

# A Systems Approach to the Engineering Work Force

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**ABSTRACT:** *The engineering function, work force and associations should be viewed as a system, for an adequate understanding of the complex interactions involved, for development of coherent policies and for achieving optimal overall performance. Such an approach embraces professional, para-professional and other categories, and requires a coherent system of qualifications, education, occupational identifiers and role definitions. For engineering education, it facilitates effective design of educational programs for each category and educational articulation between them. For industry and society, it fosters work force effectiveness and harmony. The paper provides the basis for systematising the complex of elements that make up the engineering system.*

*Keywords: Engineering, professional practice, occupational identity, engineering education.*

## INTRODUCTION

Engineering is crucial to society, so it is essential that engineering work be efficient and effective. The profession of engineering currently is in disarray through major change in the nature of professional practice and employment. A systematic approach is needed to provide the basis for the coherent organisation of the engineering work force as a whole in a future where the only certainty is change.

## ENGINEERING AS A SYSTEM

The *engineering industry* may be thought of in systems terms (Lloyd et al., 1989). It encompasses private sector manufacturing, building and construction, utility services and consulting, together with public sector utilities, departments, local government councils, education providers and the defence forces. The engineering industry system may be conceptualised as comprising the *engineering function* and the *engineering process*, in an interdependent network of relationships illustrated in Figure 1 [adapted from (Lloyd et al., 1989)]. The engineering system is embedded as a sub-system within the overall societal system. Systems theory enables us to understand that the overall performance of the industry depends more upon how the components of the system operate together, than upon how each element performs separately. This is evident in a consideration of the major system elements:

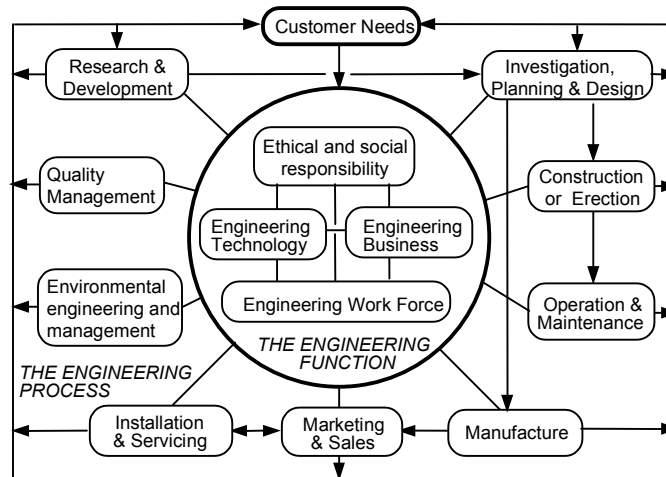
- **Engineering function:** the total effort of the work force under leadership that integrates technology, business and each occupational category working cooperatively for production of outcomes.
- **Engineering process:** the range of interdependent engineering activities that transform ideas into commercial or social outcomes.

## The Engineering Function

The sub-system described as the Engineering Function is what engineering is about: application of technologies by people in business or similar enterprises. The application of engineering technology determines the kind of people needed in the engineering work force and the education and training they need.

Engineering comprises a broad spectrum, from electric power, electronics, computing and control blending into mechanical engineering through mechatronics, manufacturing and process industries, to civil and structural engineering infrastructure. Social, ethical and commercial responsibilities bring all-pervading obligations concerning environmental care. The engineering team are not the only people with such obligations, and they must be equipped to listen to a range of viewpoints from others on such matters.

The engineering work force comprises all the occupations engaged in various enterprises in transforming engineering ideas into tangible realities. The occupations comprising 'the engineering team' are engineers, engineering technologists and engineering officers (or associates), for all of whom systems thinking provides a powerful means of integrating roles, vocational satisfaction through productive achievement, and occupational identity that flows from their qualifications.



Not all elements of the Engineering Process are present in every enterprise.

Figure 1: Engineering as a System, comprising the Engineering Function and the Engineering Process

The organised engineering function has to ensure that all occupational groups work together, and that there are adequate numbers of appropriately educated and trained people in each group. The systems view demands coordination, for each occupational group, of occupational terminology, role definition, the knowledge base needed, and the design of relevant educational and training programs. While there may be overlapping of roles, when there is fuzziness about occupational terminology and the semantics of definitions, there will be confusion impairing overall effectiveness. Hazy occupational descriptions lead to inappropriate expectations of the kind of work that people can do: too high or too low expectations lead to stress and sub-optimal performance.

