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On the Nature of Mechanical Engineering Work: An Analysis of Practice*

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An ethnographic approach was adopted to describe the types of work which engage professional mechanical engineers throughout their careers. Twenty-one engineers from a range of organizations, educational backgrounds and career stages were interviewed and the records of those interviews analysed to reveal a rich picture of mechanical engineering practice. Six different types of work were identified: problem solving, craft work, supervising, liaising, networking and integrating. The patterns of development which emerged suggest that during a career in mechanical engineering there is a substantial shift from an early focus on technical issues to concerns that are essentially to do with human relationships. Concomitant with that shift there is an increasing commitment to activities which have to do with marshalling both human and material resources to synthesize an engineered outcome to a business proposition. The paper presents a typology of mechanical engineering work, which we believe provides a useful interpretive screen for investigating the essentials of practice. It concludes with some important questions about engineering education raised by the investigation.

INTRODUCTION

THE ROLE of engineering in the future of advanced industrial economies is once again emerging as central and dynamic, just as it was seen to be throughout the heyday of the industrial revolution. From about 1950 to the late 1980s, science seems to have occupied centre stage, particularly the 'big' science which has led to spectacular discoveries about the natural world on scales from the smallest elementary particles to the astronomic. That preoccupation with science led not only to a widespread acceptance of the reality and importance of scientific method, but also to a model of industrial product innovation in which scientific disoveries made though research triggered a linear 'sequence of operations; research, development, production, marketing and sales' [1]. Now, according to Gibbons [1] the pressures of international competitiveness have undermined this linear model and a new regime is emerging wherein new products derive from the linking of a technological opportunity with a market need. In this regime 'knowing how' is equally important to 'knowing what'. Engineering, it is now clearly understood, makes its own contribution, as does science. But is there an 'engineering method' to stand alongside the scientific approach? This paper is concerned with that question, seeking to illuminate the nature of engineering work through an analysis of professional mechanical engineering practice.

An ethnographic approach is adopted in this paper. Fetterman [2] described ethnography as the art and science of describing the routine daily lives of people within a group or culture. The group of interest here is engineers in professional practice working in technology-based companies, i.e. companies primarily concerned with using technical, scientific and other relevant knowledge to produce deliverables, whether products, systems or services. A free-flowing interview technique was used to record the experiences and perceptions of representatives of this group in discussions about the work they were engaged on, both at present and throughout their careers. The records were then analysed in detail in an attempt to build a valid representation of the engineer-as-engineer, as a foundation for a better understanding of mechanical engineering work.

The paper begins with a description of the ethnographic research methodology. It presents a model of technological work developed from studies of agricultural professionals [3], which provided a conceptual framework for the interviews. It then details interview arrangements and the analysis of recorded transcripts. It builds a typology of mechanical engineering work from the emergent themes, using extensive quotes from individual interview records to ground the developing rich picture of professional practice. It concludes with a discussion of the implications of the investigation for engineering education.

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RESEARCH METHODS

Ethnography

Within ethnography, interviewing forms an important data-gathering technique. Informal interviews offer almost natural formats for data collection, having a specific but implicit research agenda. They do not involve any specific types or order of questions, and progress much as a conversation does, following the interests of the participant or the questioner. Ideally, the fact that an interview is taking place should become transparent after a short period of time, with the interview forming a mixture of conversation and embedded questions. This interview method is particularly useful in establishing and maintaining a healthy rapport.

Engineers from different sections in industry were interviewed to define their career stage, to draw out their experience in terms of the work they do now, and how the daily focus of their work has changed during their career. Each interview was conducted in a free-flowing way in an attempt to gain a rich picture of engineering work. The interviews were tape-recorded and later transcribed in full for computer-based analysis.

Five female and 16 male engineers were drawn from a range of organizations and educational backgrounds to cover four career stages. Three major industry sectors—small private companies, large private organizations and large public utilities—were represented. The sample group was chosen to realize a group of engineers whose skills and roles encompassed an engineer's working life. A breakdown of the sample group is shown in Table 1.

Model of technological work

The model of technological work that provided the theoretical framework for the interviews distinguished four different types of technological work—problem solving, employing 'craft' skills, networking and integrating—which together enable the constructive use of knowledge [3]. Competence in these four types of work do not develop at the same time or even at the same rate. Rather, there is a link between career stage, the competence mix and the main focus of technological work.

The model adopts the four career stages proposed by Dalton *et al.* [4], each stage being identified with a dominant primary relationship, namely apprentice, colleague, mentor or sponsor. Further, each stage is associated with 'major psychological issues' which relate to the power relationships within an organization. The apprentice stage is associated with dependence, colleague with independence, mentor with assuming responsibility for others and sponsor with exercising power. The primary relationships and place in the power structure are not primarily managerial in nature, but rather are related to professional expertise and standing. Power may derive from influence exerted by personality, expertise and opportunity as well as from position in the management structure [5].

