Human Factors in Requirements Engineering

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Introduction

Work in the field of human error has typically focused on operators of safety-critical equipment, such as nuclear power plant controllers, and of the design of the human-machine interfaces in such settings. Limited consideration has been given to wider system issues. Similarly, researchers and practitioners in the field of Dependable Systems are concerned with the design of computer-based systems which are intended to be operated in situations where the consequences of failure are potentially catastrophic. For example, the failure of a safety-critical system may cause great harm to people, property, or the environment. The work reported on in this paper is motivated by the need to ‘push back’ these concerns with the operation and design of dependable systems to the process by which they are developed.

Errors in the Requirements Engineering (RE) process are widely considered to be the hardest to discover. Consequently, they tend to remain undetected for the longest time, require the greatest amount of re-work, and are the most expensive to rectify of all errors in systems development. Whilst efforts to detect and rectify errors in RE and the whole of the development process are a necessity, the nature and cost of errors in requirements makes a strategy of avoidance rather than detection a more attractive prospect. The benefits of such an approach are primarily that the amount of rework can be reduced to a minimum, along with related savings in cost and time to completion of the system.

There is a broadening consensus regarding the nature of RE as a social, as well as technical, process involving a variety of stakeholders engaging in diverse activities throughout [3, 5, 9, 16]. Many of the specific details of the process followed for a given product will often depend upon the nature of the product itself, the application domain, similarities and differences to existing products developed by the organization, and so on. When these variations are combined with an often intense production pressure to release products on time, the importance of human skill and judgement in managing the contingencies, and human flexibility and artfulness in making RE processes work (sometimes in spite of the methods followed [1, 20]) becomes readily apparent.

It is our contention that much needs to be learned from the human sciences to inform the development of future safe systems and to develop a more holistic approach to requirements engineering for dependable systems. This work is part of a wider approach to process improvement for RE processes, and has been conducted as part of the ESPRIT REAIMS project.

This paper presents a large review of literature from several human sciences which is relevant to the understanding of errors in RE processes which are attributable to human activity. This activity can be considered in terms of individuals working in isolation, as participants in social groups, and as members of organizations. The following sections consider research from these three perspectives and how it relates to the RE process.

Errors in individual work

The largest body of research on ‘human error’ [18] has its roots in cognitive psychology and cognitive understandings of peoples’ interaction with technology. Work in this area has typically focused on workplace settings such as nuclear power plant control rooms and on operational risks and operator errors in such environments. Rather less work on human error specifically concerns the use of computer-based systems, and there is even less devoted to the process of their development.

A major distinction to arise from this work is between different ‘levels’ of cognitive activity: e.g. skill-based, rule-based, and knowledge-based in Rasmussen’s formulation [17]. These in turn lead to a number of error classes: skill-based slips and lapses, rule-based and knowledge-based mistakes. Skill-based slips and lapses happen during routine, familiar work, which requires little attention in order to be achieved. In RE, this would be typified by mundane activities, involving everyday skills (e.g. typing, reading, filing, etc.). Rule-based mistakes are related to errors in the plan of action when working in previously encountered situations. They can result from the application of ‘bad’ rules, or the misapplication of ‘good’ rules. In RE, the application of generic solutions can be prone to this type of error. Knowledge-based mistakes arise when working in novel situations, where no existing rule or plan can be applied and attempts are made to apply analogous rules which have worked in similar situations. This describes a great deal of RE work where either there is no previous system which is relevant to the current development, or where the personnel involved are inexperienced in the domain of application.

Violations

The distinction between violation and error has been debated, but it hinges on the intentional disobeyance of a rule or plan. Many such actions are violations in name only, because people will often disobey a bad rule in order to fix it. They can be classified in a similar manner to errors, according to whether they take place at a skill-, rule-, or knowledge-based level. Violations frequently occur in RE as short-cuts are taken in order to meet deadlines or engineers artfully present their work in project reviews or reckon with other constraints and contingencies [1, 20].