### The Engineering Process

The Engineering Process embraces the elements of research, development, investigation, design, manufacturing, construction, installation, marketing, sales, operation and maintenance, and the all-pervading elements of resource organisation and management, quality management, and environmental engineering and management.

In particular enterprises not all elements of the *engineering process* are present, but each element of the *engineering function* must be present. Different sequences of process elements of the engineering process may be found. For example, a manufacturing enterprise has market research, product research, development and design, process design, production, sales and service. A different group of activities is undertaken, for example, in the electricity utility company that investigates demand, researches customer needs, designs and constructs facilities, operates and maintains them, and provides reliable service.

The model in Figure 1 shows that every element of the engineering process relevant to a particular enterprise is connected to the elements of the engineering function. In each enterprise the elements of the process are interconnected by complex feedback loops. Feedback is the essence of process stability. Success depends upon unity of purpose in the total engineering process, whether it is building a dam or a building, or making motor cars or computers.

Thus, when the relationship between any of the elements of the engineering process system becomes unbalanced, overall effectiveness is impaired. For example, a manufacturing firm must link market research to product research and development, product design must be linked tightly to production for two-way feedback, and the sales and services must provide feedback from customers to research, design and production. In an electricity utility enterprise there must be unity of purpose across design, operations and maintenance: any strategy to curtail maintenance could not be counterbalanced by increased effort in researching customer needs.

Systems theory emphasises a holistic view in management. Engineering management integrates the effort of the total engineering system. The unity of purpose needed for successful enterprise performance depends upon a commitment from the whole of the workforce to common shared values. Such commitment depends upon leadership, which in turn depends upon engineering knowledge and experience. It is an economic imperative, therefore, that the roles and positive contributions of engineers, technologists and associates be well understood. Responsibility rests with education and the professional associations to generate such an ethos.

### THE ENGINEERING WORKFORCE AS A SYSTEM

The engineering workforce is portrayed as a system in Figure 2. The elements of the work force system are the groups of professional engineers, engineering technologists, engineering officers, and other related occupational groups. Systems theory tells us that if any occupational group is considered separately and made to operate as

effectively as possible, it does not necessarily follow that the functioning of the work force will be optimised or improved. Overall performance depends occupational groups work together.

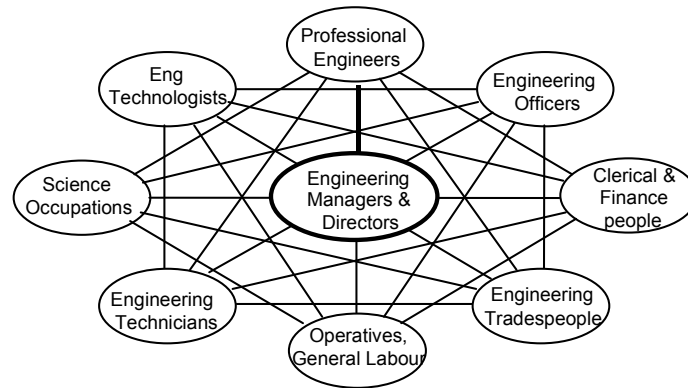


Figure 2: The occupational groups in an interconnected system

As an example of the value of the systems approach, in considering labour supply and demand at a policy level, it would be sensible to consider each group in a total work-force context. The requirement for professional engineers is influenced not only by the supply of engineering graduates and the effective employment of the existing stock of engineers, but also by the supply and effective utilisation of other groups such as engineering technologists and para-professionals. While there are limited possibilities for interchangeability between occupational categories, optimum performance depends upon a balanced workforce.

### IMPLICATIONS OF A SYSTEMS VIEW

A systems view of the work force requires an orderly approach to occupational terminology, definition of work-force roles, design of educational programs, and thus to the design and leadership of organisations within which people work. The systems approach should not imply a 'watertight box' theory of occupational roles, however a systematic structure is required.

The US federal government's Standard Occupational Classification (SOC) system aims to bring consistency to a wide range of occupational classification systems that have previously hindered the effective use of occupational data. Key principles of the revised US SOC are:

- Workers are classified in only one occupation according to the type of work performed, skills, education, training, licensing and credentials.
- Occupations are clearly defined (Levine & Salmon, 1999).

