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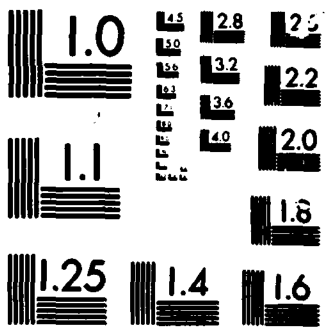

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The focus of the current research has been to employ an algebraic approach for studying the reliability of systems that can be modeled as networks. This approach has not only unified certain theoretical aspects of network reliability problems but has also suggested a number of new algorithms for calculating reliability measures. Based on this approach, both exact and approximate computational schemes have been developed, together with supporting data structures for implementing the necessary computations in an efficient manner. Empirical studies have also been designed and carried out to judge the computational merits of the various data structures. In order to increase the applicability of these research results, models have also been investigated that allow the incorporation of dependent failure modes.

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Brian W. Woodruff, Maj, USAF	(202)767-5027	NM

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LASER PHOTODEPOSITION AND ETCHING STUDY

ANNUAL TECHNICAL REPORT
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SUMMARY.

The focus of the current research has been to employ an algebraic approach for studying the reliability of systems that can be modeled as networks. This approach has not only unified certain theoretical aspects of network reliability problems but has also suggested a number of new algorithms for calculating reliability measures. Based on this approach, both exact and approximate computational schemes have been developed, together with supporting data structures for implementing the necessary computations in an efficient manner. Empirical studies have also been designed and carried out to judge the computational merits of the various data structures. In order to increase the applicability of these research results, models have also been investigated that allow the incorporation of dependent failure modes.

RESEARCH OBJECTIVES.

The underlying theme of this research project is that of studying network reliability problems from an algebraic point of view. The advantages of this approach are twofold. First, the algebraic description provides a unifying theoretical framework for summarizing existing results and for providing new insights . Second, the approach yields new computational procedures for calculating exactly, and approximately, certain network reliability measures. The research also focuses on the necessary data structures needed to carry out such algorithms in an efficient manner.

ACCOMPLISHMENTS.

The algebraic approach taken here has led to several new methods for calculating the s-t reliability of a network (the probability that an operative path exists between two given nodes s and t in the network). The first method calculates the s-t reliability based on knowledge of all paths extending from s to t. Unlike existing approaches, however, this new approach does not require the explicit determination of such paths prior to using the method. Such paths are automatically generated during the course of executing the algorithm itself. Moreover, the method proposed here is an iterative one, which produces a sequence of <u>approximations</u> to s-t reliability. This aspect is particularly important since the exact calculation of reliability can be quite time-consuming, even for moderately small networks. In addition, it has been proved that the method always generates a monotone nondecreasing sequence of approximations to the true reliability (valid over the entire range of input edge reliabilities). When applied to a sample network (one of the largest analyzed exactly), the iterative technique produces after relatively few iterations an answer that is virtually indistinguishable from the exact answer -- but in a small fraction of the time (.061 seconds versus .634 seconds). It should also be mentioned that rather than producing a single numerical answer, the method yields a general polynomial expression for the s-t reliability in terms of the input parameters. This symbolic form is especially useful for assessing the "importance" of individual links in the original network. These results have been written up and have been accepted for publication in the Proceedings of the 5th *International Conference on the Theory and Applications of Graphs*. A subsequent technical report dealing with the utility of different data structures for the iterative algorithm is also planned.

An alternative approach that has been used by a number of investigators to calculate s-t reliability involves the explicit generation of "cutsets" in the network (sets of links whose failure ensures the nonfunctioning of the system). Generating the appropriate objects (s-t cutsets) is not, however, a simple task. The algebraic approach has been modified to permit the generation of such cutsets in directed networks. The interesting idea is that by making the problem "harder" in one sense, the problem actually becomes "easier" to solve. Namely, instead of being content to determine the s-t cutsets for fixed s and fixed t, we require the calculation of s-j cutsets for fixed s and each node j. In this seemingly harder problem, there exists an interdependence present among the s-j cutsets for different nodes j and this interrelation allows a certain type of recursion to be carried out. The final result is that an iterative technique has been derived for calculating all appropriate cutsets in a directed network. Certain computational simplifications have also been found that reduce significantly the effort necessary to find such cutsets. In a fairly typical example, these simplifications reduced the needed number of operations from 14,964 to only 3,664 (a fairly substantial reduction). A controlled computational study was carried out to assess the effects of using different data structures to perform the calculations. The empirical results obtained in this study show that the choice of data structure can have a profound effect on the actual effort required. Two papers discussing both theoretical and applied aspects of this problem have been submitted for publication to Networks and to IEEE Transactions on Reliability.

