A Survey of System Administrator Mental Models and Situation Awareness

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ABSTRACT

Little empirical research has been conducted on the mental models and situation awareness of system administrators. To begin addressing this deficiency, a short survey was prepared and broadcast to system administrators via Internet newsgroups. Fifty-four sysadmins responded. These respondents indicated that there is much about the systems they oversee that they don't understand, and the more they do not understand about their systems, the more likely they are to attribute this ignorance to hardware, and not software, unknowns. The respondents attribute little of the expertise they do possess to formal education or training. Further, when faced with a novel situation, the respondents were more likely to rely on themselves and their personal contacts than on the system's manufacturers, or on third party support. However, the more the sysadmins attributed their ignorance of their systems to hardware unknowns, the more likely they were to rely on manufacturer and third party support. Compared to Microsoft oriented sysadmins, Unix oriented sysadmins were more likely to attribute their expertise to working with others, and were more likely to attribute their ignorance to hardware unknowns. Finally, respondents who felt that their organizational superiors understood what is involved in system administration were more likely to perceive these superiors as providing the sysadmins with adequate support.

Keywords

System administrator expertise, mental models, situation awareness.

1. INTRODUCTION

Despite the current explosion in the number and size of computer networks in the world, little or no empirical research has been conducted on psychological demands of system administration. This neglect might be due to the lack of an obvious physical threat posed by most computer networks, for researchers have studied the interaction between people and potentially dangerous computerized systems for years. For example, extensive human factors theory and data address such human/computer interactions as pilots in "glass cockpit" commercial aircraft [14, 23, 32], air traffic controllers using modernized equipment [11, 29, 30], operators of nuclear power plants [18], anesthesiologists [5], and drivers in proposed "automated" highways [6, 7].

Whether or not an organization's computer network has the ability to do bodily harm, however, its fiscal import suggests that the human/computer interaction involved deserves empirical study. Therefore, the purpose of the research reported here is to address some of the human factors issues affecting system administrators. The dearth of relevant theory and data necessitates the transference of theoretical perspectives from related domains, and a research methodology that is exploratory and not theory-driven. We expect this initial investigation will provide enough data to generate hypotheses which justify more in-depth study.

1.1 Mental Models and Situation Awareness

Two human factors constructs that are appropriate to the study of system administration are that of the mental model and that of situation awareness. Regarding automated systems, Scerbo [25] defines a mental model as "an individual's cognitive representation of how a system operates" (pp. 54). Situation awareness is often defined in a similar manner; and sometimes the terms are used interchangeably. For instance, Endsley [8] defines situation awareness as "a person's mental model of the world around him or her" (pp. 165). However, further examination of the meanings and usage of the terms reveal an important distinction. A mental model is more abstract and strategic than situation awareness. A mental model allows someone to anticipate future events and formulate plans [4, 15, 20, 27]. In contrast, situation awareness is more concrete and tactical. It is what is required to respond effectively to emergencies and to troubleshoot efficiently [9, 22]. Therefore, to be effective, a sysadmin requires both a useful mental model for proactive management, and accurate situation awareness for reactive remediation. Mental models are so advantageous that people forced to deal with complex systems will form these models naturally. But when mental models of complex systems are improperly formed, they can contain technical inaccuracies and lacunae.

In the extreme, a completely accurate mental model will reflect – exactly – the reality of the system as it is designed and built. Or, as stated by Kantowitz and Campbell [12], "Ideally, there should exist a 'match' between the actual operating characteristics of the system, the pilot's internal model of the system, and the designer's model of the system" (pp. 129-130). However, when

the demands of cognitive parsimony are considered, a satisfactory and usable mental model is often preferable to a completely accurate but unwieldy one. Unfortunately, for complex systems, even simplified models can require extensive effort to learn; and often no attempt is made by system designers to assist this process.

Whether accurate or inaccurate, the mental model of the system becomes a critical element of the sysadmin's situation awareness: an accurate and useful mental model will augment situation awareness, while an inaccurate and useless mental model will diminish situation awareness. However, even when a mental model is completely accurate, aspects of the system design can thwart situation awareness.

