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Evaluating Network Serviceability

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Abstract

The capability to manage network operations on a day-to-day basis has become an important area of concern given the rapid expansion of computer networks. A related, but much less studied area, is the impact that the design of a network has on the ease with which it can be serviced. Evaluating the ease of servicing the network and its components does not concentrate on day-to-day operations of the network, but rather examines the network design over a longer term to identify problematic components, configurations and dependencies between components based on expert knowledge and historical data.

This paper reports on our experience with a system to evaluate the ease of servicing a network—its serviceability—given a description of its design. The motivation for the work is that computer networks are more often "grown" than "designed" without concern for serviceability issues. The work also examines the impact of dependencies between components on the role of service and the potential disruption costs caused by these dependencies. This work is important because it is pro-active in explicitly considering the role of servicing a network when changing the components or configuration of a network. This approach is in contrast to network management, which is reactive in dealing with problems. The paper reports on a successful implementation of such as system and our experiences with it.
KEYWORDS: serviceability, expert systems, network management, agents

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1 Introduction

The capability to manage network operations on a day-to-day basis has become an important area of concern given the rapid expansion of computer networks. Network management deals with monitoring networks and the machines on the networks to detect and correct problems that occur. To aid network managers, research is being done on combining network management systems with rule-based expert systems to assist the manager in detection, and in some cases automatic correction of problems.

A related, but much less studied area, is the impact that the design of a network has on the ease with which it can be serviced. Evaluating the ease of servicing the network and its components does not concentrate on day-to-day operations of the network, but rather examines the network design over a longer term to identify problematic components, configurations and dependencies between components based on expert knowledge and historical data. This type of analysis is useful for taking into account the role of service when creating or modifying network designs. In addition it can be used in conjunction with network management to identify likely problems that should be closely monitored on a daily basis.

This paper reports on our experience with a system to evaluate the ease of servicing a network—its serviceability—given a description of its design. In our work the term "network" refers to the network itself along with the machines and components attached to the network and the software that executes on these machines. The motivation for the work is that computer networks are more often "grown" than "designed." As a consequence the serviceability characteristics of existing networks are not well understood, nor is the potential impact on serviceability of modifications to a network. However, it is important that any modifications to a network maintain or improve its serviceability, leading to a network that can be more easily managed.

This work is important because it is pro-active in explicitly considering the role of servicing a network when changing the components or configuration of a network. This approach is in contrast to network management, which is reactive in dealing with problems. The work also examines the impact of dependencies between components on the role of service and the potential disruption costs caused by these dependencies.

There is a mutual relationship between network management systems and a system to evaluate serviceability. Evaluating serviceability of a network requires information about the network, some of which may be obtained from a network management system. In fact, the prototype system constructed as part of this research uses a network management system to input the layout of the network to be evaluated and information about the network components. In the other direction, a system evaluating the serviceability of a network might automatically generate expert system rules helping to diagnose problematic components. The rules can be used by a network management system for monitoring the system on a daily basis.

This paper describes the design and implementation of a prototype system called TENNIS (so named because it deals with service over a net) to evaluate the ease of servicing a network based on a description of an existing or proposed network [4, 5]. In computer networks there has been much work and many commercial systems concerning network management and the application of expert systems to network management [6, 7, 9]. Another piece of related work looks at the issue of client/server availability and how to improve it [11]. In contrast, our work explores the potential of applying expert systems for evaluating the problem of servicing computer networks.

The next section of the paper examines measures used in evaluating the ease of servicing a network. It is followed by an overview of the prototype system in operation and an overview of the system design and implementation. It concludes with results from testing and validation, directions for future work and a summary of our work.

2 Serviceability Measures

Our definition of serviceability results from examining the set of possible service tasks and considering the "ease" with which each of these tasks could be done and factors which make these tasks more difficult. However, many of the factors we identified could not be obtained directly, which led us to use more readily obtainable data for evaluating the ease of service. The data we used implicitly combine together many of the potential factors we had identified. The different types were combined to create a Service Ease Index (SEI) for each component in the network. The SEI is a normalized measure (range of 0-1) of how easy the component is to service. Components with higher values are easier to service. This index was developed because we wanted a measure that summarized different types of data and also allowed comparison between network components.