Group process losses

There is a vast and diverse literature in the field of social psychology concerned with the effects of working in social and group settings on collective and individual performance. Space restrictions here prevent any more than a brief mention of a few well documented phenomena. *Social facilitation* [13] refers to the change in an individual’s performance when others are present observing. Work on *performance in interacting groups* has studied the relationship between the nature of the task, the relative performance of individuals in the group, and of the group as a whole [22, 23] leading to recommendations for the best strategy to encourage for different tasks. *Group leadership* is often cited as a very important factor in whether a team succeeds or fails [6]. Another body of work is concerned with the influence that team members can have on *conformity and consensus* due to their perceived status in terms of seniority or expertise[24]. The study of *minority influence* is concerned with the extent to which minority opinion in a group can sway the decisions that the group as a whole take [12]. Finally, investigations into the nature of group decision making have examined phenomena such as *group polarization* [7] and *groupthink* [8]. To the extent that RE is typically a group or team activity, these considerations are potentially relevant to its assessment for dependability.

Organizational safety

Empirical evidence already exists to demonstrate that organizational issues are important in RE [4, 11]. There also exist a number of sociological studies of organizations which have much to say on safe and reliable operations [16, 25]. Reason [18] uses the term *latent organizational failures* to describe the concept that failures of an organizational nature can remain dormant until triggered by unsafe acts (active failures) in combination with inadequate defences, thus leading to an accident. Perrow [15] classifies systems according to their *coupling*, which may vary from loose to tight, and *interactions* which may vary from linear to complex. When these two dimensions are considered together, it is possible to make recommendations for the organizational style best suited to cope with potential accidents in different industries. According to Perrow, for the tightly coupled, complex interactions combination, there is an inherent contradiction in the organizational style required, which leads to the conclusion that in such situations accidents should be considered to be *normal*, since they are inevitable. This classification has been supported and updated more recently to include the effect of computer control [14]. 'Normal Accident Theory' has been compared elsewhere with the work of a number of researchers who are more optimistic about the possibility of organizations operating safely in hazardous situations [21]. This work—sometimes grouped under the term 'High Reliability Theory'—has led to a number of recommendations for good practice in organizations in high risk domains [10, 19]. These recommendations aim to improve the likelihood of an organization operating in a reliable manner, and include:

- organization leadership should prioritise safety;
- high levels of redundancy should exist in personnel and technology;
- decentralized authority, continuous training, and strong organizational culture of safety should be encouraged; and
- organizational learning should take place through trial-and-error, simulation, and imagination.

Summary

In summary, there is a vast amount of literature from a broad spectrum of disciplines which is relevant to human reliability in processes, and therefore to the dependability of the RE process. The work reported here was conducted as the initial stage of the development of a process improvement method for RE processes, especially for the development of dependable systems. This method, called PERE [2] (Process Evaluation for Requirements Engineering) has been developed as part of the ESPRIT-funded REAIMS (Requirements Engineering Adaptation and Improvement Strategies for Safety and Dependability) Project[1].

The point we wish to stress here is that as software systems become more pervasive and the associated issues of safety and dependability become more critical, we must consider a broader interpretation of dependability. This broadening of dependability essentially requires us to incorporate the existing work within the human sciences on errors. Much of this work will require some examination and interpretation and this in turn provides a considerable research challenge for Requirements Engineering.

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[1] Main project partners were GEC Alsthom, Adelard, Aerospatiale, RWTÜV, Lancaster University and Manchester University. Further information about PERE, and about the REAIMS project in general, can be found at: `http://www.comp.lancs.ac.uk/computing/research/cseg/projects/reaims/`