The types of work employed in this model also derive from a technological or professional perspective. *Problem solving* has long been recognized as a central activity in technological work. The problem solving approach seeks to extract things from their context so their behaviour can be studied under controlled conditions. Essential elements of the method include problem definition, selection of appropriate analytical tools, production of solutions and the evaluation of these against set objectives. *Craft work* skills are gained through informed application of accepted ways of doing things, which are often enshrined in professional codes of practice or in company or institutional guidelines. Such an ability is not generally taught to a significant extent in academe, but is learnt on the job and counted as experience. *Networking* can invoke support and contributions from many different people and organizations, often necessary in the process of taking an idea and putting it to practical use. While technological work must be based on good theory and practice, it is conceived and implemented by a broadly based network of human actors. *Integrating* is a synthesizing role for the creation of new order. It involves the process of planning, design, implementation, evaluation and management, and may incorporate decisions about people, processes, economics and facilities, the whole having to satisfy business and personal needs. Its success undoubtedly depends on the ability to network and get things done, to employ craft skills and to isolate problems for analysis but it demands something more. It requires an ability to put things in perspective, to attach meaning to isolated facts, to address the real needs at issue, to identify issues of consequence, and then to design and synthesize a response to those issues.

The model shown diagrammatically in Fig. 1

Table 1. Sample breakdown

Organization		Education		Career stage	
Small private	5	Student	4	Apprentice	4
Large private	5	University	10	Colleague	9
Large public	5	Post-graduate	3	Mentor	7
University	5	Diploma	2	Sponsor	2
On career break	1	Trade	1		
		Trade + university	1		

relates the types of work to career stage and depicts how the focus of daily work changes over time. The horizontal hatching demonstrates the cumulative growth in professional skills and capabilities that take place as a career progresses. The vertical overlaid hatching highlights the main focus of work at each of the career stages. This is the model that was adopted to provide an initial interpretive screen for the analysis of the recorded interview data.

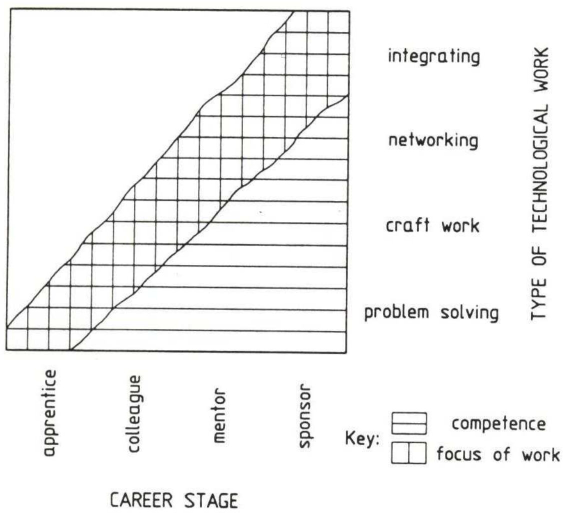

Fig. 1. A model of technological work [3].

Use of NUDIST

Tape-recording of the interviews served to capture the rich detail and flavour of the ethnographic experience. The resultant data are then organized and analysed using 'NUDIST' (Non-numerical Unstructured Data, Indexing Searching and Theorizing) [6], a dedicated qualitative research package developed by LaTrobe University, Melbourne. NUDIST operates using a document system and index system which have different functions. The document system stores any number of off-line and on-line textual documents, together with extra data about them, which are to be analysed in the project. An index system is then created to store references to ideas, concepts and facts that arise, and to store references to the text units in the documents that exhibit those ideas, concepts and facts. Within NUDIST, the index categories can be formed into a hierarchical tree structure, called an indexing tree. The categories, or nodes, within these trees can be created in advance of as well as during the process of indexing documents. There are a large number of ways of comparing and relating index categories to each other. These provide powerful methods of exploring ideas and finding the contexts of concepts. The analysis reported here focused on references to types of work.

DATA ANALYSIS

Work indexing tree

Analysis of the texts reveal that the interpretive screen had to be expanded to capture the variety of tasks undertaken by the interviewees. Problem solving, craft work, networking and integrating activities were indeed evident but two further, quite distinct roles emerged, namely supervising and liaising. Figure 2 organizes this expanded view into a work indexing tree. Statistics on the number of text units retrieved for each indexing node and from how many interview documents are provided in Table 2.

EMERGING THEMES

Table 2 reveals that most of the engineers interviewed considered that their previous jobs had focused primarily on problem solving, with 11 interviewees making 56 references to that type of work. During the interviews it was found that when asked to recall previous jobs, most tended to concentrate on their first job as a graduate. Their first solved problems proved very memorable for them. Craft work and liaising were also important activities, with six participants making 16 references to craft work, and six making 13 references to liaising. On the other hand, there were only a few references to supervising and networking and none to integrating.

A significant shift from this distribution had occurred for the group when they described their current jobs. Craft work (12 participants making 28 references) and liaising (11 making 21 references) remained important, but problem-solving activities has been much reduced, only three people making a total of 18 references. Supervising and networking, however, had emerged as new engagements, with five interviewees making 12 references to supervision and nine making 19 references to networking. Integrating had become an important role for one of the group who made 11 references to such activities. In a general way, then, the adoption of a conceptual framework in which careers in mechanical engineering developed in a particular way—beginning with problem-solving and tasks requiring on-the-job know-how and moving towards more people-oriented responsibilities—is vindicated by these rather bald statistics. The full richness of the participants' experiences, however, can only be appreciated from their own words. In what follows aliases have been used in place of real names, but the quotes are almost verbatim.

