Interactive TMC Decision Support Tool
Combining Simulation and Optimization

Prepared by:
Nathan H. Gartner, PI
Cindy Chen, Co-PI
Chronis Stamatiadis, Co-PI
Lee Jones

University of Massachusetts Lowell
Lowell, MA 01854

Proposal Abstract

This proposal addresses the operation of Traffic Management Centers (TMS). Traffic Management Centers play a critical role in the monitoring, management and planning of traffic within urban areas. The goal of the proposed study is to enhance the capabilities of TMCs by providing an advanced and versatile decision support tool that can be used across a broad range of applications. Specifically, the objective is to develop an interactive combined simulation-optimization decision support tool for TMC operations that can be used for both off-line applications as well as in real-time; can assist operators in developing optimal traffic control and management plans for a wide range of incident or emergency situations; can evaluate consequences of operator actions in response to special circumstances; can be used to train operators and management agencies to respond to special circumstances and can be used to plan for eventual emergencies.

The proposed research builds on the unique capabilities and past developments of the research team. It combines the capabilities of researchers from two disciplines: civil engineering and computer science and it includes in its team an untenured faculty member for which the UMass UTC program is committed to provide priority.

0. Background – Traffic Management Centers

The Traffic or Transportation Management Center (TMC) is the hub of a transportation management system, where information about the transportation network is collected and combined with other operational and control data to manage the transportation network in an optimal way and to produce traveler information. It is the focal point for communicating transportation-related information to the motoring public and the media, a place where agencies can coordinate their responses to transportation situations and conditions. The TMC links various elements of Intelligent Transportation Systems such as variable message signs, closed circuit video equipment, in-road and roadside count stations, etc., enabling decision makers to identify and react to incidents and any other unanticipated events in a timely manner based on real-time data.

TMCs provide a number of potential benefits. The main benefits are:

- Faster incident response and reduction in incident rates.
- By broadcasting traveler information and coordinating their activities with the State Patrol, etc, TMCs have been successful in reducing congestion in freeways and arterials.
- Increases traffic safety by effective incident response and clearance techniques. By providing traveler information regarding incidents it minimizes the likelihood of secondary incidents.
- Enhanced communication in all aspects of transportation management (planning, design, implementation, operation, maintenance).
- Monetary savings by sharing responsibilities between fewer staff, achieved by co-location of participating agencies at the center.
- Agencies working closely together in a TMC typically produce a more consistent, unified response to a situation, increasing the overall effectiveness of the transportation resources.

It is estimated that over half of the traffic congestion in the U.S. is caused by traffic disturbances. These include incidents, accidents, construction and maintenance activities, adverse weather conditions, parades, sporting events, tourist attractions, or other events (such as the 2005 Democratic convention that was held in downtown Boston) can cause congestion by temporarily increasing demand or reducing the capacity of the transportation network. Even minor incidents, such as disabled or abandoned vehicles on the shoulder can reduce roadway capacity, cause congestion and create a potential safety hazard. On top of that, there is the need for emergency planning for evacuation due to security of adverse weather concerns. emerging concerns. TMCs are the focal point for traffic management under these circumstances. While there is little data quantifying the exact benefits resulting from TMCs, one study conducted by MnDOT reported decrease in accident rates by 25 percent, 20-minute reduction in response time, 35% increase in average speeds (34 mph to 46 mph) during rush hours and 22% increase in capacity of freeways, after the implementation of their TMC.