In Australia, the Institution of Engineers, Australia (IEAust) is the engineering professional body and provides the systems framework linking occupational classification, educational preparation and professional recognition. The IEAust's National Generic Competency Standards (IEAust, 1999) identify the following occupational categories:

- professional engineer;
- engineering technologist;
- engineering associate;
- engineering technician; and
- engineering tradesperson.

Definitive competency standards and occupational definitions are provided for the first three occupational categories. The identified purposes for which the competency standard are intended to be used include:

- determination of occupational standing - both for occupational entry and articulation to higher occupational classifications within the scope of the standards;
- assessment for professional registration - for membership of national practice registers maintained by the IEAust;
- course design - as an aid to those designing courses to prepare candidates for membership of the IEAust;
- industry standards - as a reference for the derivation of industry specific competency standards;
- formation and continuing professional development (CPD) - as a basis for planning CPD activities; and
- reference for employers - to determine job specifications and appropriate levels of employment.

The nature of the engineering practice and the preparation required for entry to professional practice are intimately linked. Present educational paradigms require that professional degree courses be designed and delivered in a context in which course content is related to an idealised view of the work roles for which graduates are prepared. It is also necessary to apply labels to courses that coordinate with the labels applied to

identified work roles. Recognising that reality in the work force requires flexibility, it would be foolish to deny that the actual work roles of engineers, engineering technologists and engineering officers overlap. It would be equally foolish to hold that an engineering technologist could perform functions at the highest level for which the engineer is educated, or that an engineering officer could perform functions at the highest level for which the engineering technologist is educated. There are limits to flexibility and interchangeability.

Such an approach embraces professional, para-professional and other categories, and requires a coherent system of qualifications, education, occupational identifiers and role definitions. For engineering education, it facilitates effective design of educational programs for each category and educational articulation between them. For associations, it clarifies strategies and goals. For industry and society, it fosters work force effectiveness and harmony.

### SYMPTOMS OF NON-SYSTEMATIC OPERATION

Symptoms of non-systematic operation of the engineering workforce are many.

At the end of the 20<sup>th</sup> Century qualification-based occupational identity for engineers came under challenge, as role designations such as 'professional' and 'manager' replaced 'engineer' and 'chief engineer'. The converse of para-professionals claiming the title 'engineer' intensified the problem. Such trends result in role confusion in the work-force system, and associated professional and ethical issues. Consider the following typology:

- (a) **Colloquial:** The vernacular applies 'engineer' variously to tradespeople, train drivers, mechanics who repair domestic appliances, and the like. Such usage perpetuates public confusion about identity and roles of professional engineers, but it does not involve deliberate intent to deceive and professional or ethical issues are not present. Colloquial misuse harms the professional image.
- (b) **Marginal:** Non-professional usage in statutory or semi-official contexts, as in 'Licensed Aircraft Maintenance Engineer', 'Marine Engineer', 'sales engineer', 'Certified Microsoft Engineer', 'computer engineer', and the like, is an annoyance in perpetuating public confusion, but does not deceive informed 'clients'. Professional or ethical issues are marginal.
- (c) **Deceitful:** The 1990s saw an increase in the misapplication of 'engineer' as an identifier where 'engineer' normally means 'professional engineer'. Examples occur in some large consulting engineering firms, local government bodies, industrial companies, and para-professionals offering consulting or contracting services. When a person with a para-professional or technologist qualification, or no qualifications at all, is held out to informed clients as an engineer, fraudulent deception is likely to be present. If public health and safety depend upon the competencies of such a person, criminal deception may be present. While there may be legal redress in particular cases, in most there is no societal sanction against such occupational misrepresentation.
- (d) **Unprofessional:** The late 1990s in Australia brought pressures on IEAust to provide for competency-assessed occupational articulation from para-professional to technologist, and from technologist to engineer. There can be no objection to assessment and certification of prior studies and experiential learning in a competency-based assessment, provided that definition by function is not the sole criterion. Evaluation also must ensure possession of the normal knowledge and skills essential to the competencies of the higher occupation.

In Australia, much confusion was caused by changes in the credentialing systems of the technical education sector during the 1980s and 1990s. Refer to Figure 3 for a summary of the Australian Qualifications Framework (AQF) as it applies to the engineering workforce.

