

## Appendix C: Detailed Aspects of Engineering Practice and Expertise

This on-line appendix provides the detailed framework on which the description of engineering practice presented in the paper has been based. The first part presents all the component aspects of engineering practice observed in the interview and field study data. Each aspect was used as a code in the qualitative analysis process described in the methodology section of the paper. The second part presents all the aspects of technical and business expertise observed in the interview and field study data. The main text of the paper presents a higher level and simpler description of engineering practice. It is essential to remember that this detailed description forms the foundation on which it is based.

### 1: Managing self & career development (8 codes)

personal research	Background research, not for immediate work needs, on technology developments, organizational and planning methods, business approaches, components and alternatives: when one type of material or component is not available which ones can be used instead, all to build personal knowledge and expertise.
seminars, business events	Attend trade shows, conferences, exhibitions, supplier seminars and presentations, visit and develop knowledge of suppliers and capabilities.
formal training	Attend formal training courses, further education.
network contacts	Networking contacts in relevant industries to act as referees or to find potential alternative employers.
internal transfer	Apply for internal transfers to provide opportunities for skill improvement and work experience on particular projects or assignments.
promotion	Apply for promotion, provide knowledge of achievements to people who influence promotion opportunities.
apply for job	Apply for positions outside organization, register with employment agencies, maintain current résumé and portfolio of achievements.

time planning                      Plan personal time allocation, maintain diary and appointment schedule.

## 2: Coordination, working with other people (15 codes)

coordinate insiders, mentoring      Coordinate work of peers, subordinates and superiors. Perform technical checks on work, watch for emerging technical issues and roadblocks, may provide advice and feedback, may review technical competence, may assess training needs, provide informal training when appropriate.

supervise staff                      Supervise and support staff for which engineer has line management responsibility.

coordinate outsiders                  Coordinate with outside organizations such as other contractors working on same project, community organizations, etc.

coordinate with client                Liaise with client, expedite solution review and acceptance, coordinate installation, commissioning, monitor acceptance testing.

advocacy, negotiate shared meaning      Advocacy for a particular technical or commercial view, negotiating a shared understanding or meaning.

site engineering                      Coordinate and supervise work on site: perform inspections, watch tests, ensure that work performed according to drawings and specifications, plan site work, coordinate with foremen.

supervise contractors                Coordinate and supervise work performed by contractors: perform inspections, watch tests, ensure that work is performed according to specifications and requirements.

reverse mentoring                    Providing mentoring, guidance, coordination, training and supervision to more senior or experienced personnel

cross cultural coordination          Coordination, supervision of people from different cultural backgrounds.

report progress	Report to supervisor, team leaders, peers on project progress, solutions, financial and resource consumption. Verbal, written or in meetings. Represent interest area.
delegate technical work	Allocate responsibility for technical work: balance technical expertise and experience against cost and availability, decide whether to employ additional staff or contractors etc. Select appropriate working methods and tools.
delegate supervision	Allocate appropriate technical supervision capacity for a given activity to ensure that required performance and quality standards are measured, maintained and recorded.
build and lead team	Build and lead a project team. Create shared vision, objective, monitor team members, support team members.
networking	Networking: develop and maintain network of contacts to help with performance of job
organize socials	Organize recreational and social activities within organization

### 3: Engineering management processes (14 codes)

plan project	Plan project taking into account activity constraints (eg design completed before starting construction). Gather data such as time and resource requirements for individual activities. Perform critical path and resource analysis.
assess risks	Assess risks associated with any activity, including safety risks, commercial risks, supplier risks, early completion etc. Assess and document likely causes, consequences, relative importance and treatment options such as insurance, protection equipment, financial safeguards, safety warnings, training etc.
regulations and approvals	Research government regulations and legislation, environmental laws, employment laws, contract law, occupational health and safety. Prepare submissions

