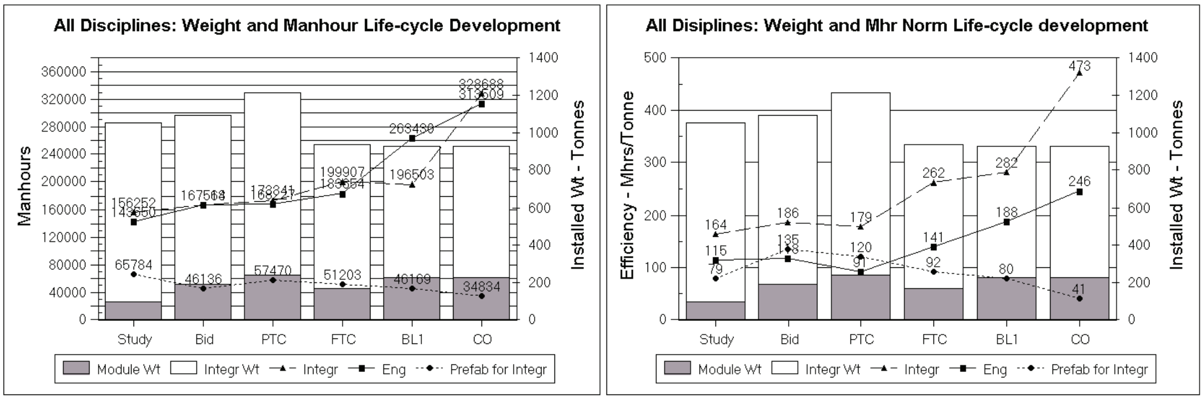

Figure 10-2: Case 2 overall man-hour and weight development

The interesting features to note are the overall decrease in prefabrication man-hours and the late abrupt overall increase in engineering and integration man-hours.

The reduction in planned prefabrication man-hours is consistent with the decision to focus, as previously mentioned, on field erection of steelwork rather than optimise prefabrication. The norm increase after FTC may be consistent with this assumption, indicating that some allowance was made in the planning basis for this decision.

The abrupt engineering increases after the FTC forecast can be associated with under-dimensioned resources and a low progress status considering the high degree of preparation required to support the intensive atshore installation program. Engineering resources are seen to rise right until termination, indicating that engineering was ongoing after preparation for the atshore phase should gave been completed, and indeed during the full duration of the atshore phase. The latter was a necessary due to the large number of field clashes reported earlier.

<u>Piping</u>

Engineering and integration resource use is high compared to similar work. This is most likely due to the initial schedule stress combined with the large number of clashes that occurred. As previously mentioned, field surveys could not be performed due to pressure of time.

There is some scope reduction but little other change as a result of the concept development, though the piping composition did change slightly towards an increased content of high grade steels (40% CS to 60% CS content).

The forecast, BL1, immediately prior to the start of the atshore phase, is of interest. Engineering is already in overrun and reported progress was only 58%, at a point in time when preparation for the atshore phase should have been complete. At this same point in time the integration forecast showed a marked reduction in the atshore man-hours associated with a decrease in integration weight. These man-hours were to double in the following atshore phase.

This indicates that the overrun problems are not a consequence of under-evaluated complexity or other unforeseen problems but, more likely, a consequence of incomplete engineering (incomplete field surveys/collisions) and installation planning aggravated by a the tight and demanding conditions of the atshore installation program.

Steelwork

The steelwork resource use is much higher than normal (median) levels of performance would suggest, but part of this is considered to be consistent with the characteristics of the work, consisting of a high content of small items, mostly welded construction, and a focus on field erection methods. Some part of the overrun may be associated with under-evaluation of this greater complexity while some part is most likely associated with rework resulting from piping clashes.

Considering the degree of preparation required to support the intensive atshore work program, the steelwork engineering progress was low at the start of the atshore phase, only 72%. At this point in time the steelwork engineering was already in overrun, and continued to draw resources all through the atshore construction phase.

This is the same situation as with piping, and the same conclusions can be drawn.