1. Statement of Project Objectives

The goal of the proposed study is to enhance the capabilities of TMCs by providing a sophisticated and versatile decision support tool that can be used across a broad range

of applications. Specifically, the objective is to develop an interactive combined simulation-optimization decision support tool for TMC operations that:

- Can be used for both off-line applications as well as in real-time
- Can assist operators in developing optimal traffic control and management plans for a wide range of incident or emergency situations;
- Can evaluate consequences of operator actions in response to special circumstances
- Can be used to train operators and management agencies to respond to special circumstances
- Can be used to plan for eventual emergencies

2. Research Contribution – TMC Operations

Development of the Decision Support Tool (DST) is designed to enhance the operation of Traffic Management Centers. TMCs allow an agency to perform traffic surveillance, detect accidents and traffic related problems and formulate appropriate responses. This involves coordination with other agencies or divisions within an agency. A typical TMC is equipped with computers, communications equipment and traffic displays and is staffed by engineers and maintenance personnel, police patrol personnel, dispatchers and dedicated TMC operators. A TMC is also integrated with various field elements such as in-road or roadside vehicle detection systems, closed-circuit television (CCTV) systems, permanently mounted changeable message signs (CMSs) and Highway Advisory Radio (HAR).

The primary role of a typical state TMC is to detect incidents and then quickly take appropriate action to reduce congestion. Upon notification of an incident, TMC operators determine its location and severity through information provided by the CCTV and vehicle detection systems and from information related by police patrol or local traffic personnel. They then attempt to assess the resulting congestion from the event and to implement a suitable traffic management response. This response will typically involve posting of appropriate CMS and HAR messages, dispatching traffic management or maintenance personnel and disseminating appropriate information to the media. They continuously monitor traffic conditions and adapt or revise the traffic management plan as needed.

Development of the proposed tool will contribute to the enhancement all traffic management aspects of TMCs. It will enable operators:

- to develop and implement better strategies (by having an integrated traffic optimization capability)
- to provide a faster response (by having a real-time decision tool)
- to better address unforeseen circumstances
- and to better prepare for the variety of incidents that can occur in the network

The proposed research is both innovative and unique in that it combines the evaluation capability (the simulation module) with the optimization capability in an integrated package. Existing traffic management tools commonly treat controls separate from evaluation (assignment) which results in sub-optimal performance of the traffic system. Microscopic simulation without optimization is therefore unable to achieve optimal results

and so is prediction (e.g., dynamic traffic assignment) if it is not coupled with concomitant optimization of all relevant control variables. The combined treatment proposed in this study will provide operators with the capability (both off-line and real-time) to assess the consequences of their actions where the various control parameters (signals, ramps, CMR, etc) have been optimized in concert with the traffic volumes resulting from those actions. Thus, we can expect improved performance of the resulting strategies.

3. Technical Approach: Development of a TMC Decision Support Tool

The core of the Decision Support Tool (DST) is the Microscopic Simulation Model coupled with the Traffic Optimization Model. A number of microscopic traffic simulation models are available that have all the capabilities required by the DST, e.g., Aimsun, Paramics, Vissim and others. Paramics has been used in some traffic simulators for ITS strategies (1). Our choice is to use Vissim with which our team has extensive experience and familiarity. This model has been used by members of the team in the evaluation and optimization of a large-scale arterial network in Boston, Mass. and Berlin, Germany. The optimization model consists of a signal optimization tool capable of optimizing signal controls for arterial streets and network systems. Either TRANSYT or Maxband-Multiband can be used. We will employ the Maxband-Multiband suite which was developed by the UMass-Lowell team and has a number of capabilities not found in other models: it can optimize both arterial streets and network systems; it can focus on providing optimal progressions along selected routes; it provides a global optimal solution using state-of-the-art optimization technology (the ILOG/CPLEX suite); and it optimizes phase sequencing at all intersections. It has also been demonstrated to provide very effective signal control plans, esp., insofar as diversion routes are concerned.