The vast majority of network reliability problems considered in the literature make the simplifying assumption that all component failures are independent events. However, in telecommunication networks the occurrence of dependent failures is often the dominant cause of system failure (for example, common atmospheric disturbances affect nearby links simultaneously). More generally, the failure of one component can place an additional load on other components, in turn making their failure more likely. The third area of research activity, jointly studied with J. D. Spragins (Electrical and Computer Engineering, Clemson University), is an attempt to model the occurrence of dependent component failures. This new model accepts inputs in a form that is easy for the user to comprehend (unlike other proposed models), and it allows both exact and approximate answers to be calculated for a given problem. Results using realistic data show that the dependent failure model gives significantly different (and less optimistic) values for network reliability compared to those obtained using the independent failure model. Therefore, the use of dependent failure models is most important for the realistic modeling of network performance. These results have been written up and appear in the Proceedings of the IEEE INFOCOM 85 Conference, held in March 1985.

PAPERS.

[1] "Iterative Algorithms for Calculating Network Reliability," Technical Report #457, Mathematical Sciences Department, Clemson University, August 1984. To appear in: Graph Theory with Applications to Algorithms and Computer Science, Y. Alavi et al. (eds.), John Wiley and Sons, 1985.
[2] "Exact and Approximate Dependent Failure Reliability Models for Telecommunications Networks," Technical Report #460, Mathematical Sciences Department, Clemson University, September 1984 (With J. D. Spragins). Proceedings of the IEEE INFOCOM 1985 Conference, Washington, D.C. (March 1985), pp. 200-205.
[3] "Algorithms for Generating Minimal Cutsets by Inversion," Technical Report #472, Mathematical Sciences Department, Clemson University, February 1985 (With D. E. Whited). Submitted to IEEE Transactions on Reliability.
[4] "Iterative Algorithms for Generating Minimal Cutsets in Directed Graphs," Technical Report #482, Mathematical Sciences Department, Clemson University, May 1985 (With D. E. Whited). Submitted to Networks.

PRESENTATIONS.

- "Iterative Algorithms for Calculating Network Reliability," 5th International Conference on the Theory and Applications of Graphs, Kalamazoo, Michigan, June 1984. (INVITED)
- "A Survey of Network Reliability and Survivability Models," Interdepartmental Seminar on Computer Networks, Clemson University, November 1984.
- "Algorithms for Generating All Minimal Cutsets in a Graph," 16th SE International Conference on Combinatorics, Graph Theory and Computing, Boca Raton, Florida, February 1985.
- "Exact and Approximate Dependent Failure Reliability Models for Telecommunications Networks," IEEE INFOCOM Conference, March 1985. (INVITED)
- "A Class of Algorithms for Generating All Cutsets in a Directed Graph," ORSA/TIMS Conference, Boston, Massachusetts, May 1985.
- "Algebraic Methods Applied to Network Reliability Problems," AFOSR Workshop on Reliability, Luray, Virginia, May 1985.
- "Network Reliability of Planar Graphs," ORSA/TIMS Conference, Atlanta, Georgia, November 1985. (INVITED)

ADDITIONAL CONSULTATIONS.

• Attended the IEEE Global Telecommunications Conference, November 26-29, 1984 in Atlanta, Georgia. Discussed various research findings with J. S. Provan (University of North Carolina, Chapel Hill).
• Chaired a panel discussion on "Reliability of Telecommunications Networks," IEEE INFOCOM Conference, March 1985, Washington, D.C.
• Organizer of minisymposium on "New Advances in Network Reliability," 3rd SIAM Conference on Discrete Mathematics, May 1986, Clemson, South Carolina.

PERSONNEL.

(1) Douglas R. Shier, Professor of Mathematical Sciences, Clemson University.
(2) David E. Whited, Research Assistant, Ph.D. Candidate, degree expected in 1986.

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