

ENGINEERING MANAGEMENT IN PROFESSIONAL PRACTICE

Pons, D.J., Raine, J.

¹ Principal Investigator to whom correspondence should be addressed: Dr Dirk Pons, Department of Mechanical Engineering, University of Canterbury, Private Bag 4800, Christchurch 8020, New Zealand. dirk.pons@canterbury.ac.nz

² Pro Vice-Chancellor Innovation and Enterprise and Head of School of Engineering, AUT University, Auckland, New Zealand.

ABSTRACT

The research question was to determine the extent to which actual practitioners used engineering management (EM), and to differentiate usage by practice area and career stage. The results of a survey of New Zealand engineers show that EM is used to a moderate extent by the profession as a whole. The usage across practice areas is broadly similar. The greatest variability is in usage though career stage. Several career phases are evident. Early career: those newly out of graduation (say up to three years) tended to have roles where EM was only used to a slight extent or even not at all. Development phase: at three years' experience the median is for engineers to be using EM to a moderate extent. Mature phase: at 13 years' engineers typically use EM to a moderate to great extent, and it is common that some use it to a very great extent. The results show that usage of EM varies with career stage, being initially low and becoming greater with job experience.

KEYWORDS

engineering management; professional practice; career; graduate; Washington Accord

1. INTRODUCTION

The practice of engineering is invariably embedded within an organisation, both invigorating the organisation and in return being supported by the organisation. The Washington Accord stipulates the skills an engineer needs to have at graduation, and these are called "graduate competencies". A significant number of those competencies are in the area of EM (IEM, 2009). The profession identifies a typical career path for an engineer as progressing from graduate to independent practitioner to project management or team leader roles, to technical manager, and subsequently general manager, or stopping at any of those points (IPENZ, 2009). There is a general expansion of responsibilities, including a growing responsibility for others and the organisation.

That practising engineers apply EM is therefore not in question. What, how and where they apply it is more uncertain. While there is a research literature describing the topics that various universities have elected to include

in their EM curriculum, there are only a few studies that investigated what practising engineers actually thought about the subject (Banik, 2008; Waks & Frank, 2000). There is abundant speculation on what topics the profession is believed to need, but surprisingly little empirical research on the actual extent to which engineers use EM knowledge, and where. This paper, based on a large survey of practis

2. RESEARCH APPROACH

The purpose of this research project was to determine how much EM is used by professional engineers, in which practice areas, and where in their careers. Such information could inform an efficient choice of curriculum in university EM courses, where inevitably time is short to cover a range of desirable topics. It can also help contextualise the subject for students, and thereby enhance the learning. Furthermore it may have implications for ongoing professional development of practitioners.

2.1 Hypotheses

The following starting hypotheses were adopted:

- That the attitudes of practising professionals towards EM become more positive with time post-graduation; specifically, that their roles include more EM.
- That use of EM varies across practice areas.

2.2 Method

The approach taken was to survey the New Zealand population of professional engineers, namely those who were Members of the Institution of Professional Engineers New Zealand (IPENZ). This is the primary professional body for New Zealand and includes all practice areas. The Institution has for some time sent out an annual salary survey to all its Members, and in 2009 a question was added on EM:

Q17 To what extent does your current role involve engineering management? Response categories: 1 = Did not answer; 1=Very great extent; 2=Great extent; 3=Moderate extent; 4=Slight extent; 5=Not at all; 6=Do not know or not applicable

While “engineering management” is widely used term in the research literature and curriculum areas (both for undergraduate and postgraduate programmes), there is no clear definition at to what the term means, or the topics that it contains. The clarification of the term is precisely what this research sets out to achieve, and why the working definition of “engineering management” is as broad and as inclusive as it can be. By asking the open question, “To what extent does your current role involve engineering management?” in the survey we deliberately open the analysis to whatever practicing engineers consider “engineering management” to be. Their perception is their reality, and it is those constructs that the research investigates. Consequently, while acknowledging that “engineering management” is not defined a priori, the openness of the question is an integral and deliberate part of the methodology.

Please note that the research question was directed at EM generally and did not try to identify the skills required of a Chartered Professional Engineer (CPEng) who is in business. Instead, we take the perspective that elements of EM are to be found in all engineering practice, and that business engineer is simply a more specialised practise thereof. Nor are we able, with this survey, to comment on the engineers who move into general management and no longer maintain a professional membership with engineering.

Other standard demographic questions were also asked: qualification, years since graduation, practice area, job points, and demographics. Job points is an IPENZ measure of job complexity and is determined by aggregating responses to several questions. Included therein are questions about the level of responsibility for decision-making by the engineer. It therefore broadly measures complexity in professional practice.

The number of responses received was 2,276, representing a 38 per cent return. The population was all the IPENZ Graduate Members, Professional Members, Technical Members, Associate Members and Fellows who were and living in New Zealand and not-retired.