	to obtain necessary approvals, negotiate with regulator
design procedures, org'n	Create, review and develop standard organizational procedures or organizational structures. Devise appropriate structure for engineering project and/or team based on previous experience of organization and individuals involved, and the nature of technical issues likely to be encountered.
manage project	Manage project: review budget and plans, time and resource estimates, progress data, resource allocation, re-plan if schedule slips or dependencies change.
assess progress	Monitor and report technical progress. Decide whom to contact and when, whom to believe, decide which evidence is needed to assess actual progress.
manage maintenance	Plan maintenance, condition monitoring, maintenance and prepare asset management plan for components and systems with high failure costs and/or consequences
logistics	Plan and manage procurement, transport and storage of materials, components, and completed product, manage inventory and stock levels.
manage information	Manage internal documentation, drawings, and other information resources; maintain indexing and filing system, ensure safe storage and/or backup, including personal computers, phones, PDAs.
follow org'n procedures	Learn and practise standard organizational procedures (eg purchasing, tender preparation, design review, configuration management, safety risk assessment, quality measurement, quality control and quality management, etc.)
walkaround inspection	Inspect work in progress, visit site or factory, conduct informal discussions. Wander around, without specific intention.
completion report	Report completion (prepare and check punch lists), prepare payment requests, prepare documentation,

file test reports, installation logs.

manage production                      Manage production capacity and resources for product delivery (product is the output of resources being managed: can be people, plant or machines or combination).

configuration management              Configuration management (records of design documentation, changes, inventory of completed parts, stock lists etc.)

#### 4: Financial processes

predict costs                              Predict costs, prepare accurate bills of materials, reliably estimate labour, accommodation, training, equipment hire, transport, consumable material and capital equipment costs.

manage cash flow                        Predict cash flow requirements for a project, predict delivery lead times, take payment deadlines into account.

invoicing & debt collection            Manage invoicing and debt collection, payments to contractors, maintain background knowledge on contractor financial status.

negotiate internal resources            Negotiate for internal resources; prepare business case for investment: calculate costs (labour, materials, etc.) and consumption or raw materials, fuel and energy, determine emissions and waste management costs, determine maintenance requirements and cost, perform discounted cash flow analysis, calculate internal rate of return.

commercial negotiation                Negotiate contract price and conditions, payment schedule, completion criteria, technical specifications, cost of changes.

#### 5: Procurement (3 codes)

research supplier                        Research, get help on component and service supplier products (reliability, quality, cost, availability, technical support capabilities), includes using network of peers for obtaining background

information on suppliers or contractors.

procurement, evaluate tenders	Evaluate tenders, quotations and specifications from contractors and/or suppliers, check against specification and requirements, check costs.
review contract terms	Review contractual terms and conditions, determine response to contingency or dispute, negotiate changes.

#### 6: Human Resources (4 codes)

research HR rules	Research, learn, get help on employment conditions and rules, pay rates, basic HR policies and procedures especially for subordinate staff.
recruit staff	Prepare a job description. Search for, advertise, interview engineering and technical/administrative job applicants for given job description, assess suitability. Assess qualifications, knowledge, skills and experience of engineers and technical staff from résumé, curriculum vitae, referees and employment reports.
provide training	Formal training for engineers, contractors, clients to perform required activities. Prepare support materials, case studies, learning plans etc.
evaluate performance	Evaluate job performance (both technical and non-technical aspects) of self, peers and subordinates.

#### 7: Business development (11 codes)

research competitors	Analyze capabilities of competitors, analyze performance of competitor in similar contracts, compare competing products.
accreditation	Accreditation, establish pre-qualification status to enable tender participation.
analyze client requirements	Analyze client requirements, may be tender specifications and drawings, prepare preliminary

	technical solutions and designs, prepare preliminary bills of materials and cost estimates.
proposals, brochures, presentations	Prepare proposals, brochures, presentations that can be used for marketing or business development purposes.
influence clients	Participate in marketing and sales presentations, functions, research potential client needs, client knowledge and expertise, in relation to industry norms, visit and assist potential clients develop projects, explore potential financing options and resources for client, possibly assist client obtain finance for project work by preparing technical specifications and performance studies.
pre-position resources	Pre-position resources, contacts etc. in order to help win bids, and execute them efficiently.
prepare tender or quote	Prepare tender bidding documents, quotations etc.
research environment	Research government and policy changes and major players in economy to help forecast business opportunities.
business development	Planning for new business, develop strategy for developing new types of business or retaining present direction. Plan resources for tendering.
research client rules	Research potential/actual client-specific business rules and applicable contract laws.
check satisfaction	Follow-up clients to assess satisfaction with work, prepare feedback reports
8: Technical, creating new concepts, problem solving, analysis (11 codes)	
solution for client	Develop technical or business solution that provides qualitative and quantitative satisfaction for clients
documentation	Document existing systems, components, processes, create database, data entry.