Problem solving

Contemporary engineering education equips graduates with a solid understanding of the scientific method. It is therefore not surprising that all industry sectors—large private, small private and public firms—tend initially to set small tasks that

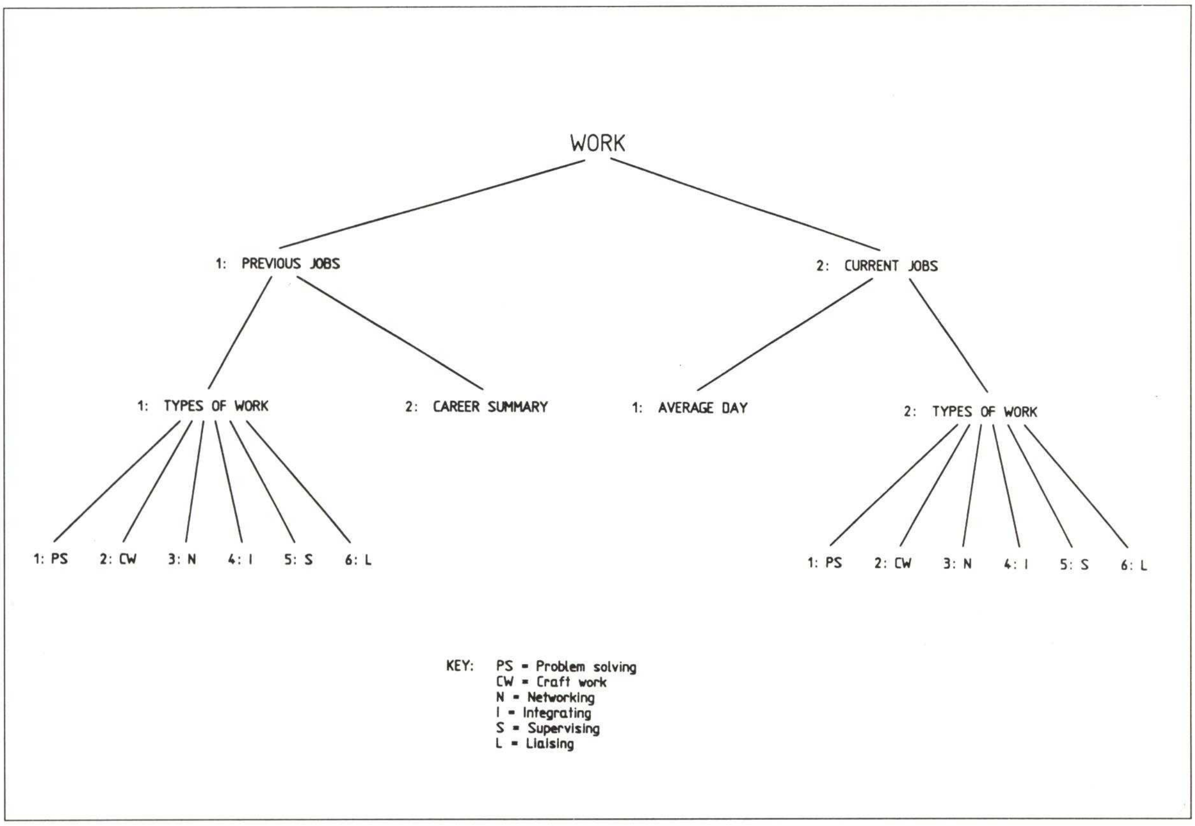

Fig. 2. Work indexing tree.

Table 2. Coding details

Node	No. of text units	From no. of participants
Previous jobs		
Problem solving	56	11
Craft work	16	6
Networking	1	1
Integrating	0	0
Supervising	3	2
Liaising	13	6
Current jobs		
Problem solving	18	3
Craft work	28	12
Networking	19	9
Integrating	11	1
Supervising	12	5
Liaising	21	11

mainly need basic problem-solving skills. These tasks can be part of a larger project or agenda so that there is support and advice available if required.

BRIAN: I worked for a group they called scientific services at that stage: it was kind of an in-house consulting group where they had chemists and engineers and scientists all in this group. And if there was any specific problem that the power station couldn't solve themselves, then they would call on this group to try and sort it out. I was doing mostly vibration measurement and analysis, they were trying to get condition monitoring things going. They were having problems with dust getting into the turbine hall of Gladstone power station. So I built a model of the power stations, and all the hills and everything around it. It was taken out to the uni, and put into the wind tunnel there to try and see where the dust was coming in. That was fairly successful, and I think they managed to redesign the venting system to prevent it.

These graduate level projects are usually relatively straightforward in a technical sense. Often, they require 'experimental' type work as a prerequisite to the calculations performed in the office. This helps to give the young engineer valuable experience in the field and confidence in their ability to see through an entire, though small, project.

NICK: In one of the cases that I did, it was a very big conveyor that never really started off very well. If that had a cold morning, you just couldn't start the conveyor. So they were going to upgrade the drives on it. It had one huge head drive, and they were going to put in what's called a tail drive. They are two different sorts of drives, and the conveyor itself was actually 30 km long. That's a belt there and back, 60 km of it. It was actually a very interesting sort of conveyor—instead of having a rubber belt with steel cords inside it, it had a rubber belt with a few cross steel cords. And it sat on two wire cables about 60 mm in diameter. So all the drive and weight was carried on the cables rather than the belt. Still, that just added a bit of fun to the job. So we actually went to the field, measured what the existing conveyor did, in terms of start-up torques, how the motor was controlled, how long it took a stress wave to travel down the existing belt, because it was unusual it was difficult to get exact stiffness of the belt. So we got all that data, fed it into the model, played around until we got the thing working right and then stuck in the tail drive, to see what they would do.

In consultancies serving particular industries, e.g. the mining industry, the areas of work for the new employee can be limited. New graduates in these firms are typically given many similar projects to build up their skills in these areas.