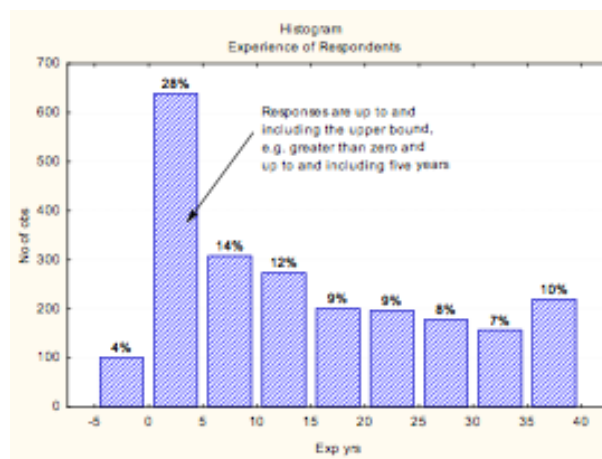


Figure 1: Demographics – distribution of the number of years of experience of respondents. The younger graduates were the most numerous, but there was still large representation from mature engineers. The bin apparently showing negative experience is simply showing those engineers with zero years of experience. What this figure shows is that there was a good sample size from experienced as well as novice engineers.

2.3 Statistical methods used

The survey data were analysed to extract (a) summaries of frequencies, and (b) association rules. These methods were selected because of the qualitative nature of the data. The software tool used was Statistica®.

2.4 Interpretation

Summaries of frequencies are simply based on the frequency with which a response was given. In some cases the results are categorised, e.g. by those in the private versus public sector. Association rules analysis (ARA) was used to explore the data and seek out hidden relationships in a posterior manner. The method, though commonly used for marketing analysis, is an uncommon research method. There are no known instances of it being applied to this type of application and therefore a brief description is provided below.

2.5 Description of association rules analysis

ARA is a powerful data-mining method that is used for qualitative data. It does not assume any prior distribution of results, nor does it require prior hypotheses. Instead it trawls through large data-sets seeking whatever associations may exist, whether or not the research has identified them beforehand. The statistical algorithm with ARA searches for co-occurrence of certain responses (items) with other responses. Perhaps surprisingly those responses do not need to be numerical, and therefore the method works for qualitative text responses. The output are rules with the structure if “body” then likely “head”, where the body and head are items in the responses. The rules may be represented as tables or graphically.

It is similar to ANOVA in seeking statistically significant association, though with qualitative variables. Consequently it only identifies the more statistically important associations. This means that just because some response seems prominent in the frequencies (above), this does not necessarily mean that it will meet the criteria for being a significant association. The associations show the co-occurrence of responses, not the absolute frequency of individual responses.

The two main measures of statistical significance for this method are support and confidence, and these may require some explanation:

- **Support** is the joint probability (relative frequency of co-occurrence) of items within the variables, i.e., separately for the Body and Head of each association rule. Thus support percentage of the time people who replied body also replied head. Or to put it another way, there is a support percentage chance of co-occurrence of body and head.
- **Confidence Value** is the conditional probability of the Head of the association rule, given the Body of the association rule. Thus for those who responded body there was a Confidence Value percentage chance that they also replied head. Or, for those who were body, there was a confidence percentage chance of them responding/doing head. Or there is a confidence percentage of head for those who had body.

ARA identifies the association between variables, not the temporal causality. However the strength of the association is not necessarily or even generally the same when the order of variables is reversed, i.e. the associations are asymmetrical. For example, it is possible that people who said X always also said Y. However, of all those who said Y, only a few also said X. Thus the strengths of the associations can be used to infer precedence, even if not causality. Thus in the example the inference is that X always needs Y, but Y on its own does not need X.

3. RESULTS

The survey resulted in a large dataset, and the present paper only describes the results with implications for professional practice.

3.1 In and With Engineering

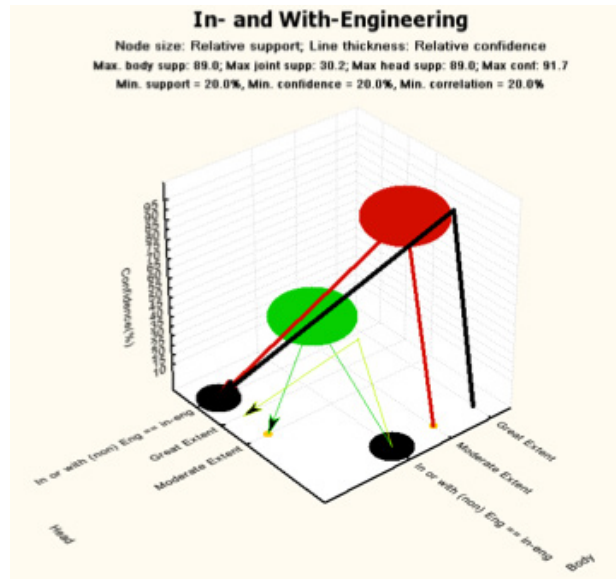
The survey differentiates between those employed in an engineering practice or management role (working in engineering), and those who apply their engineering education and experience to a non-engineering role (working with engineering).