The SEI was derived independently of consideration of actual network use, or the importance of different components in the network. However, computer networks exist to share resources among the machines in the network. A server, on which many machines depend, is more "important" than other machines because its failure, and the associated time for service, disrupts the functioning of other machines in the network. These "disruption costs" indicate the cost associated with downtime of particular components due to service. Dependencies between clients and servers are a key ingredient in the calculation of the actual cost of service.

Consequently, a key aspect of our work is to combine the ease of service of a component with its importance resulting in the "service impact" of the component. In assessing the service impact of a component, it is more appropriate to use the difficulty to service a component rather than the ease to service it. Thus the Service Difficulty Index (SDI) was defined with a range of 0-1. The SDI is simply (1-SEI) and is used in the evaluations because we wanted a measure that had more impact as it grew larger. The Service Impact (SI) for a component is the service difficulty index multiplied by the importance of that component in terms of the other components' dependencies on it. This is an intuitive measure of the potential disruption of servicing the network and is an important consideration in our evaluation of the ease of servicing a network.

Different measures for the SDI are used in our work. Each measure has a normalized range of 0-1 with larger values indicating more difficulty. The difficulty of servicing a network and its components will vary between different companies because of different technician skill and knowledge, availability of parts and overall company support. Hence these measures are computed from the perspective of a single company and derived from data in the company's databases. The measures are:

vendor rating: a ranking by experts within the company of components based on vendor and type of equipment. This measure builds on expert knowledge of which vendors to use for different types of equipment.

disruption index: the ratio of the MTTR (mean time to repair) to the MTBF (mean time between failures). This ratio is an indication of the expected disruption time; the smaller the ratio, the less disruption expected.

contract cost: a measure of the company cost to service this component. This measure is both a reflection of the company's actual cost and of competition in the marketplace. Hence, it may not be an accurate estimate of how easy it is to service a component.

calls index: a ratio of the number of company service calls for a component to compared to the number of units that have been shipped. This measure attempts to track on-site service problems with a component.

service attributes: the degree to which a component has desirable serviceability attributes as identified by company representatives. For example one such attribute is remote access capability through a protocol such as SNMP [10].

These respective measures are combined together using weights (summing to one) customized to the availability of data to compute the measures and the intended use of the outcome. If a company simply wants to determine the total service contract cost then it would give a large weight to the contract cost measure. If a company wants a more realistic measure of serviceability then the contract cost measure would have less weight.

The service difficulty index SDI_i for each of the $i = 1 \ldots n$ components is combined with its importance CI_i to compute a component's service impact $\mathrm{SI}_i = \mathrm{SDI}_i * \mathrm{CI}_i$. The importance of a component is determined by the resource dependencies between components, such as between client and file server machines on the same network segment. In this case, the importance of the segment itself and the server are incremented to reflect the dependency. If such machines were on different network segments interconnected by a bridge then the bridge would also have its importance increased.

The SDI and SI indices identify potentially problematic components and components with high potential disruption costs. These component indices are reported to users of the TENNIS system. In addition, we investigated providing a single number to users that represented the overall serviceability of the entire network. The result of this work are three summary measures:

1. the average service difficulty index for all network components $\sum \mathrm{SDI}_i/n$,
2. the average service impact for all network components $\sum \mathrm{SI}_i/n$, and
3. the weighted (based on component importance) service difficulty index for all network components $\sum \mathrm{SDI}_i/\sum \mathrm{CI}_i$.

These measures allow the overall serviceability of a network to be tracked as potential design changes are considered. The weighted service difficulty in particular helps network managers and designers to be aware of the need to increase the ease of service for important components.

3 System Overview

Given these evaluation measures, this section provides an overview of the system prototype. The general problem addressed by the system is that computer network designers, and those that suggest modifications of computer networks, do not tend to consider how easy the resulting network's hardware and software will be to service. Providing computerized assistance for these network designers and modifiers is our approach to this problem. This approach modifies the general problem to one of building a software system to assist a user during the design, modification or extension of a computer network that includes PCs and workstations from a variety of vendors. The system should provide a wide variety of comments to the user, allowing him or her to evaluate the design or modification decisions.

The system we designed to meet these requirements is called TENNIS. The developed system runs on a Digital Alpha workstation running the OSF/1 operating system with a Motif-based interface. TENNIS operates in phases and consists of a set of cooperating intelligent agents [3], built using rules. Agents have different roles and contain different kinds of knowledge about the ease of servicing computer networks. Agents have a target (what they can make comments about) and a point-of-view (the basis of their comments). Some agents provide comments to other agents, while others report only to the user.