Occupational Category	Applicability of Qualifications Framework		
	1979	Existing 1998	New 1999
Professional Engineer	BE Degree (4 year) Diploma (3 year)	BE Degree (4 year)	BE Degree (4 year)
Engineering Technologist		BTech Degree (3 year) Diploma (3 year)	BTech Degree (3 year) Advanced Diploma (3 year)
Engineering Officer (Associate)	Certificate of Technology or Engineering	Associate Diploma (2 year)	Advanced Diploma Diploma
Engineering Technician	Technician Certificate	Advanced Certificate (1 year)	Diploma, Certificate IV Certificate III
Tradesperson	Trade Certificate	Trade Certificate	Certificate IV Certificate III

Figure 3: The Australian Qualifications Framework interpreted for the engineering workforce

This paper contends that an effective systems view of the workforce is dependent upon clarity and understanding. In the period following 1979 there was a clear relationship between qualification and occupational category. The replacement of the para-professional Certificate by the Associate Diploma in the late 1980s and the introduction of Advanced Certificates caused confusion for a time, but the changes provided

clarification of the connection between education and workforce categories, and clear separation of para-professional from technician roles. The new broad-banding approach to the AQF (AQF Advisory Board, 1998) creates confusion, in that there will be a variety of qualifications called 'Certificate', 'Diploma' and 'Advanced Diploma', without certainty as to the occupational category for which they are applicable. The new qualifications framework for the engineering workforce is potentially detrimental to an orderly and systematic approach to workforce organisation and management.

Articulated education is a pragmatic means of increasing the pool of talent in the engineering workforce by widening access to professional occupations, especially for mature age people. Articulation makes sense when considered within a systems framework of definition by qualification and career progression to a higher occupation. Articulated education envisages a series of end-on courses allowing time-efficient progression through occupational levels to professional engineer. The future confusing and variable array of qualifications for the engineering workforce is likely to inhibit systematic approaches in the design of articulated education pathways to bachelor degree level.

The coupling qualifications to occupational identity is an essential element of professionalisation. While watertight boxes are not advocated for restricting the work of occupational categories, when the work-force is considered in systems terms there must be a logical consonance between education, work roles, work values and occupational titles, providing unambiguous identities based upon qualifications. Some overlaps at the margins between the work of occupations are inevitable, but ambiguous occupational identity raises false expectations for performance. Qualification-based occupational identity is at the core of the orderly, non-rigid, organisation of the spectrum of engineering work. Members of each occupation take pride in identity flowing from qualifications. Every occupation has value within a system of interdependencies requiring harmony and cooperation. The expression 'engineering team' epitomises the systems view. Therefore qualifications-based occupational identity is essential for an effective work force system. Ambiguous occupational identity leads to occupational dissatisfaction at all levels.

In Australia, the IEAust maintains a membership structure that provides Chartered status for engineers, technologists and para-professionals. It also operates two national registers, the National Professional Engineers Register (NPER) and the National Engineering Technologists Register (NETR). Prior to 1993 attainment of Corporate Member (MIEAust) and Chartered Professional Engineer (CPEng) status required three years of professional development (including design and field work) post-graduation followed by a professional interview conducted by the IEAust. More flexible criteria were required to cater for the employment spectrum from large employers providing structured professional development, to small enterprises where professional supervision might be absent. In 1993 new criteria were set out in a document Standards and Routes to Australian Recognition (SARTAR). Candidates were to present an Engineering Practice Report and undertake a Professional Interview to satisfy the National Competency Standards for Professional Engineers. The three routes, post-graduation, to MIEAust and CPEng were:

- Route 1: 3-year Structured Development Program.
- Route 2: Supervised Experience, minimum 3.5 years.
- Route 3: Acquired Professional Experience, minimum 4 years, for other engineers.

The 1993 criteria for CPEng, and the simpler criteria applied previously, were pitched at graduation as an engineer plus 3 or 4 years experience, in a systematic alignment of MIEAust, CPEng, Registered Professional Engineer, and 'Experienced Engineer' (the latter title used in the Australian Professional Engineers Awards - industrial relations agreements covering the work of professional engineers). The alignment confirmed that Chartered Professional Engineers possessed knowledge, skills, attitudes and values from educational attainment and intellectual capability, and accepted accountability for competent ethical performance. Competency-based assessment made possible reciprocal recognition agreements at Chartered level with engineering bodies in many other countries.