scoping	Resolving complex technical areas into discrete areas for design work that can be performed relatively independently. May also require resolution of difficult technical problems into simpler design tasks. Choose design philosophy.
design	Create technical solutions to meet client needs from available resources and commercial off-the-shelf (COTS) components using specific technology expertise, design of new systems or components to meet client needs constrained by need to use available materials, production technologies and expertise.
research	Research, get help on relevant technologies, solutions, and costs in response to technical suggestions from peers, clients, contractors, superiors or subordinates (or even self).
research standards & solutions	Research, get help on applicable standards for design, test, operations, safety etc. Develop ways to exploit the 'corners' in standards to maximize performance within allowable design limits. Includes referring to previous designs or calculations.
sketch or outline	Prepare sketches and outline design information for technical staff (e.g. drafting staff, programmers etc.) to produce detailed designs, software, CAD models and drawings. Issue change requests.
detailing	Document details, prepare and issue technical specifications, drawings, software code, circuit layouts and designs, etc.
programming	Create software code from specifications and outlines.
predict failure modes	Predict component and system failure modes and probabilities, determine consequences and costs of failure (FMECA)

predict performance	Predict performance (feasibility study, technical or commercial) of solutions using modelling and simulation of proposed technical solutions and/or designs, including modelling of different business approaches. (Often much time spent on gathering information to construct models and verifying model accuracy).
work package instructions	Design and write instructions, construction, installation, maintenance and operating procedures and instructions, preparing work packages.
reduce costs	Reduce costs (either in design, construction, operations or maintenance) use detailed technical and business knowledge to achieve required cost reductions while minimizing performance loss.
 9: Test and measurement (4 codes)	
survey, measurement	Performing measurements, surveys to gather data for documentation or design, conduct tests where necessary to determine performance, material properties etc, includes reverse engineering.
acceptance test	Perform (or supervise) inspections, acceptance or commissioning tests on purchased (or in-house produced and/or installed) equipment, software, systems and materials, to ensure compliance with specifications and design requirements.
diagnose problem	Diagnose performance issues (may be partial or total failure, or sub-optimal or sub-specification performance), check with databases, consult experts, gather appropriate evidence, perform measurements, locate the root cause, and possibly devise alternative technical solutions.
R&D testing	Design and testing of prototypes, pilot plants, experimentation and data collection to confirm designs, resolve design problems, provide data for full-scale or production designs.
 10: Review and checking (6 codes)	

review tech solution	Review, check technical solution; check documents and specifications against design codes, design requirements and client needs, quality, safety and environmental standards etc. Check for operability, constructability, maintainability.
check details	Check documents, assumptions, drawings, code, check calculations, performance specifications (are they realistic?), use experience with relevant technology
review design change	Review design change proposals from peers or other contractors. Prepare response detailing consequence of design changes.
review costs	Review, check technical solutions and check costs and bills of materials (use experience of operations, construction, commissioning, knowledge of prices etc., compromises between technical performance and cost, which technical features contribute how much to the cost, how necessary they are.)
respond to query	Respond to technical, business or financial questions from peers, subordinates, sub-contractors and clients on construction, installation, maintenance and operating procedures. Suggest repair and maintenance procedures when unexpected operating conditions result in failure to achieve required results.
technical standards	Review and check technical aspects of design or techniques (especially when design has been contracted out) to ensure compliance with design standards and relevant technical specifications. Design or develop technical and quality standards for organization, monitor compliance with standards, provide training and guidance. Includes creating design procedures and/or software.
 10: Hands on work (1 code)	
hands-on tech work	Hands-on technical work; production or maintenance

