

Women in Engineering: A Simple Mathematical Theory for the Rate of Adverse Experiences

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Abstract

Recruitment and retention of women in engineering fields is an ongoing issue although much progress has been made. Despite excellent company and institution policies, many female engineers report adverse experiences. As an engineer with 14 years of experience in both industry and academia, I have experienced some working environments with excellent cultures as well some where multiple frustrating incidents occurred, similar to those described elsewhere (e.g. Miller, G. E. (2004), Gender Work and Organization 11(1): 47-73) and which can be considered discriminatory.

*Anecdotal stories from female engineers (including myself) can be grouped into one of three categories:
No or very few adverse experiences as a woman in engineering
A series of minor incidents have occurred, but no “major” incidents
Serious sexual harassment or discrimination incidents
Why do some women engineers report no issues, and others report multiple incidents?*

This paper proposes a simple, probability based explanation for the first two categories above, where there are either no incidents or a string of minor incidents experienced by the female engineer. An anecdotally observed pattern is described, where women who report no or very few adverse experiences tend to work in organisations with a higher proportion of women. Based on this, the paper outlines a light-hearted mathematical description of why, regardless of organizational culture, the ratio of men to women in an organisation is a strong factor in the rate of adverse events experienced by female engineers.

1. INTRODUCTION

Recruitment and retention of women in engineering fields is an ongoing issue in the profession (Freehill et al. 2004; Hersh 2000; Isaacs 2001; Kim 2003). There are four main arguments for ensuring adequate participation of women in engineering: equity, excellence, efficacy and efficiency, explained elsewhere (for example, ETAN, 2000; Mills and Ayre 2003; Toner, 2006). Much progress has been made and in English speaking countries (USA, Canada, UK and Australia), women represent 15-20% of engineers in undergraduate education and approximately 10% of the profession (refer to Table 1 for a short summary.)

Table 1: Summary of women in engineering statistics for major English speaking nations.

Country	% undergraduate women	% professional women
USA	19.9% ^a	10.6% ^b
UK	18% ^c	7-15% ^d
Australia ^e	15%	10%
Canada ^f	20%	9%

^a Isaacs, B. (2001).

^b www.swe.org and Science and Engineering Indicators 2000, Vol 2; Appendix Table 4-33. National Science Board, National Science Foundation, USA

^c Anon (2006)

^d UK resource centre for Women in Science Engineering and Technology, Annual Labour Force Survey, IES analysis, 2005

^e Engineers Australia (2006)

^f Burrowes, (2006)

There are numerous examples and reports of overt discrimination, as well as less serious adverse experiences which can negatively affect retention of women in education and the workforce (Barres 2006; Frehill et al. 2004; Ingram 2005; Kim 2003; McLoughlin 2005; Miller 2004; Mills and Ayre 2003) To address this, human resource departments in government and professional institutions create policies which strive to create the optimal organizational culture that supports and promotes all engineers, male and female, to excel and utilize their talent. However, even companies with the best diversity policies are not always successful in preventing individual women from experiencing a “chilly climate” and discrimination rates are very high: in Australia, 36% of female engineers report experiencing some form of discrimination (Roberts and Ayres 2002) and between 30-58% in the USA (Hersh 2000). Why do some women engineers report no discrimination experience while others report multiple incidents?

As an engineer with 14 years experience since graduation, I have never entered a workplace which has a deliberately hostile attitude towards women. However, I have held positions where I was the only female engineer in that section of the company and I experienced multiple minor incidents that caused frustration. These kind of minor incidents are well described (Anon. 2006; Kirner and Rayner 1999; McLoughlin 2005; Miller 2004; Sinclair 1998), and can be considered a form of discrimination. Some examples of minor adverse events are listed in Table 2. Note that the examples listed here deliberately exclude overt discrimination and sustained, bullying harassment – only examples of adverse experiences resulting from “day to day interactions” (Miller 2004) experienced in male-dominated fields are included.