The user interface of the system is shown in Figure 1. The control panel in the lower right corner of the screen controls the system and the display. Part of the interface includes a graphical representation of the network to be evaluated (represented as a campus map in the background of Figure 1). This representation is used by the user to direct TENNIS to evaluate all or a selected portion of the network.

The primary display of TENNIS consists of windows and icons showing the different types of output from TENNIS. Windows in the middle of Figure 1 show summary results about the network that was evaluated, such as the average service

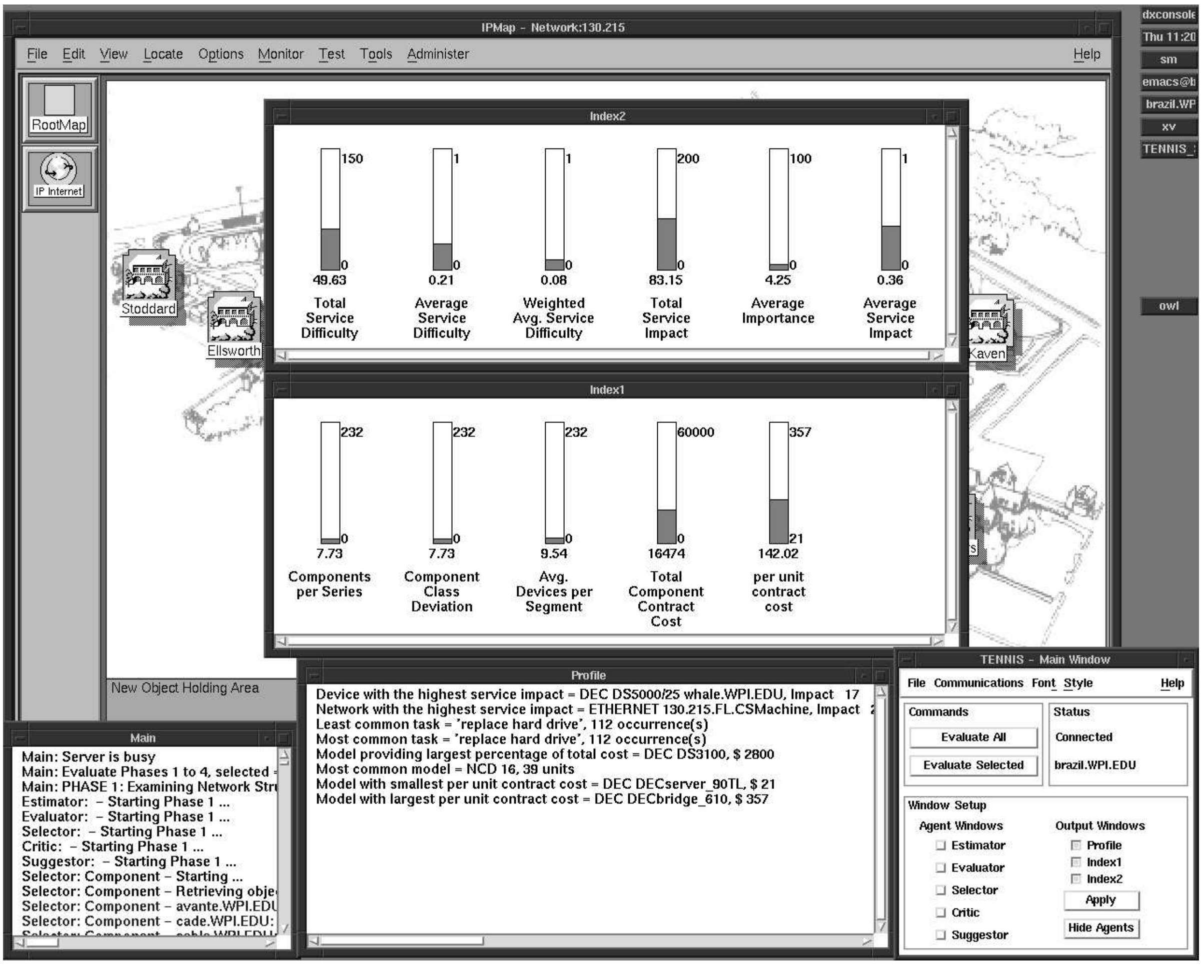

Figure 1: TENNIS User Interface

difficulty index or the average service impact of network components. In addition to this summary information, the user can request more detailed messages from different types of agents by selecting the agent type in the control panel. If an agent window is not selected for display then all of its messages are collected in the window in the lower left corner as is the case in Figure 1.