In 1998 a second change in criteria for Chartered Professional Engineer disconnected MIEAust from Chartered and Registered status. Under the changed criteria:

- Admission to MIEAust remains graduation plus three or four years experience, but is not competency tested. MIEAust retains the nexus with the industrial award provision for Experienced Engineer.
- The new National Competency Standards for Professional Engineers (IEAust, 1999) require experience virtually impossible to acquire in three or four years initial professional development, making admission to Chartered and Registered status well beyond the level of previous MIEAust and Experienced Engineer. Applicants present an Engineering Practice Report (EPR) tested in a Professional Interview. Retention of CPEng is conditional upon CPD, and lost if CPD is found wanting.
- The NCSPE include a compulsory requirement for several years experience in every aspect of engineering design, ignoring the new paradigm under which engineering enterprises outsource most design, and the much diminished public sector training opportunities in design. A late amendment coupled 'planning' with design, but the detail is about traditional design.

- Electives in NCSPE do not emphasise technical expertise. Project and environmental management are featured, but construction and maintenance engineering are obfuscated within 'engineering operations'. These decisions by IEAust disrupted the system of occupational identity that had been built up carefully to coordinate professional status with employment and industrial relations. Disconnecting competency assessment for CPEng from MIEAust, and raising the bar for compliance with the competency demands, seriously disrupted the system. By placing CPEng out of reach for most young engineers, few are likely to seek the status of MIEAust but not CPEng, because to do so would be to admit inadequacy. More graduate engineers than ever are likely to avoid the issue and not join IEAust, but simply rely on their degree and their CV. The new inhibiting criteria for CPEng could jeopardise the future viability of IEAust.

Some perceptions separate engineering from management, regarding roles above the first level of supervision as 'management', not 'engineering'. Some engineers think of career development as 'moving out of engineering into management', even when managing engineering work. However, views that separate the management function from the practice of engineering are not conducive to an effective engineering system. All engineering work requires dealings between people within business and managerial frameworks. Engineering has to be customer driven because it is about supplying the needs of communities and markets. While the engineering function is about technology and the people who develop and apply it, it is also about the people who are affected by it. Engineering teams therefore need competencies not only in technology, but also in business and management. Managerial leadership pulls everything together to meet customer needs and the commercial realities and obligations to investors.

Non-systematic and dysfunctional operation of the engineering system has been accompanied and exacerbated by radical changes in the nature of professional engineering work. Transformation of engineering work and its organisation began in the 1980s, in the 1990s engineers found themselves in situations of frequent change and uncertainty in employment, drastic decline in public sector employment, and for most a shift in emphasis from service to entrepreneurial attitudes in business. Change brought an acute decline in opportunities for new graduate professional development. Elimination of much middle management and de-engineering reduced opportunities in management. The new practice paradigm includes an expectation of whole careers in technical practice, with greater need for CPD in ever-changing technologies and work roles. The upsurge in engineers taking up studies in management reflects the new survival skills needed in a tough environment. The economic rationalism that engulfed the professional paradigm fostered individualised competition and loss of focus on the public good. At the same time, labour market ideologies scorned professional values as a veneer covering greed and self-interest, blind to a view that productivity and innovation are derived not only from competence, but also from a work environment fostering leadership and teamwork based upon human values, appropriate rewards for talent and effort, and vocational satisfaction within an ideal of ethical service. Ideologies about 'efficiency' and 'competition' threatened public good through dismantling professional values. Yet these shifts in the professional paradigm were accompanied by a drastic reduction of allegiance to IEAust and the profession of engineering.

## CONCLUSIONS

The engineering function, work force and associations should be viewed as a system, for an adequate understanding of the complex interactions involved, for development of coherent policies and for achieving optimal overall performance. Such an approach embraces professional, para-professional and other categories, and requires a coherent system of qualifications, education, occupational identifiers and role definitions. For engineering education, it facilitates effective design of educational programs for each category and educational articulation between them. For associations, it clarifies strategies and goals. For industry and society, it fosters work force effectiveness and harmony. Symptoms of non-systematic operation are seen in misapplication of the term 'engineer' leading to unethical, misleading or incompetent practice, in confusion within the Australian Qualifications Framework, in difficulties among educators in assessing Recognition of Prior Learning, in occupational dissatisfaction at all levels, in dysfunctional approaches by IEAust, and in management not seen as part of engineering and engineers not seen as managers.

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