NICK: What I was involved in was more XYZ's [the employing company] traditional line of work, which is stress analysis of heavy machinery, mining machinery, conveyors, big earthmoving machinery, load haul dump trucks, drag lines, that sort of stuff. I guess, XYZ's two main areas of focus in the mechanical section are stress analysis type of work on existing or proposed machinery as consultants. So they are generally fixing a problem; or testing work, as they call it, where you go out to the field with a bunch of strain gauges, perhaps with what they call telemetry equipment. Two of the jobs I worked on involved experimental data which had been measured by XYZ, where I was feeding it into a theoretical model, again that XYZ had developed. So I did finite element work on some fairly big models, you know, fairly big machinery. One was part of a drag line, another was stripping machinery for a bucket wheel excavator, conveyor booms and what have you. The second one was a thing called a design audit, where somebody designs it for a customer, and in this case XYZ was a third party who fitted between the two. Taking the original design, analysing it to what the customer stated its constractual requirements were, and then saying to the customer and to the designer—either it passes your requirements, or it's close, or it passes but we don't like this. So they were auditors, just like accounting type auditors, except they were doing mechanical design auditing work.

There is usually close supervision of the young engineer in these early stages to ensure the work is being done correctly and that she or he is coping with the requirements. Lack of experience particularly in interpreting results and data will often require an engineer in the colleague or mentor stage to provide guidance.

SARAH: I could always go to my boss if I had problems, but there was sort of no need. He gave me the outline and had all the bits of equipment, and I just had to make it all go together and work. Basically sitting by yourself and doing it. On the other hand, the analysis of the data when you got it back, I used to get a lot of guidance in that area. He'd seen those sort of results before and knew what it implied, and I'd never seen it before and had no idea what it was implying; well I had a vague idea, but what was causing it I didn't really know. It's fairly guided, well the coding part wasn't, that was just sit and work, nobody bothered you, but as far as thinking what to do yourself, I was totally guided. The boss would say I want this done and that done, and you'd just go off and do it, and give him back the results and hope he's happy. Whereas when you get to the higher levels, you think, ah this part of this laboratory isn't operating correctly, how can I fix it up? and you've got to work it out yourself.

Often graduates are given the routine projects that are relatively straightforward in their solution. This can lead to 'recipe' style solutions to design tasks. When graduates are repeatedly given the routine and straightforward projects when they are capable of more challenging work, they can become frustrated and disillusioned.

MICHAEL: I was unstimulated, let's put it that way. I was involved in doing work for Saxonvale coal mine in the Hunter Valley, and I got involved in the materials handling area, where they design conveyors and so on to shift the coal around the site. Now a coal mine has hundreds of conveyors, and every one of them has to be designed: and design means use a table and some formulae and things to work out exactly how this conveyor goes together. Once you've done two or three conveyors, it wears a bit thin! I sought more stimulating work within that group: I just felt that I was under-utilized. Four years of education, and come away with an honours degree and I thought 'I'm going to do something good here.' But I was just bored, really bored silly.

In small consultancies, however, there can be quite a variety in the projects undertaken by the organization. This requires more flexibility in the application of problem-solving techniques. Such an environment can offer challenges, usually with the safety net of a fairly close-knit group of more experienced engineers. With the pressure of time restrictions, there is also the possibility of a less thorough understanding of the basic principles involved with a task. This can be quite disconcerting to the young engineer who may be looking for fundamental principles on which to build his or her knowledge base.

JOHN: In consulting jobs I never got the chance to really get to the bottom of anything. You were always having to compromise on your understanding of the particular problem, just enough to get the thing solved to some extent, and make the client happy. But the actual processes involved in understanding the problem: you weren't fully conversant with some stages. And I found that frustrating. You would have to do your job very quickly, because you were being charged on an hourly basis. The charges were fairly steep $95–$100 per hour. And there's no chance really to go off to the library and sit down and understand all the intricate details of the problem. Even though on the surface you look as though you know what you're doing, you solve things, you really don't. You pick it up gradually, like over the years, with experience of course, then you start to understand what's going on.

Despite almost four years of intensive university education, the first job for an engineering graduate still involves a steep learning curve. Organizational norms need to be recognized and adopted, old skills need to be practised and new skills mastered. The first job is thus the first step taken on the path of professional development, and like all first steps, can sometimes be a little daunting.

KELLY: The bottom line is that when you finish your undergrad, you're dumb, you don't know anything. I went through that—sitting there thinking I don't know the first thing about this. But that's part of engineering, that you problem solve. It takes ten minutes to organize yourself, whereas when you first started it would take two days of sheer panic!

Problem solving thus characterizes the graduate's first work tasks. The solution of these small problems usually serves to build confidence and provide a foundation for technical knowledge during a career. They form important learning experiences for the engineer, and of course provide valuable solutions to the employing company.

Craft work

Craft work demands something more than problem solving. It requires a deeper understanding and confidence to define and interrelate an issue with other considerations. In some cases it can be seen as a form of specialization, but it can also relate to an intuitive feeling for the right course of action in a given situation. This level of ability is acquired with experience and usually on the job.

BRIAN: There is a fair bit of problem solving that we do. Except that it is a different type, you don't have a very clearly defined problem I think, with this job. I'll just try and think of an example of the kind of thinking you have to do ... Well, say we have to decide from a choice of three types of power stations that we're going to build next: hydro, gas turbine, and coal fired stations. And we have to work out which is the best option to go for. There's often more to it than just economics. You need to maintain a proper mixture of peaking capacity, and base load capacity, and intermediate capacity within the system, so that overall the system runs efficiently. So out of all those various kinds of parameters we have to bring together, we have to come up with an economic plan for the future. That isn't really a problem solving thing.