As discussed previously, an important aspect of our work is to examine the dependencies created by software in a network. Client-server software packages are used to share files, printers and other types of services between machines. File, print, name and license service dependencies can be discovered, displayed and edited through a component management tool, which is invoked from the control panel of Figure 1.

4 System Design and Implementation

The TENNIS system takes a network description as input and uses multiple agents, each with a specific point of view, to produce comments about and an overall evaluation of the network. We chose to have the network description be input to the system so that the system can be used for different networks rather than configured for only one. This decision allows "what if" scenarios to be explored where alternate network designs can be easily compared.

We used Digital's network management tool POLYCENTER NetView (PNV) for representing the network to be evaluated. This tool uses SNMP (Simple Network Management Protocol) [10] to automatically discover and maintain information about a network. This tool worked well for storing and viewing the network. Its display of the network is shown in the background of Figure 1. Although PNV automatically discovers the components and topology of the network, additional information about the components is needed by the TENNIS system to evaluate the network. This augmented information, such as dependency information between a file server and its clients is managed by a component management tool with the resulting information stored as part of the PNV database.

A separate TENNIS server uses the PNV database and expert knowledge, coded as rules in the CLIPS (C Language Integrated Production System) language [8], to control heuristic, experience-based reasoning—such as knowledge used to criticize choices of equipment. The user interface of the TENNIS system is implemented as a separate client with capabilities to retrieve information from the PNV database and TENNIS server for display.

5 System Use

TENNIS is an expert system designed to take a network description as input and produce an evaluation of the ease of servicing that network. This evaluation is performed using knowledge extracted from databases and from experts. In the following we discuss the specific results it produces for a sample network.

Figure 1 showed the results for the ease of service evaluation for networks in the Computer Science/Computing Center building on the campus of WPI. The figure shows two windows of key indices, a profile window for important messages and another window for all other messages. The upper index window shows overall ease of service indices for the network. The total and average service difficulty index (SDI) are for all components in the network. The weighted average SDI takes into account the relative importance of each component in computing this average. The results show that the more important components are easier to service because the weighted average SDI is lower than the average SDI. This is a good result for a network. The remaining indices show the total and average service impact (SI) along with the average importance of a component. These numbers indicate the number of dependencies between components.

The lower index window shows general results about the network components. The average number and deviation of components in a series of related models indicates the amount of variance in component types within the network. Generally, the fewer series of components, the easier the network is to service because the range of required service knowledge is less. The average number of devices per network segment is used to check against standard rules for the number of components on a network segment. The last two indices provide dollar amounts in terms of the service contract cost to cover all components for a month. The significance of these indices is to give an overall impact on various measures that affect the ease of service of the network.

The profile window provides important messages that have been generated by the various agents. It provides information about specific components and networks that are at the high or low end of various measures. It also provides information about the most common and least common service tasks, but, as the results show, only one service task was identified by the system. This result is because little service task data was available for incorporation into the system.

In addition to the information shown in these summary windows, there are many results given by specific agents in the system. These windows can be displayed by selecting the various agent windows using the control window of the lower right corner. Figure 2 shows a portion of the messages generated by the critic agent (scrolled right to make the longest message readable). This agent provides information about potential problems in servicing the network. In the figure it identifies devices with the five highest service impact values along with operating systems and series with only one or two instances. It also shows a network segment that contains more components than the Ethernet specification allows.

Figure 3 provides specific suggestions about how to improve the network for ease of service considerations. It suggests splitting large network segments, removing uncommon operating systems and replacing components with compatible, but more serviceable components. These suggestions mimic advice that would be given by experts evaluating the network.