Instrument: The instrument man-hour level and efficiency is may be regarded as normative considering the fact that the scope included a large component of control room work which is difficult to estimate. It is nevertheless interesting to note that the man-hour profile harmonises with the weight profile and should perhaps not be regarded as an overrun. However, it is likely that the planned construction resource needs were under-dimensioned by approx. 13000 man-hours, due to the late materials update, which can be seen in the chart Figure 10-4.

Electro: The disciplines weight share is larger than usual, of which approx 96% is cabling and associated materials. Bulk growth was experienced, but, judging by the integration man-hour profile with respect to the electro weight development profile, referring to the charts of Figure 10-4, the information appears not to have been translated into the planned man-hour basis for the atshore phase. It is interesting to note the engineering man-hour increment coincides with the weight growth. Better weight monitoring would have eliminated part of the volume related man-hour shortfall by approx. 30000 man-hours.

Equipment: Weight reductions for equipment can be attributed to the elimination of scope due to the use of revamping rather than new equipment. Man-hour usage is normal and an insignificant part of the total.

CONCLUSION

On the basis of the recorded results and in comparison with similar work, it may be concluded that the execution of the project has not been optimal. The project was not subject to significant conceptual changes and the project maturity at the time of contract award may be regarded as good. Accordingly; the reasons for the poor performance must be sought elsewhere. Some of the overrun can be attributed to quantity growth (electro/instrument) and changes in the piping material composition, but the low efficiency has other causes.

Considering the character of the work, the projects forecast resource needs for the installation phase were marginally under-dimensioned, by about 6%. But the over-consumption with respect to the contract was much larger. This was partly due to changes in the nature of the work (steelwork installation method) and growth (electro, instrument), but primarily due to poor productivity during execution, as a consequence of collisions and associated rework, aggravated by the demanding conditions of the atshore phase (high manning, high density, high work volume, unsuitable period, non-routine workforce).

In summary, the root cause of the overruns may be found in a compound of the following conditions:

- the schedule and volume of work were tight
- the atshore installation circumstances were challenging
- success was particularly dependent on the quality and completeness of the preparations for the atshore phase
- engineering resources were initially under-dimensioned
- important preparatory activities, such as field survey, were not performed due to lack of time leading to extensive collisions
- due to schedule pressure, installation planning opted for inappropriate steelwork installation methods requiring high field manning (note that this may, in the long run, have been advantageous in view of the need for extensive rework as a result of collisions)
- the atshore period was not advantageous (summer holiday)
- planned manning levels were high and the timing necessitated the use of non-routine personnel
- the effects of crashing

From this it may be deduced that organisational dispositions and circumstances of execution may exert a considerable influence on the efficiency of execution, particularly in cases such as this where the tight time frame for execution severely limited any possibility for corrective action.