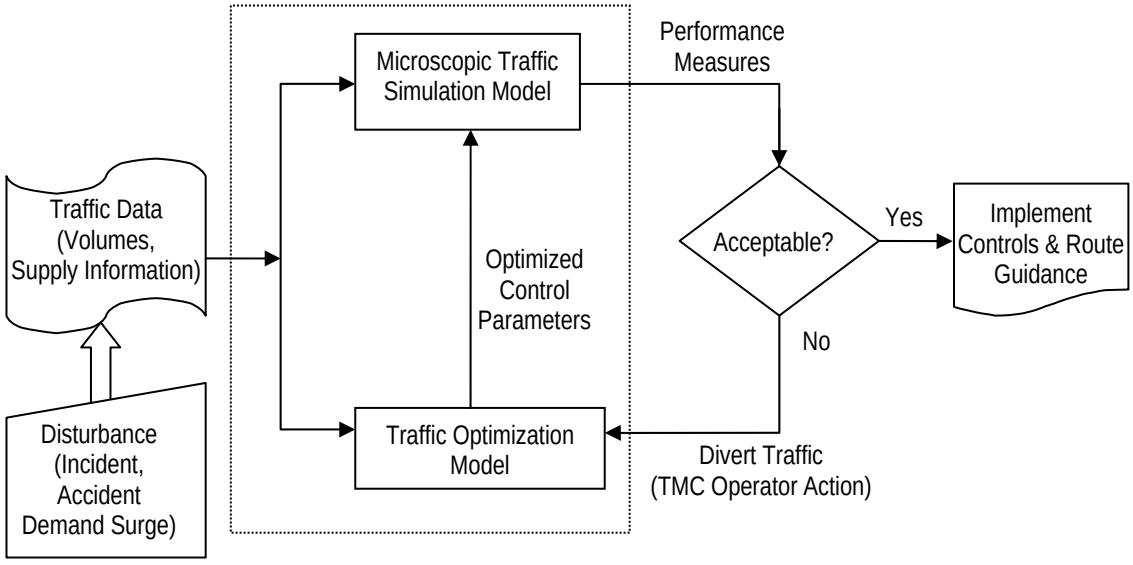

Figure 1: Logical Structure and Data Flow in Decision Support Tool.

As illustrated in Fig. 1, the combined simulation-optimization modules are fed by the same data base. The basic data for the fixed components of the system are pre-coded: street data, network geometry, capacity information, signal and VMS information, phasing options. Traffic data, i.e., volumes, turning movements, O-D data are being provided on a real-time basis with a backup of an historical data base. There are various anticipated modes of operation of the DST. In the off-line version, the system will use historical information to develop possible traffic management schemes for various contingencies, e.g., special events (political conventions, sports events, etc.), or emergency preparedness. Another major off-line application is for operator training.

The DST can also be used in a real-time mode: it is not intended for automatic operation, rather as an assistive tool for operator action. In this mode, activation of the system is under control of the TMC operators. A run would typically be triggered by a disturbance in the system. This can occur due to numerous traffic or infrastructure reasons: traffic failure - incident, or accident; supply failure - closing of a lane or a section of the network due to breakdowns (e.g., flooding, fire, utility breakdowns, etc.), or security reasons requiring the closure of streets or entire segments of a network. While numerous scenarios can be conceived and exercised, the objective of the system design is to be flexible enough so that any possible anticipated or unanticipated event can be handled.

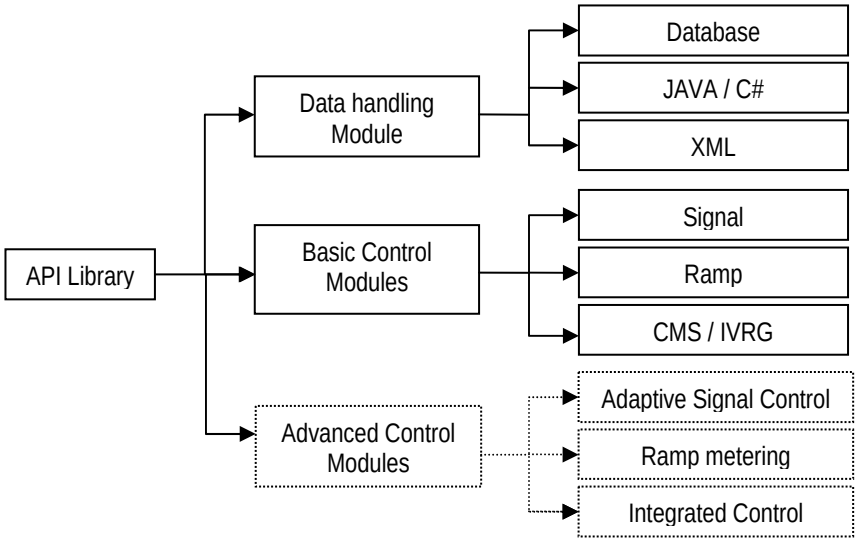

Figure 2: API Development Process.