Overall, these results TENNIS produces provide different points of view of the ease to service the network under evaluation. The results provide relative measures

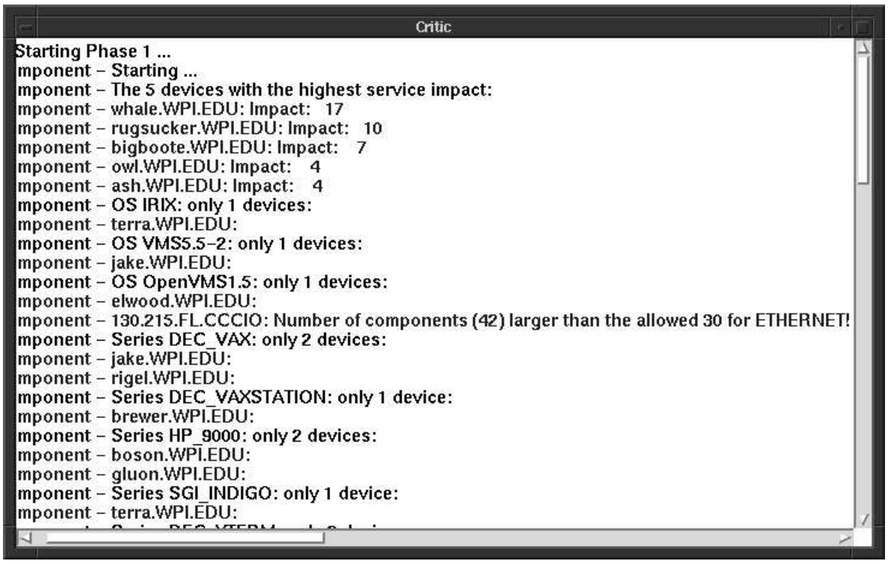

Figure 2: TENNIS Critic Window

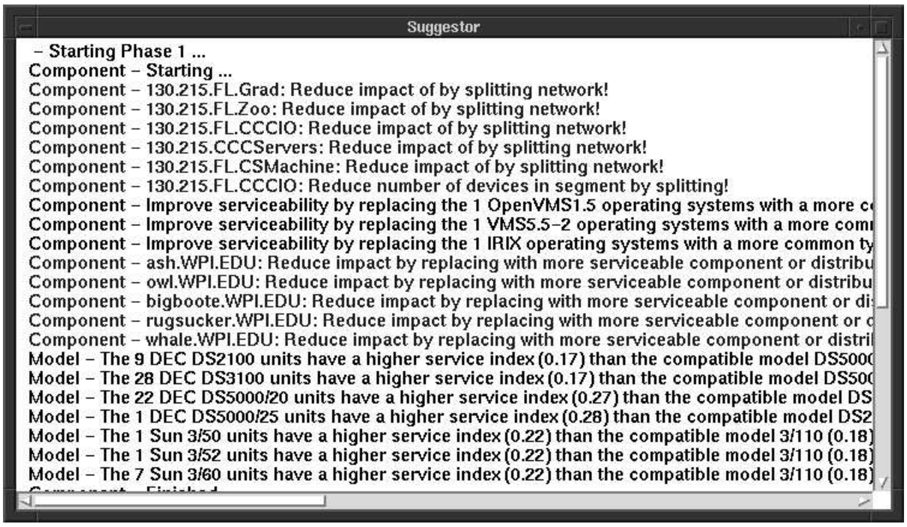

Figure 3: TENNIS Suggestor Window

of service difficulty, expected costs and specific suggestions about improving these values.

6 Evaluation and Future Directions

TENNIS was evaluated on WPI's campus-wide computer network, concentrating on the Campus Computing Center and the Computer Science Department. The experts, advisors, and project team members did not found any obvious errors in the system's output. Response to the final form of output from TENNIS has been positive, although further work on the interface is needed to reduce the number of indices, perhaps by combining some of them into an alternative graphic display, such as a pie chart.

This observation points at the principal problem with the prototype—how to provide better meaning for the results produced by TENNIS. The results, such as the service difficulty index, can be easily compared in relative terms between two network designs, but understanding what this index "means" on an absolute scale is more difficult. For example, is an SDI of 0.75 bad, very bad, or acceptable? The system needs more use by a variety of domain experts to develop this understanding. Full validation will only be possible under those circumstances. This is a current area of study.

There is a large amount of data used by TENNIS, most of which is volatile over time. Limitations of the system are the need to keep these data up-to-date and the problem of finding these data. Some of the data used in TENNIS are representative of actual data rather than real values obtained from company databases. As work proceeds in moving TENNIS from the prototype stage, these databases will need to be filled with real data and mechanisms to keep these data up-to-date will need to be put in place.