Often engineers become technical specialists through the requirements of their company, which trains the engineer to fulfil current needs. This is especially the case in large firms, where specialization at the colleague stage forms part of the career structure.

LINDA: I was considered to be a technical specialist in fibre reinforced plastics. So basically any problems that they had with fibre reinforced plastics I would be sent on site to investigate . . . [I became a specialist] through training in ABC [the employing company] because they had quite a lot of problems with their fibre reinforced plastic pipe at that time to failures and things like that. Also they had a failure with their fibre reinforced plastic paint which was at Bulimba. So there was quite a bit of work in that sort of field.

In rapidly growing industries, such as communications, new developments can lead to faster than usual career growth with technical specialization. This can be attributed to new graduates coming through from university, especially with research degrees, with a high level of technical knowledge. These graduates then become the main sources for information regarding these new industries, and can rise rapidly within this area.

SARAH: It has just come into existence this protection signalling equipment. They have international committees for the electricity supply industry, and the communications section were talking about this and decided that there were no standards or procedures for it. Nobody else is doing any work [in the area], so our senior communications engineer gave me the task of just finding out and designing these procedures. There is a bit of actual electronic design to get the circuit board to do the tests that are required as well. So [I am doing] purely development of test procedures with a lot of design. Now they want me to write papers on it and put it into some sort of Australian Standard.

Design is then an activity which necessitates informed application of a variety of skills. Design projects can thus be instrumental in the career development from an apprentice to a colleague. At the colleague level it can be considered craft work, and a successful design is usually significant for the recognition it can attract to the designer.

NICK: I've been working pretty much exclusively on development of, well I guess you could say production machinery and design related to that. So I have a bit of production machinery design, as in a cut-off line which pulls the sheet off the coil and cuts it to length. Hydraulic cylinders which needed design because we couldn't buy what we needed. Fairly small projects really. Testing from my point of view, even though they were small, because I had never done any design work. Certainly never put anything on paper, which has then gone and been built. I've done a bit of conceptual type design, but it was always up to someone else to iron out the bugs and check on material availability and things like that. Whereas I now handle all of that, which is I guess, fairly difficult design work, and is a bit of a challenge in that way.

Craft work thus encompasses technical specialization, 'know-how' and design activities for a skill more advanced than problem solving.

Supervising

Younger engineers than those in the mentor and sponsor stages can be required to fulfil supervisory or managerial duties. This recognition led to the creation of a new category, supervising, which is additional to the four types of work identified by the model of technological work [3]. Supervising involves taking some responsibility for the work, direction or output of others. However, the supervisory role is technically based and usually depends on past experience in the particular field.

ERIC: I generally have a walk around the factory. I suppose after three years I have a good knowledge of what the product looks like, and how it should look like. So I just have a wander around and that generally takes $\frac{3}{4}$ of an hour. While I'm doing that I'll have a look at the test sheds, and make sure that the operators are testing correctly, and that they're filling in the forms correctly.

An engineer within a manufacturing plant can play a vital role, smoothing out inconsistencies and problems that arise within the system. Engineering problem solving has had applications in the areas of work methodizing, production and inventory control and quality assurance systems, all of which have potential financial savings for the engineer's employer.

ERIC: My job basically is to maintain the system, to make sure it's keeping up with changes in the plant, that it's performing correctly, that the board that we're producing, or the product that we're producing conforms to our internal specifications ... We do tests at the end of the production run, and throughout the production, just to make sure that if you get bad tests at the end of the production line, that somebody does something about the board—they hold it or they throw it away, or they decide that the problem is not that great and they pass the board fit for sale. But when they decide to do that, they record it and tell somebody that they've made the decision.

Such activities indicate the assumption of responsibility for others' work earlier in a career than was expected from the proposed model of technological work. This can be an excellent developmental experience for the young engineer, with opportunities to acquire organizational skills.

HELEN: That was in an operations type role, where most of my work was based on construction and commissioning of projects. And that job, most of the time, was out in the field, finding out where we're at, where we're going, sorting out a few problems that happen along the way, making sure everything is happening on time, and chasing up suppliers for various bits of cable and relay that's not here. So that was a lot out in the field, and a lot on the phone as well. People asking 'What's this, and where's this, and I don't think this is quite right, can you check this out', and that sort of thing.

However, managerial roles are also common later in a career when the engineer has reached the mentor stage. The tasks are similar to those above, often involving the co-ordination of the work of tradesmen, contractors and other technical staff.

WAYNE: I've got two electricians and an apprentice electrician who is in his fourth year this year. I've got a leading hand electrician. Plus an offsider as well. Plus I look after all the contractors that come in; I get a lot of work done by contractors. Just this weekend I've got two big gearboxes apart, and I've got two different engineering places making parts for me and that, so I can get them all back together hopefully by Wednesday.

Engineers in the manufacturing industry can undertake supervisory duties to try and ensure integrity in the process operations. This has become especially important with the advent of company accreditation to the new Australian Quality Standards, AS3901 and AS3902.

ERIC: So now my job is a lot, not a lot of the time, but sometimes supervisors on the production line will get a measurement that's below specification, or outside specification, and they'll just let the product go through. Because the property that they're measuring isn't critical, so they just let it go through. So my job is to grab them and say, hey, we've got AS3902 and you've just blown it, and belt them about the ears a bit, once, and hopefully they won't do it again, or after the third or fourth time they stop doing it.