The following tasks will be conducted to accomplish the objectives of the research:

Task 1 – Development of a data handling capability: the on-line data collected at the TMC are being processed in a form that can be used by the simulation module and by the optimization module (for training purposes we can use recorded traffic data).

Task 2 – Integration of the optimization module with the simulation module via the API. The set of activities planned in this task is illustrated in Fig. 2. (Advanced control modules are envisioned for future development and are not part of the present study).

Task 3 – Test the combined system with scenarios obtained from the Mass Highway TMC in Boston and from other TMCs around the country. Our initial testbed will be the I-93 corridor leading into the Boston CBD.

Task 4 – Develop user procedures and training materials.

Task 5 – Final Report/Documentation.

4. Anticipated Results

The proposed study will develop an advanced and versatile decision support tool that can be used across a broad range of applications. As stated in the objectives section this will be an interactive combined simulation-optimization decision support tool for TMC operations that:

1. can be used in off-line applications to evaluate potential operator actions under hypothetical incident conditions, to contemplate various evacuations scenarios under emergency conditions, and to train operators in the implementation of traffic management strategies
2. can be used in real-time applications to develop, implement and monitor effective traffic management strategies with a substantial degree of confidence, and

3. can be used as platform for future development of automated real-time control systems involving, for instance, adaptive signal and ramp control, automated traveler information and route guidance, etc.

The anticipated results should be of immediate application to TMC operators, to government and emergency personnel involved in developing emergence evacuation plans, as well as to consulting firms involved in the development of such plans.

5. Technology Transfer

The anticipated developments lend themselves to a wide range of technology transfer activities, including but not limited to: technical reports that will be widely distributed, conference presentations, journal articles, newsletters (e.g., New England ITE Newsletter), workshops to inform and train government personnel, TMS operators, consultants and students.

6. Principal Investigator and Other Staff

The personnel listed below are included in the research team, their one-page resumes are attached.

PI: Nathan H. Gartner, Civil and Environmental Engineering
Co-PI: Cindy Chen, Computer Science

Co-PI: Chronis Stamatiadis, Civil and Environmental Engineering
Faculty: Lee Jones, Mathematics

Profs. Gartner and Stamatiadis will be responsible for the traffic module integration , scenario development and strategy evaluation.
Prof. Chen will be responsible for the data base development, data processing and API related activities.
Prof. Jones will assist with algorithmic and statistical issues related to optimization model performance, simulation results validation and O-D estimation.

Nathan H. GARTNER,
Professor and Chair, Department of Civil and Environmental Engineering

2. Education

Sc.D. Transportation Engineering/Operations Research (1970)
M.Sc. Transportation/Systems Engineering (1967)
B.Sc. Systems Engineering (1961),
Technion–Israel Institute of Technology

3. Faculty Positions at University of Massachusetts-Lowell

33 years; Full Professor (1981-present), Dept. Chair (2003-present), Associate Professor w/tenure (1978-81), Assistant Professor (1973-78).