Research has demonstrated that engineering which supports greater situation awareness is beneficial to system performance [13, 17]. Unfortunately, engineers tend to demonstrate their technical prowess, even when doing so produces a system that detracts from situation awareness [21]. For instance, engineers will attempt to automate the simple, rote activities of the user whenever possible. This can be a desirable feature with systems that will not require manual override – such as elevators – but can destroy situation awareness with systems that ultimately depend on humans as safeguards – such as system administration or commercial aircraft [16, 24]. In fact, for pilots in automated aircraft, Wiener [31] noted that this engineering tendency results in a system that off-loads pilots during periods of low workload, but increases pilot workload under high workload conditions. From a human factors perspective, this is the opposite of what is desired.

Consider, as an analogy, two people on a long automobile trip. The person driving the car is more likely to respond well to the car in front skidding on wet pavement than the passenger who is simply handed the wheel at the critical moment. The driver has better situation awareness than the passenger, even if the passenger is consciously attending to the situation. The price the driver must pay for this situation awareness is involvement in the continuous response and feedback dynamic that informs the driver of the state of his car, the road, other traffic, and himself in relation to these factors. When the emergency arrives, the driver's selection of the most appropriate response will reflect a deeper understanding of the situation than the passenger can generate. With human cognition, complex tasks have meaning as holistic, multi-modality processes, and not just as a series of unrelated, visual and/or aural events [10]. Thus, humans who are expected to respond to dynamic situations do so better when they have a situation awareness continuum to draw upon, even if this means not allowing the automation to handle all the tasks that it can [1].

Therefore, with this theoretical background, the original goals of this research were to examine the mental models and situation awareness of system administrators. Interviews with volunteer sysadmins would first be employed to focus and specify these research goals, and develop appropriate questions to administer to a larger sample of sysadmins. When completed, these questions would be broadcast, as a confidential survey, to sysadmins via appropriate Internet news groups.

2. PROCEDURE

2.1 Preliminary interviews

The preliminary interviews consisted of open-ended discussions with a system administrator and a network technician at a local university. It soon became apparent that the original thrust of the interviews – examining sysadmin mental models and situation awareness by inspecting the details of what sysadmins do and how they do it – was inappropriate. There were too many unknowns and too little empirical foundation for such refinement in the study. Therefore, the focus of the interviews became more general: examining sysadmin mental models and situation awareness by asking the sysadmins how much they know, how they came to know it, and how they handle the unknown.

Neither of the preliminary interview subjects was formally trained or educated for the position he currently held. Each stated that there were aspects of their systems that were mysterious to them. Each relied upon years of hands-on experience, personal research, experimentation and a network of contacts to manage and troubleshoot their systems. Also, each interviewee perceived differences between the system administration of Unix oriented systems and Microsoft NT oriented systems. In general, the interviewees felt that Unix was a more flexible and sysadmin controllable environment than NT but that, for most usages, Unix required a higher degree of expertise from the sysadmin than NT. These issues were pursued in the following interviews.

2.2 Semi-structured interviews

Unlike the preliminary interviews, which were open-ended, the next three interviews employed specific, detailed questions that addressed the themes revealed in the preliminary interviews. However, these interviews also allowed the interviewees to elaborate or digress if they felt this was appropriate. All three interview subjects were sysadmins of large, elaborate networks in non-commercial domains. These interviews reinforced and refined the themes mentioned previously, while contributing two new themes. First, each of the sysadmins felt that his system was, for the most part, unusual. The possibility that all sysadmins felt this way -- or that each system in existence is, in some way, unusual -- had to be considered as a major factor in the understanding what sysadmins know and do. Second, it was suggested that some sysadmin supervisors might not fully comprehend what the job of sysadmin entails and, as a consequence might not provide the resources necessary to effectively reduce the risk of system failure or security breach. These themes, along with the ones revealed earlier, were addressed in the first drafts of the survey.

2.3 Draft surveys

The draft surveys were administered to seven sysadmins of networks in both commercial and non-commercial domains. A talk-aloud protocol was used to allow the sysadmins to comment on specific questions, phrasings, and any other issues brought to mind while responding to the surveys. Later drafts of the survey then reflected the alterations instigated by previous respondents. Recognizing the need to keep surveys that are administered to volunteers as short, clear and intriguing as possible, the final draft of the survey consisted of only eight questions that addressed the main themes suggested by the interviews, and were phrased in language that was intended to be unambiguous and provocative.