References

1. Anderson, R., Button, G. and Sharrock, W., Supporting the design process within an organisational context. In *Proceedings of ECSCW'93* (Milan, Italy, 1993) Kluwer, pp. 47-59.
2. Bloomfield, R., Bowers, J., Emmet, L. and Viller, S., PERE: Evaluation and Improvement of Dependable Processes. In *Safecomp 96—The 15th International Conference on Computer Safety, Reliability and Security* (Vienna, 1996) Springer Verlag.
3. Bowers, J. and Pycock, J., Talking through design: requirements and resistance in cooperative prototyping. In *Proceedings of CHI'94* (Boston, MA, 1994) ACM Press, pp. 299-305.
4. Emam, K.E. and Madhavji, N.H., A field study of requirements engineering practices in information systems development. In *Proceedings of RE'95* (York, UK, 1995) IEEE Computer Society Press, pp. 68-80.
5. Goguen, J.A., Social issues in requirements engineering. In *Proceedings of RE'93* (San Diego, CA, 1993) IEEE, pp. 194-195.
6. Hemphill, J.K., Why people attempt to lead. In *Leadership and Interpersonal Behaviour* Petrullo, L. and Bass, B.M., Eds., Holt, Rinehart & Winston, New York, 1961, pp.
7. Isenberg, D.J., Group polarization: a critical review and meta-analysis. *Journal of Personality and Social Psychology 50,* (1986) pp. 1141-1151.
8. Janis, I.L., *Victims of Groupthink.* Houghton Mifflin, Boston, MA, 1972.
9. Jirotka, M. and Goguen, J.A., Eds., *Requirements Engineering: Social and Technical Issues*. Academic Press, London, 1994.
10. La Porte, T.R. and Consolini, P.M., Working in practice but not in theory: theoretical challenges of 'high reliability organizations'. *Journal of Public Administration Research and Theory 1,* 1 (1991) pp. 19-47.
11. Lubars, M., Potts, C. and Richter, C., A review of the state of the practice in requirements modelling. In *Proceedings of RE'93* (San Diego, CA, 1993) IEEE Computer Society Press, pp. 2-14.
12. Maass, A. and Clark, R.D., Hidden impact of minorities—15 years of minority influence research. *Psychological Bulletin 95,* 3 (1984) pp. 428-450.
13. Manstead, A.S.R. and Semin, G.R., Social facilitation effects: mere enhancement of dominant responses? *British Journal of Social and Clinical Psychology 19,* (1980) pp. 119-136.
14. Mellor, P., CAD: Computer-aided disaster! *High Integrity Systems Journal 1,* 2 (1994) pp. 101-156.
15. Perrow, C., *Normal Accidents.* Basic Books, New York, 1984.
16. Quintas, P., Ed., *Social Dimensions of System Engineering: People, Processes, Policies and Software Development*. Ellis Horwood, London, 1993.
17. Rasmussen, J., Skills, rules, knowledge; signals, signs and symbols; and other distinctions in human performance models. *IEEE Transactions on Systems, Man and Cybernetics SMC-13,* 3 (1983) pp. 257-266.
18. Reason, J., *Human Error.* Cambridge University Press, Cambridge, UK, 1990.
19. Roberts, K.H., New challenges in organizational research: high reliability organizations. *Industrial Crisis Quarterly 3,* 2 (1989) pp. 111-125.
20. Rodden, T., King, V., Hughes, J. and Sommerville, I., Process modelling and development practice. In *Proceedings of the Third European Workshop on Software Process Technology, EWSPT'94* 1994) Berlin: Springer-Verlag, pp. 59-64.
21. Sagan, S.D., *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons.* Princeton University Press, Princeton, NJ, 1993.
22. Steiner, I.D., *Group Processes and Productivity.* Academic Press, New York, 1972.
23. Steiner, I.D., Task-performing groups. In *Contemporary Topics in Social Psychology* Thibaut, J.W., Spence, J.T. and Carson, R.C., Eds., General Learning Press, Morristown, NJ, 1976.
24. Van Avermaet, E., Social influence in small groups. In *Introduction to Social Psychology* Hewstone, M., Stroebe, W., Codol, J.-P. and Stephenson, G.M., Eds., Basil Blackwell, Oxford, 1988, pp. 350-380.
25. Westrum, R., *Technologies and Society: The Shaping of People and Things.* Wadsworth Publishing Company, Belmont, CA, 1991.