4. Related Experience – teaching, industrial, etc.

Visiting Fellow, DLR–German Aerospace Center, Berlin, Germany, 2003
Vis. Professor, INRETS–The French National Institute for Transport and Safety Research, 1995
Research Affiliate (Visiting), Center for Transportation Studies, MIT, 1986-89
Vis. Professor, Universities of Nagoya-Tokyo-Kyoto, Japan, 1989; Univ. of Naples, Italy, 1985
IPA/DOT Fellow, Federal Highway Administration, USDOT, Washington, D.C., 1976-78
Visiting Scientist, Operations Research Center, Massachusetts Institute of Technology, 1973-76
Asst. Professor (Vis.), Dept. of Civil Engineering, Massachusetts Inst. of Technology, 1972-73
Postdoctorate Fellow, University of Toronto–York University, Canada, 1971-72
Lecturer, Technion–Israel Institute of Technology, 1970-71

5. Principal publications, last 5 years:

(plus 3 books & monographs and 45 prior refereed publications)

N.H. GARTNER, A.J. RATHI and C.J. MESSER (Editors): Monograph on Traffic Flow Theory: A State-of-the-Art Report, Turner–Fairbank Highway Research Center, Federal Highway Administration, U.S. Dept. of Transportation (to be published as Special Report, Transportation Research Board, National Research Council (available on the web at URL: http://www.tfhrc.gov/its/tft/tft.htm).

N.H. GARTNER and P. WAGNER: "Analysis of Traffic Flow Characteristics on Signalized Arterials." Transportation Research Record No. 1883, J. of the Transportation Research Board, 2004, 94-100.

N.H. GARTNER and Ch. STAMATIADIS: "Progression Optimization Featuring Arterial- and Route-Based Priority Signal Networks." J. of Intelligent Transportation Systems, Vol. 8, 2004, 77-86.

N. H. GARTNER: "Development of an Adaptive Control Strategy in a Traffic Signal Network: The Virtual-Fixed-Cycle Approach." Transportation and Traffic Theory in the 21st Century (M.A.P. Taylor, Ed.), Pergamon, 2002, 137-155.

N. H. GARTNER: "Combined Models for Signal Control and Route Assignment in Urban Traffic Networks." J. of the Society of Instrument and Control Engineers (SICE) of Japan, Vol. 41, No. 3, 2002, 217-224.

N.H. GARTNER and Ch. STAMATIADIS: "Arterial-Based Control of Traffic Flow in Urban Grid Networks." Mathematical and Computer Modeling, Vol. 35, 657-671, Pergamon, 2002.

N.H. GARTNER, F.J. POORAN, and C.M. ANDREWS: "Optimized Policy for Adaptive Control Strategy in Real-Time Adaptive Control Systems: Implementation and Field Testing." Transportation Research Record 1811, J. of the Transportation Research Board, 2002, 148-156.

6. Honors and Awards

First Dissertation Prize – Transportation Science Section, Operations Research Society of America (now INFORMS), 1972

Postdoctorate Fellowship – Joint Program in Transportation, University of Toronto – York University, Toronto, Ontario, Canada, 1971-72.

IPA/DOT Fellowship – Federal Highway Administration, U.S. Dept. of Transportation, 1976-78.

IATSS (Japan) Fellowship – Distinguished Visiting Professor at the Universities of Tokyo, Kyoto and Nagoya, 1986.

Cindy Chen

Department of Computer Science
University of Massachusetts, Lowell

EDUCATION

2001 Ph.D. in Computer Science, University of California at Los Angeles, CA, USA
Dissertation: Data Models and Query Languages of Spatio-Temporal Information

1997 M.S. in Computer Science, University of California at Los Angeles, CA, USA

1990 B.S. in Space Physics, Peking University, Beijing, China

EXPERIENCE

2003-present Assistant Professor, University of Massachusetts at Lowell

2002 Visiting Scientist, AT&T Research Labs, Florham Park, NJ

2001-2002 Postdoctoral Fellow, IBM T. J. Watson Research Center, Hawthorne, NY

RECENT PUBLICATIONS

a. Refereed Book Chapters

2007 **Cindy X. Chen**, "Spatio-Temporal Query Language", to appear in "Encyclopedia of GIS", Springer, 2007.