This survey, summarized below, is available in its entirety at http://faculty.washington.edu/stiber/pubs/sigcpr01.ps.gz.

3. RESULTS

A total of 54 sysadmins responded to the survey. Some sysadmins failed to respond to some items, thus reducing n-size for certain questions and comparisons.

3.1 Question 1

As far as you can tell, the system you currently supervise is ...

unlike any other system in the world.	1
for the most part, unusual.	2
equal parts unusual and generic.	19
for the most part, generic.	26
completely standard.	6
	(N = 54)

Only 3 of the 54 sysadmins answering this question felt that their systems were more unusual than generic.

3.2 Question 2

How well do you understand this system? Specifically, at what percent of completeness - from 0% to 100% -- is your mental representation of this system?

	77.03%
	(N = 53)

The 53 sysadmins answering this question approximated the completeness of their mental map of their systems at approximately 77%, leaving approximately 23% that is either unknown or poorly understood.

3.3 Question 3

How much of what you DO know about the system you currently supervise is due to ...

hands on experience (with this system and other systems)?	48.93 %
formal training programs (e.g., Microsoft, Sun, Novell)?	7.64 %
reading / research on your own (e.g., books, newsgroups)?	25.31 %
relevant formal education (e.g., college, junior college)?	5.65 %
working with and learning from others?	11.91 %
something not listed above?	0.56 %
	(N = 54)

The 54 sysadmins answering this question can be described as "self-taught," since over 86% of what they know they attribute to hands on experience, personal research, or working with others. Interestingly, there was a significant positive correlation between how much the sysadmins felt they knew about their systems and how much they felt they had learned "hands on" (Spearman's rho = .350, p = .010, N =53).

3.4 Question 4

Thinking only about what you DON'T KNOW about the system you currently supervise, what percentage of what you DON'T KNOW about this system is due to...

hardware unknowns?	29.17 %
software unknowns?	70.83 %
	(N = 53)

The 53 sysadmins answering this question attribute the vast majority of their system ignorance to software, not hardware, unknowns. However, there was a significant positive correlation between how much the sysadmins felt they didn't know about their systems (i.e., 100% minus the response to Question 2) and how much they felt this ignorance was due to hardware unknowns (Spearman's rho = .306, p = .027, N =52).

3.5 Question 5

When you have to do something to this system or fix something on this system, and you DON'T already know how to do it or fix it, which of the following actions do you take and what percentage of the time do you take them?

Consult with people you know who have experience.	24.75%
Contact manufacturer support.	15.91%
Contact third party support.	2.77%
Do research via books or technical literature.	23.58%
Do research via the web, bbs or newsgroups.	43.47%
Experiment to try and see what works.	37.25%
Use manufacturer supplied diagnostic tools.	9.87%
Use third party diagnostic tools.	5.72%
Take an action that is not listed above.	4.17%
	(N = 53)

Corroborating the findings for Question 3, this question suggests that the 53 sysadmins answering this question are also "self-reliant." Whenever there is a problem of unknown resolution with their systems, their primary responses are to experiment with the system, do personal research, and/or consult with their personal network of consultants. Contacting the manufacturer only appears as the fifth most likely course of action. In addition, there was a significant positive correlation between what the sysadmins blamed their ignorance upon, and this "self-reliance." The greater the percentage of ignorance they attributed to hardware (Question 4), the more likely they were to contact manufacturer support and/or third party support (Spearman's rho = .274, p = .047, N =53, and Spearman's rho = .281, p = .044, N =52 respectively).

3.6 Question 6

The system you currently supervise has ...

how many servers?	Range: 1-900; Md: 9.5
	(N = 54)

Multiple servers were the norm for the responding sysadmins, with a median of 9.5.

3.7 Question 7

How many of the servers mentioned in question 6 are predominantly ...