### Technical Knowledge Categories (37 codes)

Definition of product	Knowledge of product details and components, function and location of each component, how each component contributes to the function of the whole assembly.
Customer needs (technical, social, business)	Understanding of individual client needs, including technical requirements for performance, life, maintainability, compatibility, industry standards etc., understanding client social needs, both within local community and as individual people, understanding client business needs such as price, financing method, delivery timing, client organisation logistics, business rules, installation, maintenance, service and support, repairs etc.
Selling the product	Knowledge of appropriate techniques to represent product to client so that decisions can be influenced, knowledge of aspects of product that are important to client and how to describe and present these. (Also see business development aspects)
Applications of the product	Knowledge of how product is applied and used by client's personnel. The client is more likely to have detailed knowledge than the engineers developing and making the product.
Operating the product	Knowing how to operate the product safely and correctly to obtain desired performance and avoid damage, how to recognize operational problems, how to start the product, how to stop the product and shut it down, how to "mothball" the product for extended storage, how to protect the product from external environment or potential damage, how to care for the product (other than maintenance).
Maintaining the product	Knowledge of maintenance procedures for individual components and for the finished product, including the labour skills and knowledge required,

appropriate maintenance planning and scheduling techniques to be used, spare parts management, procurement and logistics.

Repairing, remediation, modifying the product	Knowledge of repair methods to restore a damaged product to working condition, including repair methods for damaged materials and components. Modification of the product to obtain improved, even satisfactory performance in a given application. (Knowledge of modification methods typically lies with users and may not be known to the makers or producers.)
Disassembly, reassembly of product	Disassembly and reassembly knowledge required for inspection, installation of upgraded components and repairs.
Failure symptoms, signs of “trouble” with the product	Problem indicators, cues, queues and symptoms can include unusual noise, smell, heat, and visible fragments (chips, smoke, rubbings, flakes, fragments, dust, particles -- particles may be attracted or retained by secondary effects such as wet or oily surfaces). Evidence of heating can include discoloration, burn marks, heat haze, shimmering as well as direct tactile contact or temperature indications. Visible damage can include cracks, dents, scratches, marks, rubbing, bends, crazing, discoloration, wrinkling, distortion in light reflections, and burn marks. With electronic equipment signs of trouble can include intermittent failures, heating, even audible noises. Problems can also be evident from operator comments, even the contents of trash bins, for example discarded copies from a photocopier.
Failure modes of product	Symptoms suggest specific failure modes given an understanding of the product and how it operates (T01). For example, a sticking valve in a process plant can cause chemicals to spill from a tank. The failure symptom is spilled chemicals. The failure mode is a valve failing to operate correctly. (See FMECA, E14)
Diagnosis methods for product	Technical methods for collecting data and analysing data to determine the cause of performance loss or failure. This also relies on having a model of how the product functions (T01) and relevant physical

principles (T29).

Packaging, storing, transporting product	Materials and techniques for packaging, packing the product, labelling, batch/serial number identification, storage facilities, transportation of product.
Documentation techniques and standards	Drawing and documentation methods and standards, ways to represent the internal operation of machines and physical systems, use of visual representations, flow diagrams, process and instrumentation diagrams, SAMA diagrams, 3-d models, charts, maps, plans, three-dimensional mapping systems, mine~, building~, and geographic information systems, use of specifications and standards.
Properties, models of product	Properties of completed product, models of product behaviour (technical and commercial) in given applications. Software, mathematical models of technical or commercial performance.
Prediction, forecasting methods, analysis, simulation.	Knowledge to predict future events based on present conditions, anticipation of future events. Knowledge of models and methods to calculate future conditions.
Industry standards and codes	National standards (e.g. BS, DIN, AS), industry standards (IEC, API), and international standards (ISO), codes for design and operations (ASME, ASCE, ASTM etc.), government regulations for technical work. Companies can also have their own internal standards.
Measurement, test, inspection methods	Measurement methods and instrumentation, inspection methods, data collection, analysis of data and presentation of results, data storage and archiving, calibration of instrumentation, certification of calibration, quality assurance of measurement process.