Table 2: Examples of minor adverse incidents experienced by women engineers

Emails addressed “Gentlemen”
Use of “he” or “his” to describe the actions of an engineer (Anon. 2006)
Being mistaken for a secretary (Anon. 2006)
Being “one of the boys” to fit in with the culture
Lack of change and bathroom facilities for females
Questions regarding boyfriends, marital status etc. (Kirner and Rayner 1999)
Safety equipment stored in the male change rooms.
Comments on clothes or physique (Kirner and Rayner 1999)

Anecdotal stories from female engineers can be grouped into one of three categories:

1. No or very few adverse experiences as a woman in engineering
2. A series of minor incidents have occurred (similar to Table 1), but no “major” incidents
3. Serious sexual harassment or discrimination incidents (e.g. unwanted sexual advances, or deliberate denial of promotion)

This paper proposes a simple, probability based explanation for the first two categories above, where there are either no incidents or a string of minor incidents experienced by the female engineer. Qualitatively, a pattern can be observed: women who report anecdotally no or very few adverse experiences tend to work in organisations with a higher proportion of women. Based on this observation, outlined below is a light-hearted mathematical description of why, *regardless of organizational culture*, the ratio of men to women in an organisation is a strong factor in the rate of adverse events experienced by women.

1.1. Anecdotal explanation of adverse event experiences

For the purpose of the derivation, a fictional company Engineers & Co. has 10,000 employees, all men. They have recently hired a new female engineering graduate. Lets assume that the corporate culture is excellent and 99% of employees are supportive and professional towards women engineers. This means there are 100 people in the company who will create an adverse event or experience (AE) when they first meet the new female engineer (see Table 2). For the purpose of the derivation, these AE would all be *random, isolated incidents that occur only on the initial meeting and are not subsequently repeated*. These negative initial interactions are subsequently replaced with “normal” professional behaviour towards the female engineer.

However, *since there is only female engineer in the company, she will personally experience 100 adverse events*. Even if she meets only $\frac{1}{4}$ of the staff during her employment with Engineers & Co., this single

individual woman will still personally experience 25 negative incidents. This represents the best possible scenario since the company culture is positive and all AE occur only once per employee. In reality, a company with 99% male employees would most likely have a masculine climate and the real frequency of AE would be much higher. Although each incident is isolated and not repeated, to the individual they form a persuasive *pattern* of a “chilly climate”.

However, the proportion of women in the organization is crucial. If Engineers & Co. hires a new batch of 20 graduates, and 9 of them are women, the pattern of adverse events changes considerably. Since the events are random and unrepeated, then each woman will experience 10 AE on average during her career (100 potential events distributed over 10 female engineering employees). Under these circumstances, most of these women will answer “no or few AE”, as the number of women in the organisation have effectively spread and diluted the AE.

2. Mathematical representation of AE Probability theory

The anecdotal explanation above can be expressed as a simple mathematical AE probability theory. The frequency of adverse experiences is the product of the total number of men N_{men} multiplied by the probability of any interaction resulting in an AE, p_{AE} :

$$f_{AE} = N_{men} p_{AE} \quad (1)$$

The p_{AE} is treated here as a constant throughout society, regardless of the professional field, and is not assumed to be specific to engineering. In the example above, 99% of employees at Engineers & Co. had a professional attitude towards female engineers, i.e. $p_{AE}=0.01$ and is a measure of corporate culture.

The total number of adverse experiences to an individual female employee is obtained by dividing equation (1) by the number of women in the organisation.

$$AE = \frac{N_{men} \cdot p_{AE}}{N_{women}} \quad (2)$$

where AE has the units of #events/female engineer. Further, N_{men} and N_{women} are related:

$$N_{total} = N_{men} + N_{women} \quad (3)$$

Where N_{total} is the total number of employees in the company. In addition,

$$N_{women} = N_{total} \cdot w \quad (4)$$

where w is the percentage of women in the organisation.

Rearranging equations (3) and substituting together with equation (4) into equation (2) we have:

$$AE = \frac{(1-w)N_{total} \cdot p_{AE}}{wN_{total}} = \frac{(1-w)p_{AE}}{w} \quad (5)$$

Thus, equation (5) suggests that the probability of an adverse experience by a woman in engineering is independent of the size of the company, and dominated by the percentage of female staff (w) and the organizational culture (p_{AE}). Figure 1 shows how the probability of adverse experiences falls exponentially as the percentage women (w) is the organisation increases for an arbitrary value of $p_{AE}=0.01$. If the company has 10% women, each woman will experience an adverse event during 1 in 10 ($AE=10\%$) of initial interactions. Once the percentage of women reaches 50%, the frequency of AE is close to zero. Conversely, as the percentage women approaches zero, the likelihood of adverse event approaches infinity.