Microsoft family.	9
Unix family (including Linux).	34
Macintosh, Novell or Other	6
	(N = 49)

The responding sysadmins were categorized according to the operating systems installed on the servers they supervised. Specifically, were the majority of the servers they supervised Unix based, Microsoft based, or based upon some other operating system. Of the 49 sysadmins who provided sufficient information to evaluate this question, 34 were predominantly Unix based and 9 were predominantly Microsoft based. There was a significant difference between the Unix oriented sysadmins and the Microsoft oriented sysadmins regarding how they had learned about their systems. Unix oriented sysadmins were twice as likely to attribute their knowledge to "working with and learning from others" than

were Microsoft oriented sysadmins (Mean = 14.50% vs. 7.78% respectively; Mann-Whitney U = 82, p = .032). Also, there was a marginally significant difference between the Unix oriented sysadmins and the Microsoft oriented sysadmins regarding where they felt their ignorance lay. Unix oriented sysadmins were twice as likely to attribute their ignorance to hardware unknowns than were Microsoft oriented sysadmins (Mean = 33.42% vs. 17.50%; Mann-Whitney U = 84, p = .094).

3.8 Question 8

In the organization that employs you as system administrator, the people who make the decisions about the allocation of resources ...

DO understand what is involved in system administration, and DO provide the resources needed to do the job properly.	18
DO understand what is involved in system administration, but DO NOT provide the resources needed to do the job properly.	2
DO NOT understand what is involved in system administration, but DO provide the resources needed to do the job properly.	18
DO NOT understand what is involved in system administration, and DO NOT provide the resources needed to do the job properly.	12
	(N = 50)

Of the 50 sysadmins responding to this question, only 40% felt their supervisors understood what the job entails, but 72% felt their supervisors provided adequate support. There was a significant relationship between perceived supervisor understanding and perceived supervisor support. Supervisors perceived as understanding were more likely to provide support than supervisors perceived as not understanding (Pearson Chi-Square = 5.36, p = .021; Fisher's Exact Test p = .026).

3.9 Survey broadcast

The finalized survey was broadcast as an ASCII text message to 12 newsgroups that were deemed appropriate venues by both topic and traffic volume. These 12 newsgroups are listed in http://faculty.washington.edu/stiber/pubs/sigcpr01.ps.gz. The survey was sent four times to each newsgroup over the duration of the data-gathering period, which was from May 10 to May 31, 2000. Respondents were encouraged to email their completed surveys back to the originator of the message and not to the newsgroups.

4. CONCLUSIONS AND DISCUSSION

These findings reflect the views expressed by the self-selected respondents who frequented one of the 12 newsgroups listed above sometime during the period of May 10 to May 31, 2000, and saw the posted survey. Thus, the survey participants were not a random sample selected from a pre-defined population, so these results cannot be generalized to any such population. However, these results can provide a preliminary and useful insight into the mental models and situation awareness of that population of computer network administrators described by the abstract term "sysadmin;" and these results can suggest potential avenues of inquiry for future, more formalized research.

4.1 Methodology

Given the traffic volume on the selected newsgroups, it was reasonable to expect a greater response than that received. We assume that most of the sysadmins frequenting the newsgroups and seeing the posted survey were simply unmotivated to respond. However, the sysadmins participating in the preliminary, face-to-face interviews expressed great interest in the research and provided extensive assistance. Therefore, we conclude that the format of the data-gathering instrument – an anonymous survey – was too impersonal and/or to restrictive to provide the impetus needed for sysadmin participation. We therefore recommend future research employ face-to-face interview modalities – either structured or unstructured – whenever possible.

Asking the sysadmins to categorize their systems by number of servers, workstations and users proved problematic. Focusing on the servers alone is recommended, unless face-to-face clarification is possible. Finally, future questions addressing how sysadmins handle unusual problems should also address process: what do the participants try first, what second, etc.

4.2 Question 1: Generalizibility of findings

Most of the respondents categorized their systems as, for the most part, generic. This was unexpected, given the findings from the interviews, and might reflect differences in the network domains addressed: chiefly non-commercial domains for the interview subjects vs. chiefly commercial domains for the survey respondents. As a consequence, however, the findings from this survey can be said to reflect sysadmin experiences with systems that are, by the sysadmins' own judgment, unexceptional. In addition, if, as suggested by the interviews, Unix is a more flexible platform than Windows NT, then Unix might be more favored by the sysadmins in non-commercial settings who must deal with more unusual configurations, than by their more commercial counterparts.