Normal standards for technical work	Relevant to product manufacture and assembly, knowledge of normal standards of workmanship and finish, knowledge of production faults (related to failure modes of production tools and equipment), visible (or audible) symptoms of production faults and other signs of "trouble" indicating present or future problems.
Manufacturing methods	Techniques for manufacture, assembly of product, construction methods, time/cost and resources needed, planning and organization.
Programming product	Applicable principally to products comprising a significant computational component, techniques for programming the product, time/cost and resources needed, planning and organization.
Control of production or working environment	<p>Ways to control the work environment, elimination of errors, quality control, safety, such as (for example):</p> <ul style="list-style-type: none"> <li>* A system of technical standards covering all aspects of work practices, and staff whose job it is to ensure that these standards are followed. This means continually mentoring and guiding technical workers, and helping them understand how to do the work so that it conforms to the standards.</li> <li>* Ensuring that appropriate tools and materials are available.</li> <li>* Setting out all required parts, materials and tools in an organized way before starting the work and maintaining the layout through the job.</li> </ul> <p>(plus many others)</p>
Tools	Tools, techniques and processes for product assembly, use of tools, maintenance of tools.
Component and material failure modes.	Similar to failure modes for the finished product (T10), this involves knowledge of the failure modes of the constituent materials and components.

Component and material properties	Knowledge of the components and materials including models, singly and in combinations, used in a product (T24): here we are referring to the properties of the components and materials. This information is often needed to create a useful model of the product. Many components and materials behave distinctly differently when used in combination with each other, for example, certain plastics may soften or dissolve when exposed to heat or certain oils or organic solvents, oil and water together will often encourage bacteria to grow on the fluid interface, many metals will dissolve or corrode quickly in the presence of acids, others in alkaline solutions.
Knowledge of components, materials	Knowledge of component, design detail or material, what it is normally used for, why it would be used in given circumstances, and qualitative feel for usability (hard, easy) and cost. Includes ability to recognize component or material on visual inspection.
Procuring components and materials, storage, logistics, transport	Component and material suppliers, reputation (price, reliable delivery, support), dependant on order size and lead time constraints, transport, packing and protection, inspection and acceptance testing, quality control, storage and safe handling.
Information retrieval and presentation	Locating required technical information in large amounts of mostly irrelevant written documentation. This might mean finding the minimum clearance between a part (held by a tool) during an assembly operation. To find out, an engineer has to find all the possible components, tools and fixtures that could cause clearance problems and then decide on typical or worst case configurations and calculate or measure clearances to find the most critical ones. Another task might mean looking at every different fastener used in a given work environment to assess how many different types are in use and what they are used for. It takes knowledge and experience to know how to read the documentation, how to interpret information to extract the pieces that are needed, and finally how to reassemble the relevant details into a message that is understandable for someone else.

Defining complete list of operations, parts and materials	Defining complete list of parts and assembly/manufacturing steps required for given assembly and tools and other equipment required for construction, production and assembly. This knowledge is required to be able to prepare and manage robust plans for production, maintenance, shutdowns and repairs.
Productive resource management	How to use resources efficiently, spotting inefficiencies. (E28, E42)
Mathematics and science-based abstract knowledge	Abstract knowledge, mathematics and science-based, from formal education to construct an abstract model of a machine, organism or physical system needed to predict performance or diagnose performance deficiencies.
Human behaviour	Anticipation of human behaviour, how people design, operate, maintain, work with, and interact with natural and engineered systems, fundamental for safety engineering because so many safety problems are caused by people not following normal “sensible” rules of behaviour.
Design philosophies, economic design	Design philosophy (e.g. minimum capital cost, minimum life cycle cost, minimum design cost, minimum downtime, maximum reliability, design for form or function, design within time constraints, extensive tacit knowledge of designs and products
Previous designs for similar products	Most engineering is based on earlier designs, both in-house and from competitors.
Sources of engineering expertise, know-how and skills	Knowledge of people with valuable expertise or access to information. Includes ways to assess relative level of knowledge of a person.
Waste management, recycling, decommissioning	Handling, removing, recycling, treatment, reuse of waste products, decommissioning of plant
Environmental effects	Knowledge of how product and processes interact with environment, general environmental knowledge.