Supervising is fundamentally the role of responsibility for other company workers. It involves co-ordination and organization to achieve set objectives using the people available. In this way it is a skill that can be used as a stepping stone to the next career stage.

Liaising

Liaison and communication is such a fundamental part of engineering that it can be found at all levels. Where it frequently presents the greatest challenge, however, is at the apprentice stage, in the engineer's first employment. After an education that plays down the importance of liaison skills, the graduate often finds that their first job is characterized by social development rather than development of technical skills:

> JOHN: The thing that I learned in eight years or so is that consulting is not technical things. The technical development is less than the personal development and the communication development and the social development, and dealing with people. So while I don't think that should be in the course so much, it's something that one realises when one starts a job. All the things that you learn very quickly are things that you didn't learn how to do in your course, like how to write a letter, how to present information clearly to managers and clients, and how to deal with bottlenecks in the system. They are all things that you learn, and you learn very quickly on the job, and that's where you should learn those things.

Similarly, engineers will find that the most effective way to deal with organizational problems and goals is through meetings, and personal communication. Assessments of the time spent in a typical day showed that a large proportion of most engineer's time would be spent liaising with others.

> ANDREW: If I was to look at it on a daily basis, my current day: probably two hours of it would be liaison type meeting situations—just nurturing the ideas for this quality assurance system. It's definitely meeting based.

The kinds of information that is shared in these liaisons naturally varies. Sometimes the exchange consists of purely technical knowledge, or the results of personal work or research. Brainstorming and productive meeting sessions can also be classed as liaison type situations. Overall they are a vital and probably under-valued part of engineering work.

> BRIAN: I need data to run my simulations, and there is communication going on at this level to get data. We used to communicate with them anyway, just for various reasons. Sometimes if we needed a particular program for something, we'd usually ask the other states if they had anything, and what they thought of packages you could buy from overseas.

There is a key, as with any personal exchange, to be prudent with whom information is shared. A couple of engineers were able to relate experiences where they had given important knowledge to the 'wrong' people, where it was either misinterpreted or acted upon without full understanding. This occurrence is probably fairly common, especially among younger engineers who are still identifying other people's roles within their organization.

> SARAH: You give the information to different people, to appropriate people. It's something that you learn, you make a few mistakes when you first get there by telling things to someone, and because they don't have a good understanding in that area, they may be a high manager but—like the managers here basically are in the power field, and they aren't too up on the communications. So while they may foresee it as being a large problem in their understanding of the field, it is not really a major problem in a communications background. So you give the people with the right expertise the right information, that's always the best way to deal with it. The others could always get their hands on the information—if they came and asked me for it, I would give it to them!

The information gathered from practising engineers pointed to a lack of preparation for the essentially social nature of engineering. Meetings, formal and informal communication and group situations were repeatedly emphasized as being a vital element of professional practice. While liaising emerged as being an important skill for a professional engineer, it is unfortunately not recognized and not cultivated during a university education.

Networking

Networking also involves the social dimension of the workplace. Engineering achievement can demand a willingness to support and contribute from many different people and organizations. It then becomes vitally important to develop and maintain working relationships with people both internal and external to one's organization.

> BOB: We are involved in setting up a new manufacturing company, in terms of production. I am involved in organizing the factory layout, the manufacturing method, setting up the system, documenting, manufacturing, and in my spare time act as quality assurance manager as well. I guess in this last two years with a change of job, my position is somewhat changed. Then again in other ways it hasn't. To a large extent I still work on major involvement in leading a group of people in the right direction, and I guess that's still basically what I do best. The group of people is a lot smaller here, but I don't think that alters the whole principle of it.

In a consultancy, preparing proposals for work is an important precursor to securing the contract. This activity requires knowledge about the nature of the work and the client's requirements. A good rapport between client and engineer thus needs to be developed and this is facilitated by the networking process.

> KELLY: Depending on what kind of job it is, and your area of expertise, if it is in my area, I might go and talk to the client beforehand, and actually find out what he wants. In some cases you actually put a thought in his head, that he needs something done, and then he'll come back to you and say 'Gee, we really do need that done, can you do it for us.' And we get the jobs like that, because we've known him for 20 years you might say. In other cases you read it in the paper, or you

are sent a little job brief, because a lot of clients just send it out to known firms, people that they know. My role then would be to go and talk to those clients, find out what he actually wants, then prepare a proposal. You might go back and talk to them again and say to him, 'Well we thought of doing this, what do you reckon, do you like that idea?' All of these things are essential for developing a relationship with a client.

A younger engineer can experience difficulty when attempting to achieve results without the necessary support from others within the organization. A lack of experience with the process of networking and enlisting assistance will invariably end in frustration for the engineer who is attempting to introduce new ideas.

MICHAEL: I was 22, and I was dealing with fellows 30 years my senior, with 30 years' experience in that particular industry. I had a great deal of difficulty getting my ideas across, and the things that I wanted to do were not readily accepted. So I got quite a bit frustrated with that. I was designing new upgrades to equipment, and the only way I could get these things implemented was to deal through the maintenance manager, because he had the fitters and the boilermakers on tap to do the stuff. And his interest was in maintenance, and my jobs were invariably given low priority, and yeah I just felt it was a bit frustrating. I felt that I was probably too young to be in that position, because there was no other engineer in the firm.