Core Parameter Comparative Performance Summary

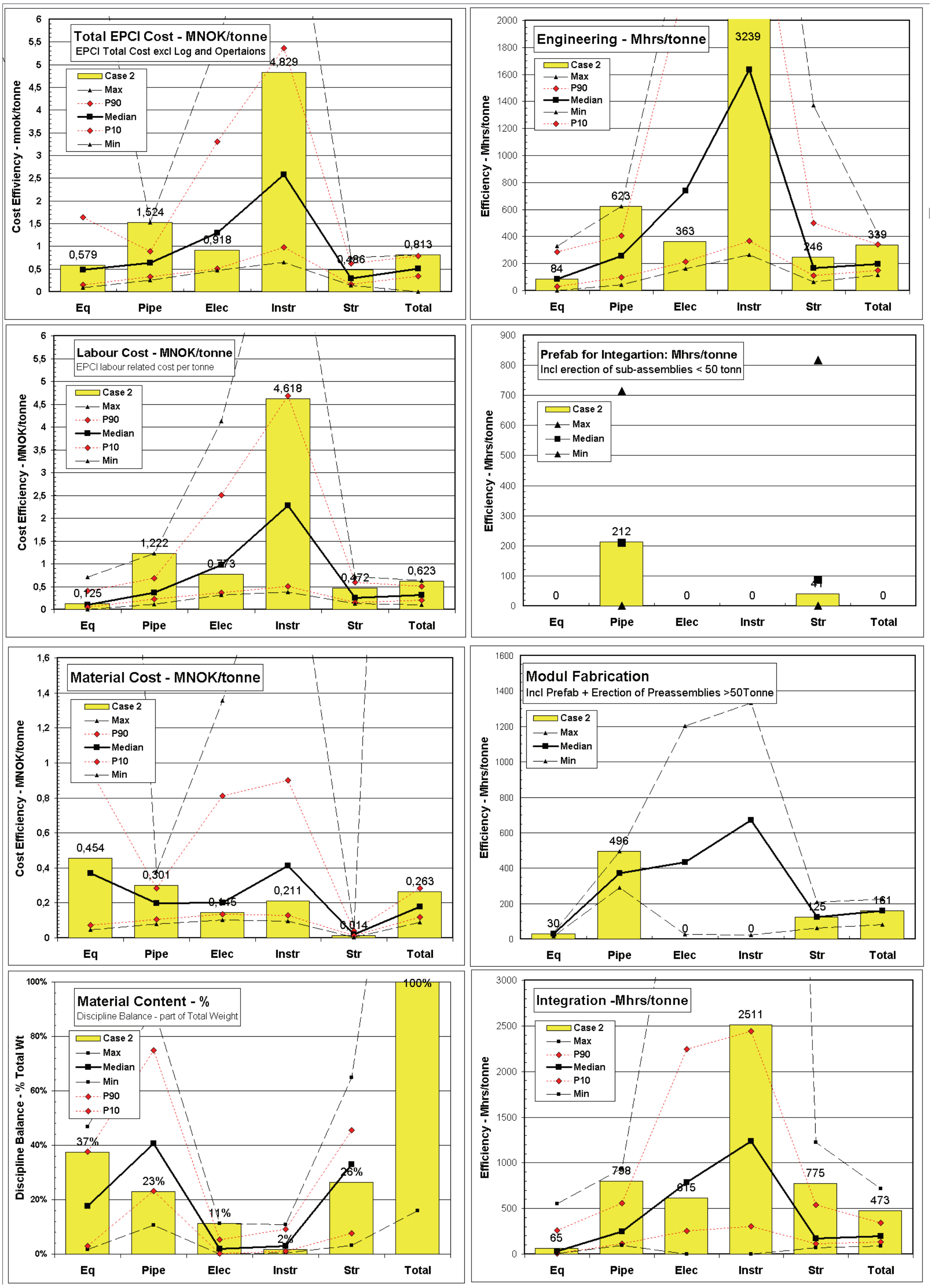

Figure 10-3: Case 2 core parameter comparative performance summary

Discipline Weight, Man-hour and Norm Development Summaries

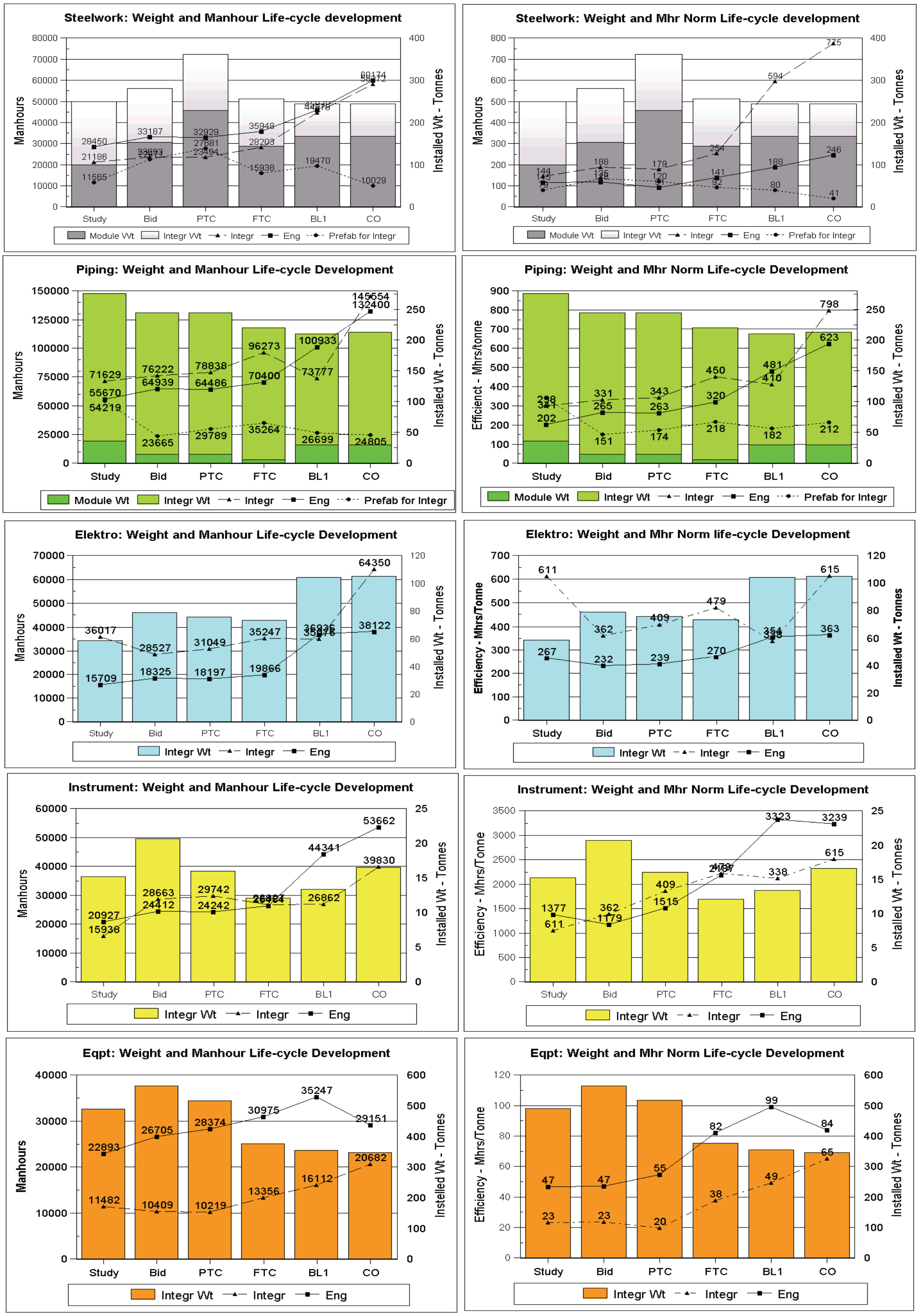

Figure 10-4: Case 2 discipline weight, man-hour and norm development summary

11 APPENDIX 3: Criteria for selection of estimating parameters from performance data and premises of the simulation model

Introduction

This dissertation promotes the use of performance measurement data from completed projects as basis for the various project control practices that rely on estimating. Amongst these proposals is a quantitative risk analysis model based on performance data from completed projects. Since the normative perspective underpinning risk analysis theory basically does not rely on the use of statistical data directly [74], it has been found necessary for the sake of consistency to seek some form of alignment between the normative perspective and the use of data derived from performance measurement of field work.

In general the dissertation has favoured the use of median values drawn from the data in preference to the average values of normative practice. This practice has been adopted because of alignment with the 50/50 concept and believing that the median, being less sensitive to influence of highly deviant values in an array than the average, is more representative of the most likely value of any given array of data than the average. Acknowledging a certain objectivity in retaining extreme values in an array of performance data, this approach makes it possible to retain the deviant value in the data set, but without excessive distortion of the reference values drawn from the array. The median perspective is also seen as consistent with the normative theory underpinning stochastic uncertainty analysis routines, which assume that the sub-elements in an estimate are most likely values or modes (Arrto, 1986; Austeng, Hugstad, 1995; Hilsen, Hulett, 2004; Hulett, 2002/2003; Klakegg, 1994; Lichtenberg 1984, 2000; Rolstadås, 2001; Westney, 1985). It follows that medians, being closer to the modes than averages and assuming an upward skewed distribution profile, are to be preferred to averages. Given that the mode of an array cannot be established with the same ease as medians and averages, and knowing that the result will have a margin of conservatism, it seems pragmatic to select median values as reference values for the base estimates.