We might expect that people who have moved out of engineering would use EM more than those who have stayed in it. However the data show the opposite: that 36 per cent of those working in engineering are more likely to

be using EM to a great or very great extent, compared to 25 per cent of those in a non-engineering role.

The results were confirmed by the association rules analysis which showed that those with moderate and great involvement with EM were statistically associated with working in engineering as opposed to non-engineering roles (see Figure 2).

To explain the ARA rules: for those with moderate involvement with EM there was a 87.5 per cent chance of them working in engineering. Likewise of those with a great involvement 92 per cent were working in engineering.

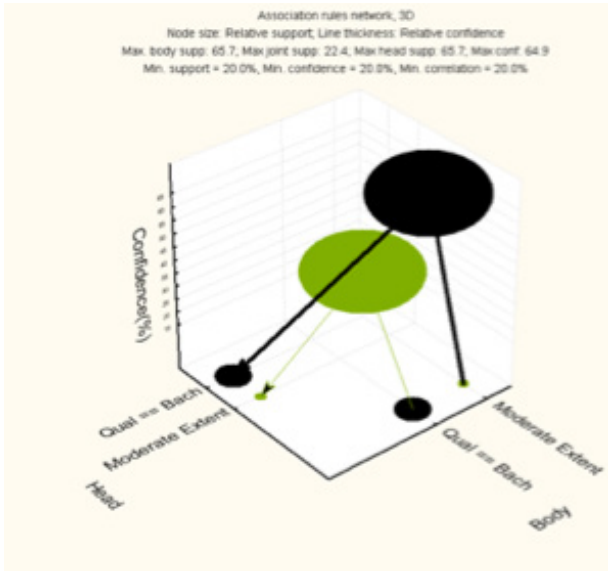


Body		Head	Support %	Confidence %	Correlation %
Eng Management Involvement == Moderate Extent	==>	in-eng	30.2	87.5	54.5
Eng Management Involvement == Great Extent	==>	in-eng	20.4	91.7	45.8
in-eng	==>	Eng Management Involvement == Moderate Extent	30.2	34.0	54.5
in-eng	==>	Eng Management Involvement == Great Extent	20.4	22.9	45.8

Figure 2a, b: Results from association rules analysis for involvement in engineering management and in/with engineering, showing the significant associations found in the data: (a) diagrammatic, and (b) tabular representation. The two are equivalent. What this figure shows is that those who were working in engineering (as opposed to non-engineering roles) were using engineering management to a moderate of great extent. So we can conclude that engineering management is important even to those engineers who stay in engineering roles.

3.2 Qualification

Of the various types of qualification, the most significant association was with Bachelor degrees: about 34 per cent of those with Bachelor's degrees were applying EM to a moderate extent; of those using EM to a moderate extent, 65 per cent had a Bachelor's degree (see Figure 3).



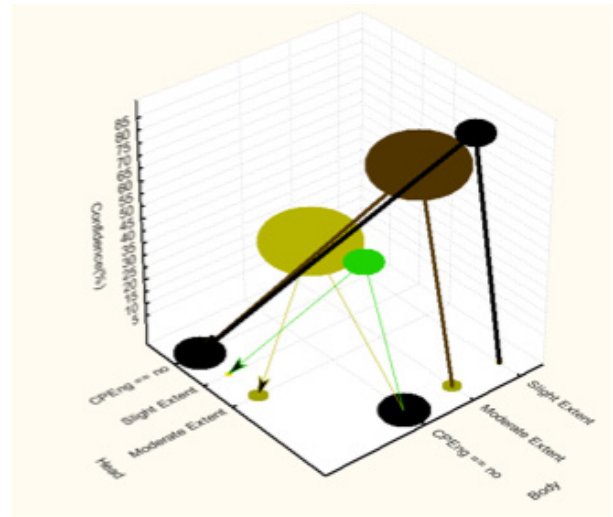
Body		Head	Support %	Confidence %	Correlation %
Qual == Bach	==>	Moderate Extent	22.41758	34.11371	47.04769
Moderate Extent	==>	Qual == Bach	22.41758	64.88550	47.04769

Figure 3a, b: ARA for qualification type, showing that those using EM to a moderate extent tended to have Bachelor degrees. What this figure shows is that it is mostly the engineers with Bachelor degrees as opposed to higher or lower qualifications that are involved with the bulk of the engineering management work. One could also interpret this as implying that engineering management is a core professional activity for engineers, and is not limited to a subset of engineers with specialist qualifications.