Cost estimation rules	Rules and knowledge for estimating costs in area of practice: information on labour rates, time and resources allowances to achieve given results, material rates, usually based on extensive written knowledge, rates books etc.
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#### Organizational Knowledge Categories (27 codes)

Engineering actors	Personal knowledge about personalities in the firm, and parties external to the firm, including owners, architects, other engineers, contractors, steel detailers, and peer reviewers. Knowledge of engineering actors encompasses how these parties accomplish their work, how they construe the world, what their objectives are, and what responsibilities they shoulder.
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Project management	Methods for planning projects, forecasting time and resource requirements, use of appropriate software tools, progress reporting and documentation.
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Contract management	Techniques for managing the execution of work under contracts, ensuring that requirements of contract are complied with.
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Cash flow management	Methods for forecasting and monitoring cash flow against forecasts in a project or operational context.
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Organization procedures	Knowledge of organisation procedures for handling projects, contracts, engineering work, procurement, tenders etc. Also knowledge of project organisation used by the firm, clients and close associates. Includes quality management procedures and systems, environmental management procedures and systems, occupational health and safety procedures and systems etc.
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Intellectual property	Patents, trademarks and registered designs, application procedures, agreements, conventions for representing technical concepts in legal documents, principles of intellectual property protection, how patents and trademarks are used in practice to defend intellectual property.
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Interpersonal, relationship skills	Techniques for building relationships and influencing people, gaining willing and conscientious cooperation without resorting to authority or contractual relationships
Team and work group leadership	Techniques for leading small workgroup
Political, economic, social issues	Knowledge of current affairs, politics and the economy as it affects the conduct of engineering work and implications for planning and executing projects.
Advertising, public relations	Knowledge of methods for influencing public awareness of firm or project, methods for providing relevant information for members of the public when needed.
Business process, model	Commercial aspects of method by which company conducts business, how the company aims to execute work profitably
Management accounting	Methods for recording costs of internal and external transactions, includes cost accounting methods, depreciation accounting, balance sheets etc.
Finance analysis	Principally for engineers this means methods for estimating return on investment (RoI) or net present value (NPV).
Finance and investment	Methods for financing engineering work, debt, equity financing, debt to equity swap, financial risk management methods.
Marketing, Business development	Knowledge of competitors and their strengths and weaknesses, knowledge of relevant market for engineering services and products, knowledge of firms business development approach, relevant procedures.
Contract law	Restricted knowledge of contract law appropriate for engineering contracts, including contracts for engineering work, procurement, selling, employment

contracts.

Regulations	Knowledge of relevant government regulations that cover engineering work, methods for preparing application for approvals, permits etc.
Managing client relationship	Techniques and procedures for managing client relationship, limits of authority to accept or undertake additional work or modifications.
Presentation skills	Skills used in making commercial presentations and communicating with clients, includes both written and verbal communication skills
Commercial negotiation	Knowledge of negotiation methods, particular methods used in engineering contract negotiations.
Risk management	Knowledge, experience of likely risk events, consequences, likelihood reduction measures for hazards, consequence reduction measures, risk sharing and transfer options, insurance, ways to take advantage of positive risks.
Legal liability	Liabilities incurred in relevant engineering work, how to minimize adverse consequences, how to ensure client is aware of potential consequences of decisions.
Industrial relations	Employment rules government regulations, internal firm procedures for dealing with relations between firm and employees.
Pay and conditions, employment contracts	Knowledge of employment contracts and conditions for self and others for whom some level of supervision is provided.
Performance review, evaluation	Method and procedure for handling review of work performance. Ways to represent achievements to ensure appropriate recognition in the review process.
Search and recruiting	Knowledge of process to find, select and recruit appropriately technically qualified personnel.

Training and staff  
development

Knowledge of firm process for human resources  
development, training.