When the networking process is well utilized, the benefits can be of great importance to an engineer's work. This social skill uses relationships of power and appears to be instrumental in the career progression of a professional. Ultimately it is vital in one's personal development to be able to enlist the contributions of others.

Integrating

Integrating is a crucial and complex role, and often demands decisions about people, processes, economics and facilities. These frequently need to be weighed and combined for a business plan for the future.

HAROLD: In the Rockhampton area, or Capricornian electricity board, they have a group of people in there who are well skilled in transmission type material and equipment. They, as well as a group in Townsville and in Mackay and in Cairns, operate on our behalf, on our assets, virtually as contractors. So from an agreed dollar value, so an agreed amount of labour input each year which is pre-planned, to a maintenance plan which we draw up and agree with them, it is virtually a contract of performance. We try and monitor the amount of work achieved, work output in units of output of their efforts. We relate that to the reliability of the system, and we do that via a ratio of corrective to preventive maintenance. By that I mean that preventive maintenance is that which we we do based on the need to be doing it, and corrective is in response to an emergency situation. That ratio of corrective to preventive is a very good indicator of whether the amount of maintenance we do is too little, too much or just right. If we plot it over a period of time, we hope to get some trend to see which way we are going.

A high-profile role within the Institution of Engineers, Australia can also provide opportunities for integrative type work. Although this work is voluntary, it still involves many of the components of integrating that are to be found in any private or public corporate organization. The role of coordination of a number of conflicting demands shows well in the following excerpt.

THOMAS: The Institution is quite a strong body now, it is a real business in fact. Its income is about $8 million, or more than that actually with its income from publishing and conferences and so on, so it is around a $10 million per year business. That's run by quite a large permanent staff in Canberra, around 80 people, and a large number of voluntary people like myself, who form a council out of those people. The organization is also structured to run a number of boards. I chair one of those boards, that's Member Affairs, at the moment. That involves looking after the division of monies to all the divisions around Australia, there are offices in all states, and member issues of course. The major subcommittees under member affairs are Young Engineers, Women in Engineering, and a new one that we have got going at the moment is Unemployed Engineers. I'm performing a coordinating role for the Institution's activities, assisting unemployed engineers around Australia. As well as that, I guess there is always a considerable effort in that portfolio to make sure that our standards are recognized by the rest of the world.

Integrating skills are generally implemented after a career developing the other types of work outlined above. It is unique, drawing on all, yet demanding more of the individual engineer. Usually it is most required in a position of higher responsibility within an organization.

A TYPOLOGY OF MECHANICAL ENGINEERING WORK

What emerges from the analysis is that not only is mechanical engineering work rich in the variety and level of technical challenge but also the focus of that work may shift away from technical matters as a person's career progresses. There seem, therefore, to be two major determinants of the sort of work that mechanical engineers do in technology-based businesses. One factor is the particular aspect of the operation engaging the attention of the engineer. Linstone [7] argues that there are three such aspects, the technical, the organizational and the personal. According to Linstone, in a socio-technical system, technologies are embedded in an environment of human beings. Human beings are then involved in two ways: as social entities and as individuals. The second factor is the current career stage, defined by primary relationship and place in the power structure. Power may be interpreted to include forms exerted by personality, expertise and opportunity as well as the perhaps more widely recognized form deriving from position in the management structure [5]. In that case these two factors, aspect and power, can in the first instance be considered reasonably independent. This suggests their use in constructing a typology of mechanical engineering work.

Figure 3 sets up the two factors along orthogonal axes. The baseline locates the three aspects. The order in which they appear—technical, organizational and personal—is derived from the change in the modes of enquiry that are commonly associated with them. Technical matters are usually seen to be amenable to enquiries that seek to establish 'objective' facts, independent of values and not conditioned by considerations of purpose. Personal matters, on the other hand, clearly are value-laden, and considerations of human judgement and purpose are essential elements of enquiry in that domain. Organizational aspects lie between these two positions, containing both 'objective' or structural elements and 'subjective' human elements. The second (vertical) axis locates career stage along a dimension of increasing power to influence what happens within a business. The picture that has emerged from the analysis of the interview transcripts may now be charted on this 'map'.

The new graduate, then at the apprentice stage of a career, is typically first given project work which involves using the problem-solving skills developed during education. Over time, the graduate builds on these technical competencies through increasingly complex engineering tasks, which also require an understanding of the contextual ways in which particular companies operate. Side by side with this development, the engineer is increasingly given supervisory duties, adding organizational aspects of work to technical issues. Competence in both technical and organizational aspects results in an acknowledgement of particular expertise and the expectation it can be exercised independently. Further developments may shift the focus of attention to liaising with suppliers, customers and colleagues, or to networking internally and externally to advance engineering projects by team work. There are more responsibilities to promote the interests and professional development of other people, and in time, the power to influence policy and direction. It seems, therefore, that problem solving and craft work reside more or less