3.3 Chartered Professional Engineers and IPENZ Membership

Do Chartered Professional Engineers (CPEngs) use EM more than professional engineers who are not chartered?

The results show the mode is about the same: both use EM to a moderate extent (3). However, CPEngs use EM more. Of the CPEngs, 81 per cent use EM to a moderate or greater extent, compared to only 59 per cent for non-CPEng. ARA shows the most significant association was that those who were not CPEng tend to apply EM to a moderate or slight extent (see Figure 4). ARA did not find any significant association for those who were CPEng.



Body		Head	Support %	Confidence %	Correlation %
CPEng == no	==>	Moderate Extent	23.16484	34.33225	47.97833
CPEng == no	==>	Slight Extent	18.24176	27.03583	46.72102
Moderate Extent	==>	CPEng == no	23.16484	67.04835	47.97833
Slight Extent	==>	CPEng == no	18.24176	80.73930	46.72102

Figure 4a, b: ARA for professional competency. Those who were not chartered tended to apply engineering management to only a moderate (34 per cent confidence) or slight extent (27 per cent confidence). What this figure shows is that CPEngs tend to use engineering management more than engineers who are not chartered. We might have expected the CPEngs to be more focused on technical competence and less on engineering management, but this is not so. The implications are that engineering management skills are an intrinsic part of functioning as a CPEng.

3.4 Grades of IPENZ Membership

Of all the types of Member (Graduates, Professional, Fellows, Technical and Associate), it is the Professional Members who were most statistically associated with greater EM. For all those who were Professional Members, 36 per cent of them were doing a moderate amount of EM. The reciprocal statistic is that for all those who were involved in EM to a moderate extent, there was a 47 per cent chance of them being a Professional Member. The other types of Member did not show up as being singular. The Members who are using EM to the least extent are the recent graduates.

3.5 Work activity

Which work areas use EM the most? The results show that project managers and general managers use it most. Those who use it the least were the research and development engineers. All the rest use it to moderate extent, see Figure 5.

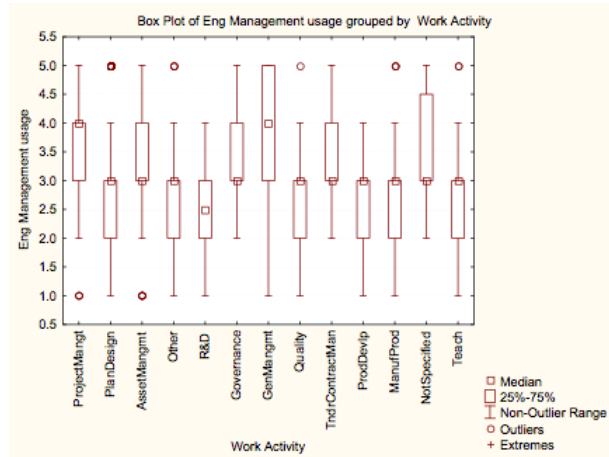


Figure 5: Use of engineering management across various work activity areas. Note that 5=Very great extent, 1=Not at all. What this figure shows is that most engineering “work activities” are using engineering management to a moderate extent, some more and others less. The implications are that there are not many engineering jobs where engineering management can be avoided, so can we infer that EM is a core skill.

Association rules show that the most statistically significant association is with planning and design: 37 per cent of these work activities involved EM to a moderate extent. Conversely, for those with a moderate amount of EM, 47 per cent were applying it to Planning and Design.

3.6 Miscellaneous variables

3.6.1 Insignificant variables

There was no significant correlation found with ARA between use of EM and geographic region or hours worked.

3.6.2 Significant associations: employment

A significant association was found in employment status: For those in full-time salaried roles, 57 per cent used EM to a moderate or great extent, and another 23 per cent to a slight extent. This is consistent with the interpretation that temporary work involves delivery of engineering services and not the supervision of others or the management of business activities.

3.6.3 Practice area

Practice area was a not a strong differentiating factor (see Figure 6). As expected, the business engineers used it the most, mining engineers too, though there were only a few of them. The mechatronics area reported the least usage of EM. The rest used it to a moderate extent. Curiously, those who did not identify their practice area tended to

use EM more. The reason for this is uncertain: might it be that these are multidisciplinary engineers, or engineers who have moved into broader roles in their organisations?