4.3 Question 2: Completeness of mental map

If a mechanic, accountant or engineer was uncertain about 23% of his expertise domain, he would be considered unqualified. But organizations must have system administrators, and it is a relatively new and constantly evolving profession. As a consequence, an appreciable level of sysadmin uncertainty is expected and tolerated. However, we do not believe the current level of sysadmin uncertainty will be tolerated indefinitely. Whether this issue is ultimately addressed by a more formalized education requirement, a more user-oriented system design, a more foolproof system design, or some other approach can not be determined at this time.

4.4 Question 3: Formal education and training

The respondents attributed only 13% of their expertise to formalized education and/or training. Whether this was because the respondents had not been exposed to formalized education and training, or because they considered such education and training to be valueless could not be determined from the survey data. Similarly, the positive correlation between how much the sysadmins felt they knew about their systems and how much they felt they had learned "hands-on" might reflect the limitations of formal education and training, or might just be self-congratulatory. It is interesting to note that the interviewed sysadmins frequently expressed contempt for manufacturer sanctioned training programs. Either through personal exposure or indirect association (such as dealing with people who had been formally trained) these interviewees had reached the conclusion

that such programs were chiefly concerned with "cookbook procedures" and not with "really understanding" the systems involved. Of course, if a system is always configured in a manner that has been anticipated by designers, and always behaves as expected, then cookbook procedures are all that is required for proper administration: no mental model or situation awareness is called for. It is only when the unusual and/or unexpected occurs that a deeper understanding of the system becomes necessary.

4.5 Question 4: Hardware vs. software unknowns

Sysadmins, by their very title, are concerned with an entire computer system: both hardware and software. Indeed, a strong argument could be made that a sysadmin cannot understand the system's software functionality fully until he also understands the system's hardware functionality. This connection is reinforced by the positive correlation between how much the sysadmins felt they didn't know about their systems and how much they felt this ignorance was due to hardware unknowns[1]. To what extent formal, or informal, sysadmin training focuses on hardware is unknown, but should be investigated in future research. Other relationships between hardware ignorance and survey measures are detailed below.

4.6 Question 5: Handling unknowns

Assuming the profession known as system administration is so new and/or so difficult to predefine that formalized education and training programs are effectively impossible, how sysadmins handle novel problems becomes a significant concern. That is, without a sanctioned mental model, situation awareness is suspect, so what does a sysadmin do? The 53 sysadmins answering question 5 indicate that when they have a novel problem, what they do not tend to do is utilize manufacturer or third party support or diagnostic tools. Why this is, is unknown. Manufacturer / third party support and diagnostic tools might be too expensive, too difficult to acquire, too time consuming, too restrictive and/or too damaging to the sysadmins' self-efficacy. Then again, the sysadmins might consider such novel problems perfect opportunities to develop their mental models of the system. Certainly, the possibility that sysadmins choose to personally uncover and thus better understand the mysteries of their systems cannot be ignored. In this regard, the positive correlation between hardware ignorance and contacting manufacturer and third party support is striking. From this result it would appear that sysadmins who don't understand the hardware do not strive for self-reliance as much as sysadmins who do understand the hardware.

4.7 Question 6: System complexity

Question 6 attempted to quantify the complexity of the systems the responding sysadmins were addressing. While such data are important for better understanding of these and similar findings, the question was poorly phrased and constructed. Several respondents either did not answer all facets of question 6, or – when compared to data from Question 7 – provided contradictory and/or vague responses. However, the data regarding the number of servers contained in the systems the sysadmins supervised were complete and appeared non-contradictory. With these data and the responses to Question 7, the sysadmins could be categorized by the operating system they most predominantly employed.

4.8 Question 7: UNIX vs. Microsoft

Despite the similar traffic volume on the UNIX and Microsoft oriented newsgroups where the survey was posted, the majority of respondents were predominantly UNIX oriented. However, there were just enough Microsoft oriented respondents to allow for some UNIX vs. Microsoft comparisons. Unfortunately, why the UNIX oriented sysadmins were twice as likely as Microsoft oriented sysadmins to attribute their knowledge to "working with and learning from others" cannot be determined. This might be the result of sysadmins from collegiate – and UNIX based – backgrounds having more of an unofficial "apprenticeship" than sysadmins from business / Microsoft backgrounds. Similarly, why UNIX oriented sysadmins were twice as likely as Microsoft oriented sysadmins to attribute their ignorance to hardware unknowns cannot be determined. UNIX sysadmins might, relatively speaking, understand their software better, Microsoft sysadmins might, relatively speaking, understand their hardware better, or some other factor might be involved.