Circumstances where there is large diversity in the reference data, such as the modification reference data presented in Chapter 3 which are sensitive to effects of scale, are not quite so easy to handle, since neither medians nor averages taken from the full array will be fully representative. Trend functions have been identified using standardised functions in the software, but none are considered to be correct for all cases. The estimator is left in an undesirable position with at least four alternatives amongst which to select a reference value for any particular case. The basis for selection is not obvious since individual trend lines may deviate considerably from each other, presumably a result of the high degree of variability in the reference data. For practical purposes some means must be found to resolve the problem in the interests of consistency of practice amongst several users and in the interest of QA practices that seek predictable results.

The problem has been resolved partly by objective means and partly by subjective intuitive means, by comparing results of the standard trend functions with moving average and moving median values in the data sets.

[74] The unique nature of many projects and the associated lack of performance data has resulted in the adoption of subjective methods based on expert judgement for assessing uncertainty and quantifying risk (Artto, 1986)(Hillsen, Hulett, 2004)

Comparing the results of the standard trend functions in the software

The trend functions in the software include best fit functions, which ought to provide a basis for comparing and selecting the most representative trend functions. However, due to the high degree of variance in the data, the 'fit' is by no means good for all functions and the best functions are often judged to be wrong on an intuitive basis. The basis for this intuition is demonstrated visually in the chart of Figure 11-1 below referring to the trend line TREND - Integr Rawdata (Log), which has the best 'best fit' values. However, it can be seen from the extrapolation towards larger projects that the slope of the trend line is too steep compared to the other trend lines. This raises doubts about the correctness of the values of the trend within the range of the reference data as well. Note that the linear trend function, which is located above the log function, has not been shown on the chart, since this introduces negative values in the array. On this basis the linear function is also suspect, leaving the power and exponential functions as credible candidates to provide consistent results within the range of the data and in extrapolation. These two functions are also seen to fit best with respect to each other.