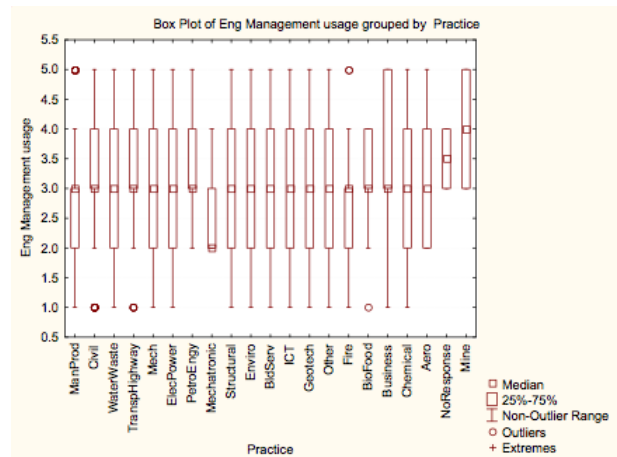


Figure 6: Usage of engineering management with 5 being the most and 1 the least, for different practice areas. What this figure shows is that most engineering practice areas are using engineering management to a moderate extent. There is not a lot of variability in this figure, so the implications are that pretty much all engineering areas involve some management, with the possible exception of mechatronics.

3.6.4 Employment field

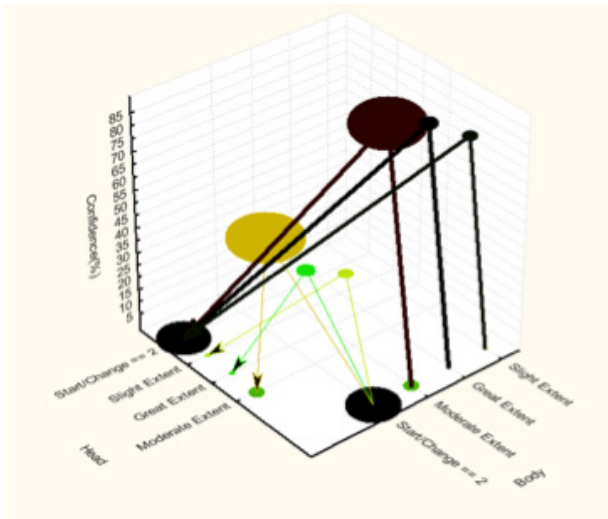
For the employment fields, consultancy stood out as significant: of those using EM to a moderate extent, 55 per cent were working in consultancy.

3.6.5 Sector

Usage of EM was about the same for the private and public sectors. About 35 per cent of those in the private and public sectors used EM to a moderate extent. The public sector was a slightly larger user of EM.

3.7 Job changers

For those who did change jobs (start/change=2) in the past year, there was a 59 per cent chance that they would be using EM to a moderate or great extent, and only a 23 per cent of a slight usage, see Figure 7. This would seem to imply that promotion involves greater use of EM (assuming that the job changes were primarily upwards, which is unknown). Also, for those who were using EM to a great extent, 83 per cent had a job change. This could variously suggest that movement into management generally requires a job change rather than an incremental change, or that these users of EM were more prone to change jobs, or that more opportunities were available to them. Note that “job change” does not necessarily mean that people changed employers.



Body	Head	Support %	Confidence %	Correlation %
Start/Change == 2	Moderate Extent	28.30769	34.90515	53.47815
Start/Change == 2	Great Extent	18.37363	22.65583	43.30444
Start/Change == 2	Slight Extent	17.80220	21.95122	41.58869
Moderate Extent	Start/Change == 2	28.30769	81.93384	53.47815
Great Extent	Start/Change == 2	18.37363	82.77228	43.30444
Slight Extent	Start/Change == 2	17.80220	78.79377	41.58869

Figure 7: The ARA found the most significant associations were for job changers (=2) to be involved with engineering management, often to a greater extent than the non-changers (though sometimes also a lower extent). It is difficult to be definitive about the interpretation of these results, but they do tend to suggest that new jobs often involve increasing management responsibilities, i.e. that promotion involves more management. This is broadly consistent with the IPENZ model for career progression, so in some ways is not surprising, but it is interesting to see that there is some hard evidence for this.

3.8 Importance of engineering management changes over time

The original hypothesis was that EM became more important as engineers developed in their careers. Career development was measured by years of experience, and separately by job points.

In both cases the importance of EM did increase over time and job points. The results are shown in Figures 8 and 9.