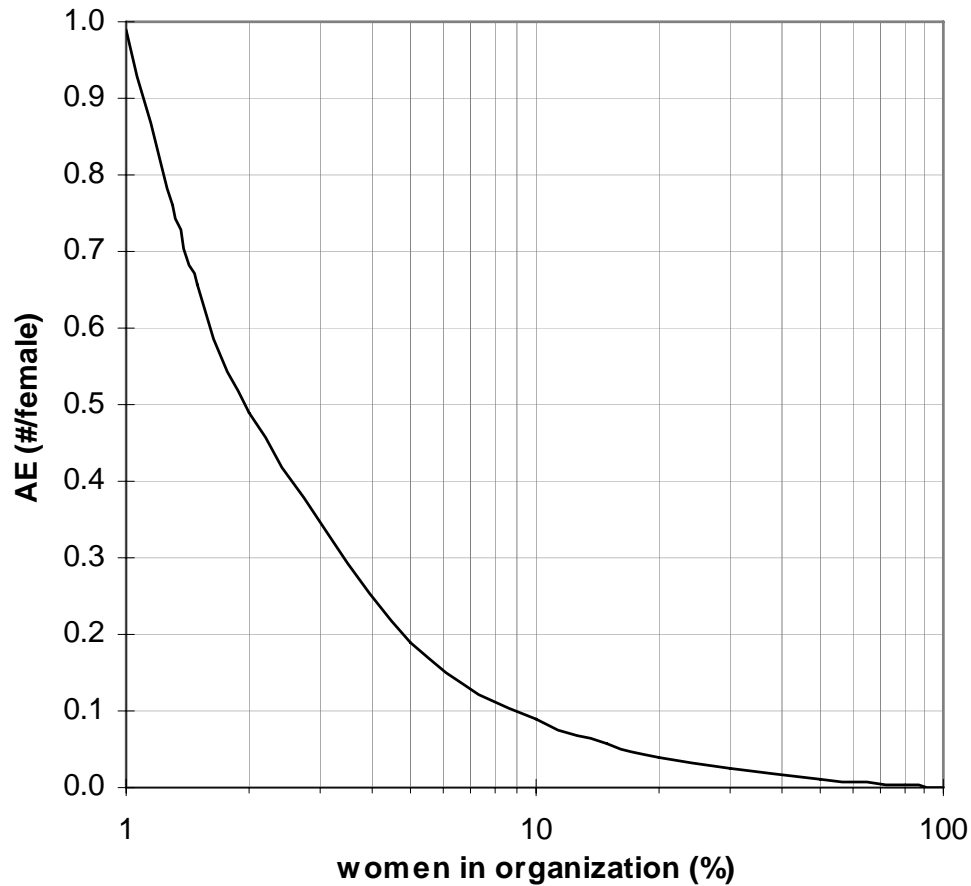


Figure 1: Adverse events (AE) occurring as a function of the percentage of women (w) in the organisation with $p_{AE}=1\%$

For female employees of vendor or consulting firms, adverse experiences can result from interactions with colleagues from the company as well as from clients and customers. In these situations, the value of w should be calculated as the overall fraction of women employed by the consulting company and all the client/customer companies that the female engineer interacts with. This may improve the situation or exacerbate it, depending on the gender balance in the client industry sector. Once again, this situation demonstrates how changing the internal organisational culture is only partly a solution and will not always be effective in reducing the rate of adverse experiences.