4.9 Question 8: Supervisor support

The uncertainty of the system administrator's job can be ameliorated somewhat by a supportive supervisor. On the other hand, supervisors who understand less about the system than their sysadmins might be reluctant to provide blind, open-ended support. It is interesting then that there was a significant relationship between perceived supervisor understanding and perceived supervisor support. Whether this relationship is due to the unwillingness of supervisors to provide adequate support to a job they don't comprehend, or whether it is due to the sysadmins' belief that supportive supervisors are more understanding, cannot be determined from these data alone.

4.10 Future research and prescriptive measures

What sysadmins know, how they come to know it, and how they augment this knowledge – or minimize the potential damage done by their ignorance – are clearly topics deserving of further study. The exploratory interviews and survey discussed in this paper provide a rudimentary foundation for more rigorous research, and raise provocative questions regarding:

- the depth of sysadmin understanding,
- the importance of formal training,
- the significance of understanding hardware,
- the ability of sysadmins to handle novel problems
- the manner in which sysadmins handle novel problems,
- differences in the most widely used operating systems
- whether one operating systems might be preferable to another in a particular circumstance, and

[1] Given the yoked relationship between hardware and software unknowns -- together, they had to sum to 100% -- this correlation was reversed for software: the more the sysadmins felt they didn't know about their systems, the less they attributed this ignorance to software.

- whether sysadmins are receiving the support they require.

It is far too early to prescribe specific actions to redress specific deficiencies in the mental models and situation awareness of sysadmins, but certain themes from related fields are suggestive. For example, other domains have concluded that, when people are integral components of a system, the system is best designed for the people who must use it [2, 3]. This "human-centered" approach acknowledges that people cannot be gently phased-out of a complex system. Either human decision making is part of the control system – in which case the system design must address human cognitive needs and capabilities – or human decision making is not part of the control system – in which case the system can be designed in the most elegant technological manner [26].

Elevator operation provides an illuminating analogue. When first introduced, elevators required an experienced operator to open and close doors as needed for passengers, take the passengers to their desired floors in the most efficient manner possible, and line up the bottom of the elevator with the floor the elevator was stopping at. The control system had to be built around the needs of the operator. As automation advanced, sensors allowed the technology to determine the most efficient route for the elevator, when doors should be opened or closed, and when the bottom of the elevator lined up with the desired floor. But the technology was acknowledged to be error-prone and so operators with override capabilities were still required. It wasn't until the automation became more reliable that operators with their support technology disappeared. Today, a passenger with no conception of how the system works simply pushes a button to request an elevator, and then pushes another to indicate his destination. The control system requires no human decision-making and, thus, requires no mental model or situation awareness in the passenger.

But piloting a commercial aircraft is not, yet, a human-free activity. Experienced, knowledgeable and intelligent decision makers are required on the flight-deck to handle unexpected or unusual events. Therefore, ideally, the technology in modern "glass-cockpit" aircraft should be designed to accommodate those decision makers. Similarly, system administration frequently requires a human decision making component. Not always of course. Some networks are so simple and predictable that no mental model or situation awareness is required from the "sysadmin." The sysadmin of such a system can just push buttons until something goes wrong, at which point, like the elevator passenger, he calls out for expert help. But other systems are not so forgiving. These systems are constantly evolving – expanding, adapting and re-formulating – to accommodate more challenging and dynamic requirements. For systems such as these, accurate mental models and extensive situation awareness best serve the sysadmins.

Wickens [28] has expanded upon the ways in which automation can best serve the human decision maker. Dividing information processing into three components – information integration, decision choice, and response execution – Wickens concludes that automation can clearly augment the first and last components and, to a greater or lesser degree, assist the second. Specifically, automation can effectively integrate, configure, filter and highlight raw data. The automation can then provide diagnosis, prediction and interpolation assistance as needed by the human decision maker, and as possible by the state-of-the-art. Finally, the automation can often execute the decision maker's response with greater efficiency and speed. Ideally, automation would adapt its level of assistance to the abilities of the user [20, 25]. However, the design of such adaptive automation for system administration should be dependent upon a solid empirical understanding of the mental models and situation awareness of the system administrator.

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