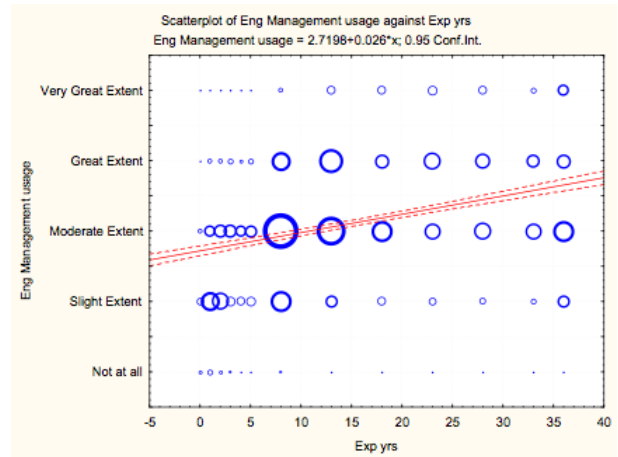


Figure 8: Importance of engineering management changes with years of experience. Note 5=Very great extent, 1=Not at all. What this figure shows is that the trend is for increasing involvement with engineering management over a career. The trend line is upwards and there are many data points so we can be reasonably confident about where the mean lies (the dashed envelope shows the 95 per cent confidence interval for the mean). Ignoring the mean line, and concentrating on the detail shows that the average engineer's involvement with engineering management increases up to about 15 years of experience, and then diverges: some increase it to the highest level, while others drop back out of management roles, and the majority stay in the middle.

The trendline in Figure 8 shows that recent graduates use EM to only a slight extent. With time the usage increases. However, there is variability in the usage: some recent graduates report they are immediately using EM to a great extent, whereas some engineers at the point of retirement are still only using it to a slight extent. This suggests that while EM is core knowledge to learn, it is still possible to have an engineering career that mostly avoids it, normally through remaining in purely technical roles with minimal responsibility for the work of other employees. Nonetheless, total avoidance is almost impossible: note that those with about a decade of experience will at least use it to a slight extent, and the not-at-all responses are statistical outliers at this stage.

The picture is more marked in Figure 9, where the horizontal axis is job points (JP). This is an IPENZ variable that measures the complexity of the role and the level of organisational responsibility.

Those engineers with low job points (who tend to be recent graduates but not exclusively so) use EM to less than a slight extent. In contrast, those with high job points (JP=60) use it to a great extent. Other IPENZ results show that remuneration increases with job points. So we infer that higher use of EM is likely associated with higher income.

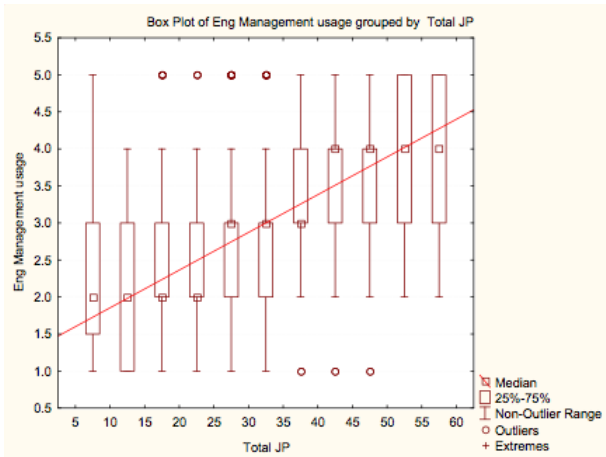


Figure 9: Importance of engineering management changes with total job points (JP), an IPENZ measure of job complexity. Note that 5=Very great extent, 1=Not at all. What this figure shows is that use of engineering management increases strongly with job points. The implications are increased management responsibilities are part of the territory that goes with promotion and increased salary.

We identify several phases in the data:

1. Early career: those newly out of graduation (say up to three years or 15 job points) tended to have roles where EM was only used to a slight extent (2) or even not at all (1). In this stage it was unusual (but not impossible) for engineers to use EM to a very great extent (5).
2. Development phase: at three-plus years' experience or over 15 job points, the usage changes. Now the median is for engineers to be using EM to a moderate extent (3), and the range is from not at all (5) to a great extent (2).
3. Mature phase: at 13 years or 35 job points there is another shift. These engineers typically use EM to a moderate extent (3) to great extent, but now it is common that some will use it to a very great extent (1). The not at all (5) response is now rare.

The results show that usage of EM does indeed vary with career stage, becoming greater with job experience.

The two measures of career development – time and job points – may be plotted against each other to determine linearity (see Figure 10). The results show that job points increase approximately linearly up to about 40 points at 15 years. After this, points are approximately static to about 35 years, after which there is a decline for some (but not all) engineers. Perhaps the latter corresponds to retirement.

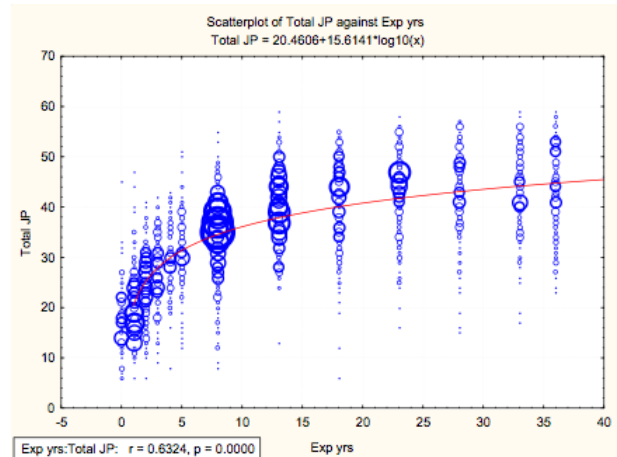


Figure 10: Total job points and years of experience are similar measures of career progression. This chart plots them against each other. If they were perfectly correlated then there would be a straight line relationship between them, but the actual results show that job points rise with experience, initially fast but tending to plateau in the longer term. What this figure shows is that starting engineers rapidly get greater organisational responsibilities, over say the first eight years, with a more steady increase thereafter. The implications are that there is a lot of learning on the job that happens in the first decade. This confirms the profession's importance of ongoing professional development.