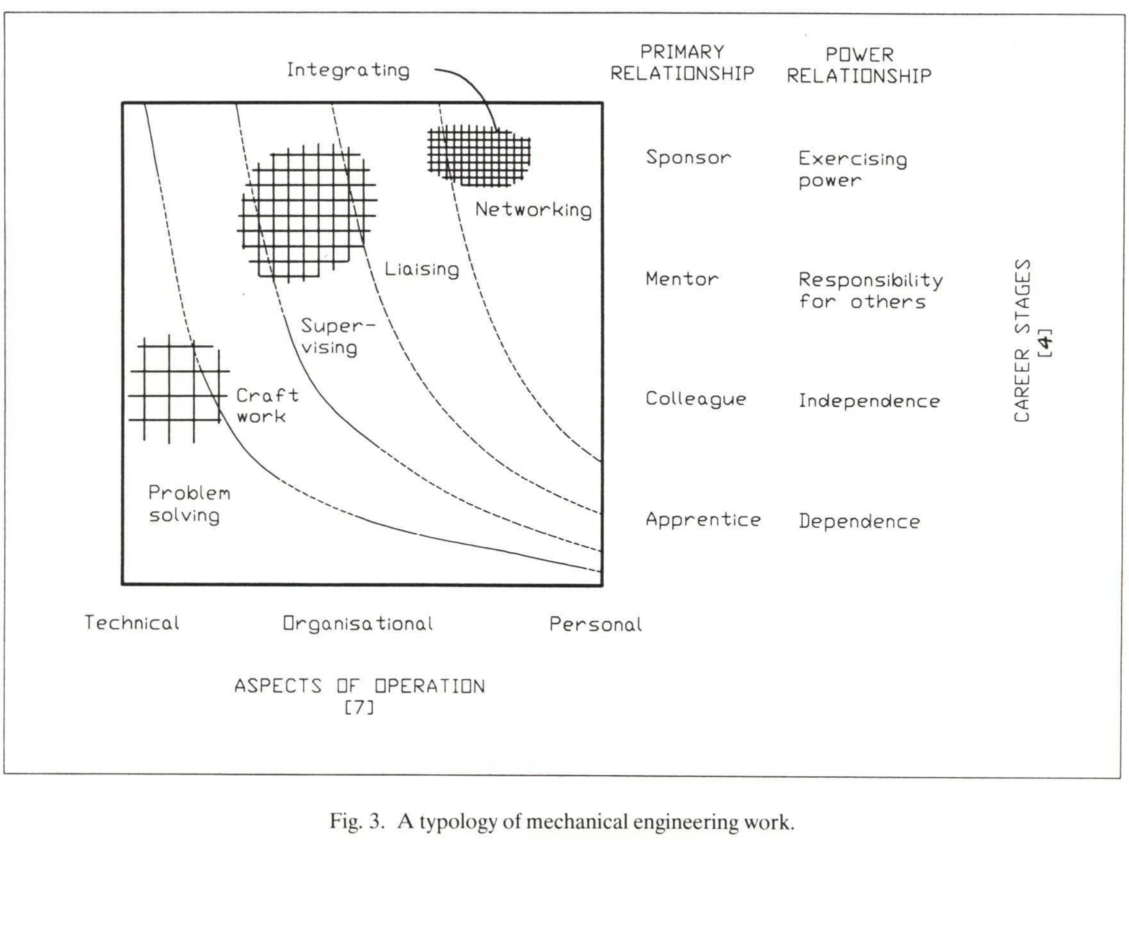

Fig. 3. A typology of mechanical engineering work.

in the region defined by the baseline technical and organizational positions. Supervising and liaising are centred about the organizational position, but also embrace to some extent both technical and personal issues. Later career stages open up opportunities for enhancing individual progress and contributions so that networking should be placed above the personal position of the horizontal axis. The various types of work, therefore, may be represented as broad contours on the typological surface, as shown in Fig. 3. The spacing between the contour lines has been guided by the occurrence of references in Table 2.

Integrating type work seems to be an exception. While only two interviewees, both at fairly senior levels, clearly identified integrating activities as distinct and important, it appears that most of the engineers were engaged in activities which required a synthesizing role. In the early stages of a career this role can be recognized in design activities. In the later stages it appears as the ability to create order by marshalling the skills of a group of people in the accomplishment of a task. It should perhaps be regarded as providing the direction and form an engineering task takes, within which the other types bring an idea to fruition. To represent this, integrating is shown as an increasingly dense overlay, covering the whole typological surface.

A career path in mechanical engineering then might be pictured as starting in the bottom left-hand region and moving, most commonly, towards the top right. There is a spread of distance travelled along this route which would see most engineers occupying the centre regions. Other paths might be imagined to head more vertically or horizontally, depending on the nature of the organization's business and the engineer's place in it. In any case this analysis suggests that most engineering careers lead to a substantial involvement with people and that it is the social fabric that both empowers and constrains the accomplishment of engineering tasks.

THE CHALLENGE FOR ACADEME

The analysis has important implications for the education of professional mechanical engineers. Traditional tertiary courses seem to have evolved from the premise that engineers are essentially problem solvers. Furthermore, the problems to be solved belong mainly in the technical, material domain. There has been, in recent times, a recognition of the role of management in a professional engineering career, with the consequent demand for management studies in undergraduate programmes. However, very often such studies adopt a problem-solving philosophy, favouring a 'rational' or objective model of human behaviour. For example, management by objective is claimed to provide an entire and appropriate management system. The result of this analysis, however, point to the need for a whole range of competencies in a developing and changing career, many of which lie outside a technical world view.

Some challenging questions arise. Can the graduate engineer be better prepared for the opportunities and demands of a career path that leads many into the unfamiliar territory of value-laden and subjective judgement? Should the responsibility for personal development in these directions reside in the workplace rather than in academe? Should the educational institution have an ongoing role in professional growth, perhaps adopting a university-for-life philosophy? It is clear that contemporary industrial structures require a careful and informed consideration of these and similar questions. Furthermore, it is in formulating answers that a better understanding of the engineering method will emerge, and the contributions that mechanical engineers make to society will be enhanced.

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