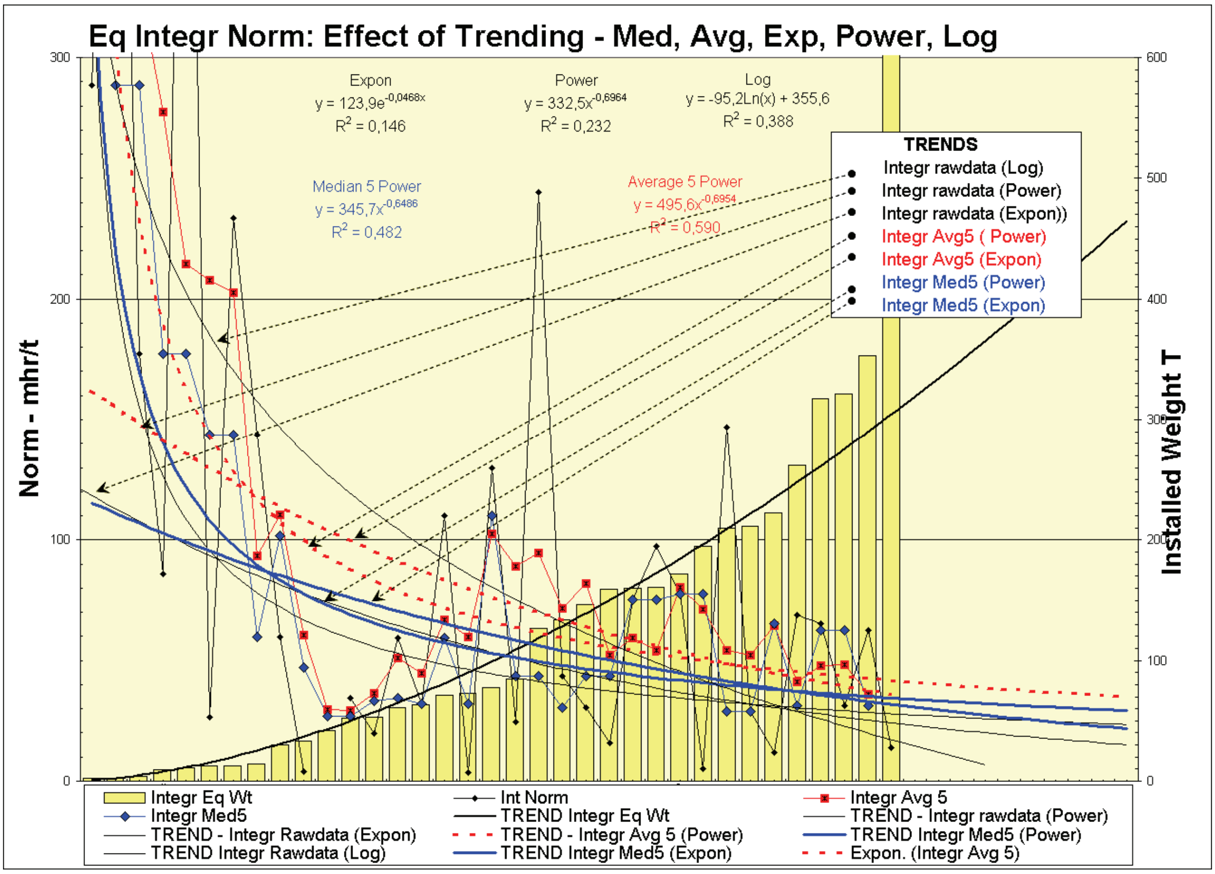

Figure 11-1: Equipment integration norm - Effect of trending

Considerations of medians versus averages:

Following the discussion in the introduction to this Appendix, the medians are the preferred choice judged on a general basis. Consistent with this view, a method must be established to identify which of the standard trend functions coincides best with the median values of the subgroups in the array. Accordingly, plots of median and average based trend lines were established using subgroups of 5 size-related cases centred on each case in the array and moving progressively through the entire range, noting that the range was aligned by size.

These new datasets were in turn trended using the standard functions, and the results were compared to the trend lines derived from the raw data. This process was repeated for all disciplines and for both the man-hour–related data and the cost related data. By this process of comparison it was observed that the median-based power and exponential trend lines corresponded best with rawdata-based power and exponential trend lines. The locus of the median trend lines was in some cases above and in some cases below, but mostly above the rawdata-based trend lines.

By a similar process of comparison, the average-based log- and linear trend lines were found to correspond broadly with rawdata-based log and linear trend lines.

Conclusion:

On the basis of the above rationale, the power and exponential trend lines are deemed to provide the best overall fit. Further, since the rawdata trend line lies below the median based trend line, this rawdata value may approximate the mode of any data subgroup more closely, and may thus be used as the reference value for estimating sub-elements, in preference to a median based value. In the cases where the rawdata trend line lies above the median trend line, the use of parameters from the trend line will be conservative.

Finally, noting that the power and exponential trend lines cross at two points, an approximation for selecting norms may be achieved by using a midpoint approximation. However, at the large project end of the array, and judging by the results of the extrapolation, it is assumed that such an approximation should follow the power trend line.

Considerations of the risk analysis model

The choice of median or average as a basis for dimensioning the sub-elements of an estimate has implications for the premises of the risk evaluation model. Most companies define estimate acceptance criteria to be either a 50/50 or Expected Value with prescribed upper and lower limits within a confidence interval of 80%. Similarly most companies predefine recommended levels of contingency in order to raise the base estimate to an acceptable level consistent with commercial risk and uncertainties inherent in the estimate. Analytic or simulation techniques are then used to verify or override the recommended levels of contingency, although some companies avoid the use of such techniques, regarding them to be of little value. However, in the absence of a consistent definition of the basis for deriving the base estimates, the results can be misleading.

From the chart above it can be established that, dependant on size, the difference between median and average parameters has an order of magnitude varying between 15% and 25%. This implies that the base estimates derived from median- or average-based parameters will vary by a similar order of magnitude. In broad terms the sum of the sub-elements based on averages may be equated with the Expected Value. This is not the case regarding median based sub-elements, where some simulation procedure will be required. However, it can be seen from the above that the uplift from median-based base estimate to an expected value will have a similar order of magnitude. Since it is common practice to use averaging, and uncommon to prescribe the use of medians, it seems reasonable to assume that base estimates will often be average-based and thus already approximate an expected value. In such circumstances, uncritical application of a prescribed contingency will have a result that is too high by an order of magnitude similar to the above. Accordingly, for the sake of consistency, median-based estimates should be prescribed.

The same conclusion will apply to the application of stochastic analysis techniques.

In a simulation situation, the results will similarly be dependent on a clear understanding of the correct premises for defining variable constraints.