PNV worked well for storing, viewing and retrieving information about an existing network and demonstrated that TENNIS could be integrated with a network management tool. TENNIS supports the evaluation of all or just portions of a network. This approach allows users to refine their view of a network's ease of service by running TENNIS on the complete network, and then selecting those portions that TENNIS indicates may be problematic for further analysis.

Another strength is that the set of indices displayed by the system, and the outputs from multiple agents in multiple phases, provide multiple points of view, producing a more subtle and complete picture of the network than a user might normally consider. These agents not only offer criticism but also offer suggestions. They can do "context sensitive" estimations and evaluations that consider more than just a single component at a time. All of this analysis adds to the richness of the information available to the user. Despite this richness, the interface has been designed to present essential results only, with additional details retrieved as needed to all the user to fully understand the implications of the indices. Additional work has been done as part of the project on how to provide and present intelligent feedback to the user about the ease of service [1, 2].

7 Conclusions

The TENNIS system complements existing work in network management to evaluate expected problems in a computer network. It is based on this notion of impediments to service, where various indices provide the user an evaluation of the network. These indices, such as service difficulty index and service impact, are intended to be intuitive and natural, and of use for comparing the ease of service of one network with another.

We consider the concept of these ease of service indices, as well as the set incorporated into the prototype version of TENNIS, to be a contribution of this research. The identification of component importances and incorporation of these importances into the calculation of service impact is a new approach for evaluating the potential disruption caused by service problems.

We feel that TENNIS is a practical and useful tool for service-related evaluation of computer networks. It has been designed to allow flexible extensions with several possibilities having been presented. It can use data from network management systems for use in evaluations as well as provide input to network management systems to help them diagnose problems that occur.

The main practical contributions of an ease of service system, such as TENNIS, is the increased awareness that it brings to network designers and modifiers about the importance of considering service in the design of the network. It can also have an impact on network managers by identifying potential problem areas that can be monitored as the network operates on a daily basis.

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References

[1] Marton E. Balazs, David C. Brown, Peter Bastien, and Craig E. Wills. Graphical presentation of designs: A knowledge intensive design approach. In M. Mantyla, S. Finger, and T. Tomiyama, editors, *Knowledge Intensive CAD*, volume II, pages 173–188. Chapman & Hall, 1997.

[2] M.E. Balazs, D.C. Brown, P. Bastien, and C.E. Wills. How to present designs. In *Proceedings of the Second Workshop Knowledge Intensive CAD*, Pittsburgh, PA, September 1996. IFIP Working Group 5.2.

[3] D.C. Brown, R.E. Douglas, and D.C. Zenger. A concurrent engineering demonstration system for use in training engineers and managers. In *Proceedings of the AI in Engineering Conference*, Toulouse, France, 1993.

[4] D.C. Brown, C.E. Wills, B. Dunskus, and J. Kemble. Computer network ease of service evaluation system. Report to Digital Equipment Corporation, August 1994.

[5] D.C. Brown, C.E. Wills, B. Dunskus, and J. Kemble. Tennis: A computer network ease of service evaluation system. In *International Joint Conference on Artificial Intelligence Workshop on AI in Distributed Information Networks*, Montreal, Canada, August 1995.

[6] A. Dupuy, S. Sengupta, O. Wolfson, and Y. Yemini. NETMATE: A network management environment. *IEEE Network*, pages 35–43, March 1991.

[7] B. Faul. Using a CLIPS expert system to automatically manage TCP/IP networks and their components. In *Proceedings of the 2nd CLIPS Conference*, pages 41–51, 1991.

[8] J.C. Giarratano and G. Riley. *Expert Systems: Principles and Programming.* PWS Publishing Co., Boston, MA, 2nd edition, 1994.

[9] P. Nelson and J. Warpinski. NMESys: An expert system for network fault detection. In *Proceedings of the 2nd CLIPS Conference*, pages 52–57, 1991.

[10] William Stallings. *SNMP, SNMPv2, and CMIP: The Practical Guide to Network-Management Standards.* Addison Wesley Publishing Co., 1993.

[11] Alan Wood. Predicting client/server availability. *IEEE Computer*, pages 41–48, April 1995.