3.9 Career paths within engineering management

The above section shows that years of experience and job points are complementary but not-identical measures of career progression. The scatterplot of these variables against EM usage is shown in Figure 11.

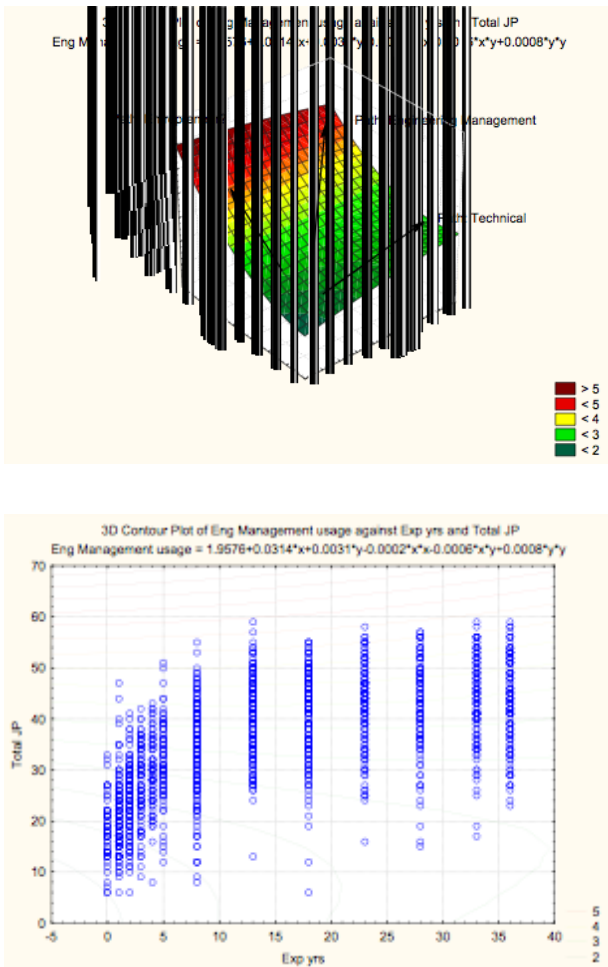


Figure 11A,B: Scatterplot of usage of engineering management against both years of experience and job points. (A) Three dimensional representation – the surface shown here is the mean based on a polynomial fit, and the shading represents the usage of engineering management. (B) Contour plot, showing where the actual data points lie. Note that some regions are poorly populated even though a mean is indicated. What this figure shows is that engineers who chose a technical career path tend not to use engineering management very much and their job points (and by implication salaries) are limited accordingly. A more typical career path is to increase engineering management involvement with time and also job points.

We interpret three career paths in the data:

Technical

These engineers accumulate experience, but not in EM. Their job points do not increase much. To the extent to which job points are a proxy variable for salary, these engineers will have satisfactory but not exuberant salaries.

Management

These engineers increase in engineering management skills with time, and find roles of responsibility where those capabilities can be deployed. Their job points therefore also trend upwards.

Entrepreneur

There are some engineers who report high job points (30 or more) despite short experience (12 or less years), and claim to be using EM to great or very great extent. We tentatively classify these as entrepreneurs. Either that, or they may be misrepresenting their responsibilities (faking good). The profile of these engineers is shown in Figure 12: they are mostly graduates with Bachelor degrees, not yet CPEng, working in the private sector in the Auckland region (the largest city in New Zealand). They tend to see their role as project management. They were not associated with any specific practice area.

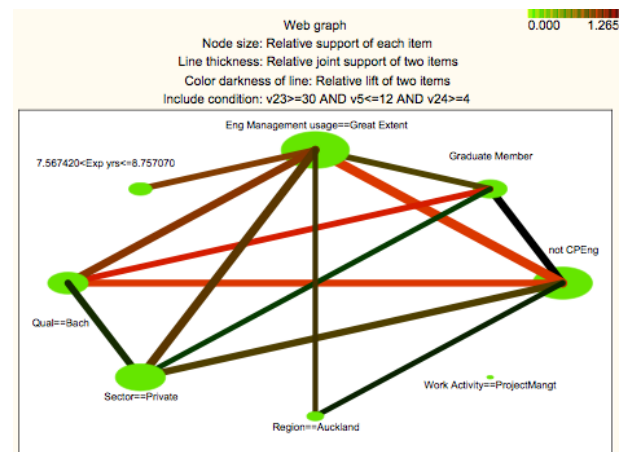


Figure 12: Profile for “entrepreneurial” path. (ARA with variables 3-4 7-8 10 15 21 24 5 23, support minimum 30 per cent, confidence minimum 15 per cent.) What this figure shows is that entrepreneurial engineers tend to use engineering management to a great extent, and they tend not to pursue professional membership of IPENZ or higher qualifications.