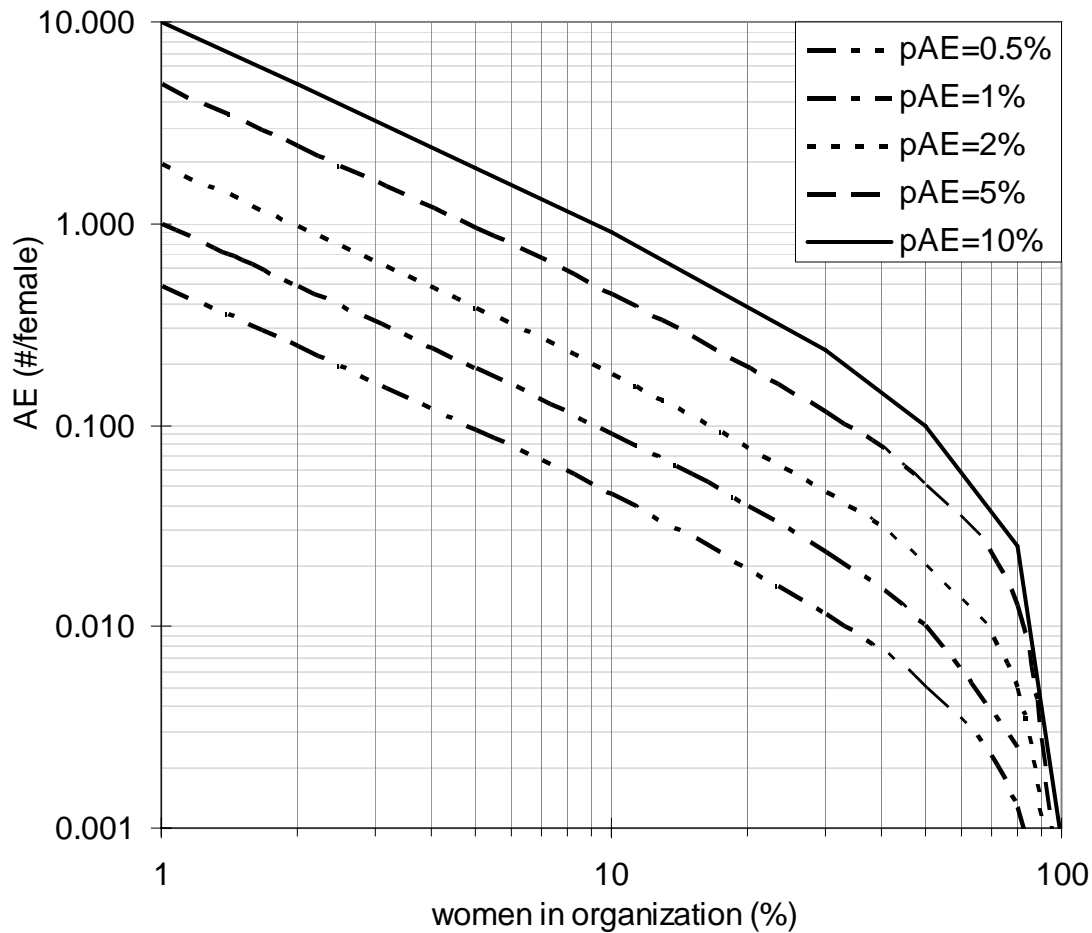


Figure 2: Effect of the probability of an adverse experience (p_{AE}) on the overall AE frequency per female employee.

There are many well documented cultural and organizational factors that influence the experiences of women, the majority of which influence the value of p_{AE} used in equation (1). This is the ultimate, long term solution to improving the diversity of the engineering profession. The system is also expected to be self-correcting, in that as the percentage of women increases, the organisation culture can be expected to improve, thus decreasing the probability of adverse events p_{AE} and creating a further improvement in organizational culture. Figure 2 illustrates how improving corporate culture and reducing the p_{AE} value from 10% to 0.5% results in an exponential decrease in AE .

There are some practical physical restrictions on equation (5) in that w has a minimum limiting value that varies with the size of the organisation. For a company with 300 employees and only one female, w is limited to $1/300$ or 0.3%. If the number of employees is 10 and there is only one female, the minimum possible w is 10%. Interestingly, this predicts that small firms will have more positive environments for women, assuming that there are no cultural differences affecting the value of p_{AE} between small and large firms.

The mathematical description provided here is intentionally simplistic to highlight how the number of women in an organisation is a key factor affecting the experience of individual female engineers, in addition to the organizational culture. The mathematical analysis could be improved using a more detailed approach to statistical probability. Some general data on the number and type of adverse experiences in Australia was located through the online searchable database of the Australian Government's Equal Opportunity for Women in the Workplace Agency, but was not detailed enough to use with equation (5). A specialised survey would be required in order to validate the proposed theory.

3. Conclusions

The analysis presented here is a light-hearted representation which may provoke a smile followed by some reflection. Discrimination is a serious issue, and this analysis is not intended to trivialize the importance of diversity. The mathematical treatment is by no means rigorous, but hopefully will highlight how a series of random, unrepeatable "one-off incidents" can combine to form a persuasive pattern of discrimination to an individual. In addition, I hope the analysis also highlights how the diversity of the organisation has a direct bearing on how concentrated these incidents are to a single individual employee. Finally, there is an important message which I hope will generate further thought and discussion: *increasing the number of female engineering employees is the simplest way to reduce the negative experiences experienced per individual.*

4. References

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