Ranges of variance for the simulation model may be drawn from the performance data by establishing p10 and p90 trend lines in a similar manner to the average and median based trend lines described above.

From the above it can be understood that in the case of estimating parameters derived from performance data it is relevant to question on what basis the estimating parameters should be determined and what implications the choice will have for the premises of the risk analysis procedure.

Modification projects appear to have a large variability and by experience require a larger prescribed contingency than greenfield projects. This general conclusion is also validated by the analysis of overrun projects from Chapter 5. It may be a consequence of this greater variability and anticipated need for higher contingencies, that the anomalies described above have greater visibility in modification projects than greenfield projects

Premises of the risk evaluation model

Consistent with the arguments presented above, the following premises have been applied to the risk analysis model defined in Chapter 5:

- estimating parameters are median-based, derived from the effects of scale curves
- the profile of the sub-elements are defined as log-normal
- the range of the sub-elements is defined as P10/P90 values of the range of all the projects in the array

In addition the following elements have been defined:

- the range of the weight input is taken from weight uncertainty prescribed for the class of the estimate under review, but applied asymmetrically consistent with experience that weight growth is seldom negative
- correlations are applied 1:1 between weight input and the weight dependent activities
- correlations are applied 1:1 between engineering overrun with respect to the base estimate and the engineering dependent activities

The engineering correlation is a consequence of the overrun analysis described in Chapter 5.

The model premises may be adapted to conform to successive stages of development and execution in the following manner:

- Forecasts are estimated on the basis of updated weight estimates. These forecasts form the input to the simulation. The residual work is defined on the basis of the forecast degree of completion. The variances in the model are limited to apply only to the residual work. Problems may arise in situations where the actual performance does not align well with the estimates that are based on total installed weights. In such cases some correction factor will need to be applied to the completed work to reflect the actual performance.
- The technical uncertainty is defined by the weight variances, which can be narrowed successively in line with the estimate class requirements as engineering develops. The piece-small and weightless elements that often materialise in the field are normally accounted for, partly in the norms themselves and partly in the performance variance. Nevertheless, special attention should be paid to quantifying these items in terms of

discipline and sub-discipline characteristics, by means of field surveys, so that they can be incorporated in the base estimate input to the risk simulation.

- The engineering correlation elements will endure as long as engineering proceeds and can normally be removed after completion of detailed engineering. Residual elements of engineering inefficiencies that may endure through the integration and hook-up phase, are accounted for in the performance variances. However, special attention should be paid to the system testing and commissioning phase. This model can realistically only account for the above uncertainty on a generalised basis and should be supplemented with a more detailed evaluation
- The fabrication correlation elements between the prefabrication and the offshore integration can be removed after completion of prefabrication. However, special attention should be paid to the effects of carry-over from onshore module fabrication to the offshore integration and system testing. The sensitivity case 6 currently assumes a 5% manhour carry-over, but the simulation model does not account for carry-over effects. Particular consideration should be paid to quantifying the nature of the outstanding work in terms of discipline and sub-discipline characteristics, so that these effects can be incorporated in the base estimate input to the simulation. As this model can realistically only account for the above uncertainty on a generalised basis, it should be supplemented with a more detailed evaluation.
- The fabrication correlation elements between the offshore integration and the logistics cost elements will endure until the job is completed.
- The equations that define correlation can be altered to suit the circumstances. This model covers a full spread hire for the duration, which has been coupled to schedule uncertainty by applying an offshore manhour overrun penalty to the flotel hire costs. This sets the premise that the accommodation costs and flotel hire costs must be separated. Similarly, carry-over can be modelled into the module fabrication in the form of an overrun penalty. This approach may also be used to apply a rescheduling penalty to an HLV contract.

Conclusion

Experience with the model so far indicates that the deterministic base estimate is lower than the mode, and the simulated Expected Value is lower than the value of the Recommended Value (base estimate plus the prescribed contingency). This suggests that the mode would be a suitable basis for setting performance targets and the Expected Value, or the Recommended Value, for setting budget levels, while project management should look to the P90 value for motivation to introduce the risk mitigation procedures described elsewhere in this dissertation.

The dispersion profile Figure 5-2 is representative of this view.