4. DISCUSSION

4.1 Outcomes: What has been achieved?

Hypothesis 1 is supported: practising engineers use EM to increasing extent as their careers progress.

Hypothesis 2 was that that use of EM varies across practice areas. There was indeed an effect in extent-of-usage but it was not strong. As expected, business engineers used it the most. The rest used it to a moderate extent.

The results show that EM is an important component of engineering professional practice. While there were engineers who were not using EM at all, even late in their careers, this was rare. Engineers with high joint points (hence generally also higher salaries) were using EM to a great extent.

This work is one of only a few studies that has taken a large-survey approach of asking engineering practitioners about their usage and establishes the changing use of EM with career. It also demonstrates the application of association rules analysis to this area.

4.2 Implications for practitioners

The implications for engineering practitioners are best understood by career phases:

Early career engineers (one to three years): New graduates can generally expect to use EM to a slight extent. However there are exceptions and some immediately use it to a great extent. Engineers in this group might consider looking for opportunities to progress in the next stage.

Developing engineers (three to 13 years): From about three years' experience, engineers can expect to be using EM to a moderate extent. Consider professional development. Project-management and team-leader roles might be useful entry points into EM, and engineers may like to consider such opportunities as they arise. Engineers who are feeling that their employment is restricting their development may need to discuss the options with their employer: perhaps consider a more active approach to professional development, or request project type roles. All the same, it is just possible (though rare) to have an engineering career with almost no involvement with EM.

Mature engineers (13-plus years): From about 13 years or 35 job points there is another opportunity to shift up a level regarding usage of EM. At this level engineers use EM to a moderate or great extent, and it is common that some will use it to very great extent (1). Presumably the ability to make this transition depends on the competencies learned in the "Developing" stage.

There are also implications for educational institutions: graduates will not need their EM knowledge immediately after graduation, but instead a few years deeper into a career. It may be helpful for students to know that. A possible message might be: "You will perhaps not need this knowledge immediately after graduation, though even then some of you will. However, you will almost certainly need it three years into your career."

4.3 Limitation and implications for further research

We know where in a career the need arises for EM. We also know that the need is similar across all the practice areas. However, what is not yet evident is which topics within EM are important, and whether that importance varies across practice areas. Those questions are addressed by a companion paper.

Future surveys might benefit from defining practice areas more broadly, specifically the inclusion of multi-disciplinary and organisational roles. This is worth doing as the results of the present survey showed that those who did not identify their practice area tended to use EM more.

Future work might explore the distinction between general management and the professional registration category of "Business Engineer", e.g. find the core competencies for "business engineer" and the factors that might differentiate it from general management. By comparison the present work has the much more basic research objective of determining what practitioners identify as "engineering management" and how they use it, regardless of whether or not they are registered business engineers.

5. CONCLUSIONS

The research question was to determine the extent to which actual practitioners used EM, and to differentiate usage by practice area and career stage. The results of a survey of New Zealand engineers show that EM is used to a moderate extent by the profession as a whole. The usage across practice area is broadly similar. The greatest variability is in usage though career stage. Several career phases are evident. Early career: those newly out of graduation (say up to two years or 10 job points) tended to have roles where EM was only used to a slight extent or even not at all. Development phase: at three years' experience or 15 job points, the median is for engineers to be using EM to a moderate extent. Mature phase: at 13 years or 35 job points engineers typically use EM to a moderate to great extent, and it is common that some use it to very great extent. By this stage the "Not at all" response is rare. The results show that usage of EM varies with career stage, being initially low and becoming greater with job experience.

In the context of the broader role of professional engineer, the results show that EM is used extensively. Those engineers who have the greatest involvement with managing and leading organisations (i.e. greatest job points) have a greater involvement in EM. While engineering might seem to be mainly about technology, from the perspective of undergraduates, it is necessary to involve EM to implement that technology. It is particularly challenging to do so within the constraints imposed by society and simultaneously add value to the organisation. While it is still possible to have an engineering career that mostly avoids EM, by remaining in purely technical roles, nonetheless the results show that total avoidance is almost impossible. EM is not an optional extra for the occasional person who wishes to have a better paid career path, but an indispensable part of professional practice.

6. ACKNOWLEDGEMENTS

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