2004 **Cindy X. Chen**, Haixun Wang, and Carlo Zaniolo, "Toward Extensible Spatio-Temporal Databases: an approach based on User-Defined Aggregates", in *Flexible querying an reasoning in spatio-temporal databases: theory and applications*, pages 55-74, Springer Geosciences/Geoinformation series, 2004.

b. Refereed Conference/Workshop Publications

2006 Xun Z. Tu, Kajal Claypool and **Cindy X. Chen**, "ACache: Using Caching to Improve the Performance of Multiple Sequence Alignments", in *Proceedings of 18th International Conference on Scientific and Statistical Database Management*, pages 1-1, Vienna, Austria, July, 2006. (*approximate acceptance rate: 20%*)

2005 **Cindy X. Chen**, George Mihaila, Sriram Padmanabhan and IsabelleRouvellou, "Query Translation Scheme for Heterogeneous XML Data Sources", in *Proceedings of International Workshop on Web Information and Data Management*, pages 31-38, Bremen, Germany, November, 2005. *(approximate acceptance rate: 25%)*

2004 Anuradha Gali, **Cindy X. Chen**, Kajal T. Claypool and Rosario Uceda-Sosa, "From Ontology to Relational Databases", in *Proceedings of International Workshop on Conceptual Model-directed Web Information Integration and Mining*, pages 278-289, Beijing, China, November, 2004. *(approximate acceptance rate: 50%)*

2004 Rosario Uceda-Sosa, **Cindy X. Chen** and Kajal T. Claypool, "Framework to Design Ontology Views", in *Proceedings of the 23rd International Conference on Conceptual Modeling*, pages 844-849, Beijing, China, November, 2004. *(approximate acceptance rate: 25%)*

2003 **Cindy X. Chen**, Jiejun Kong and Carlo Zaniolo, "Design and Implementation of a Temporal Extension of SQL", in *Proceedings of the 19th International Conference on Data Engineering*, pages 689-691, Bangalore, India, March, 2003. *(approximate acceptance rate: 15%)*

CHRONIS STAMATIADIS, Ph.D.

Associate Professor
Civil & Environmental Engineering,
University of Massachusetts Lowell

EDUCATION

B.S. in Surveying Engineering, Aristotle University, Greece, 1985
M.Sc., in Civil and Environmental Engineering (Transportation and Traffic Engineering), Michigan State University, 1987
Ph.D. in Civil and Environmental Engineering (Transportation and Traffic Engineering), Michigan State University, 1992

PROFESSIONAL EXPERIENCE

University of Massachusetts Lowell, Department of Civil Engineering:
Associate Professor 1998-present
Assistant Professor 1992-1998

Principal or Co-Principal Investigator in
UTCP-Region 1: "Traffic Flow Characteristics on Arterial Streets and their Impact on Capacity and Level of Service," 9/2005-8/2006;
UTCP-Region 1: "Development of a Web-Based Course on Traffic Principles for ITS," 9/2003-8/2004
FHWA: "Network-Wide Optimization Models," 1/1993 – 5/1997
FHWA: "Real-Time Traffic Adaptive Control Systems," 12/1992 – 12/1996
MHD: "Evaluation of the Massachusetts Motorist Assistance Program," 10/1995-5/1997.

RECENT PUBLICATIONS & PROCEEDINGS

Gartner, H.N., Stamatiadis, C.: "Progression Optimization Featuring Arterial- and Route-Based Priority Signal Networks." *Journal of Intelligent Transportation Systems*, Vol. 8, 2004, 77-86.

Gartner, N.H., Stamatiadis, C.: "Arterial-Based Control of Traffic Flow in Urban Grid Networks", *Mathematical and Computer Modeling*, No. 35, 2002, pp657-671.

Gartner, N.H., Stamatiadis, C.: "Combining Traffic Assignment and Adaptive Control in a Dynamic Traffic Management System", 9th IFAC/IFIT/IFORS Symposium on Transportation Systems, Braunschweig, Germany, June 2000.

Stamatiadis, C., Gartner, N.H.: "Progression Optimization in Priority Arterial Signal Networks", 9th IFAC/IFIT/IFORS Symposium on Transportation Systems, Braunschweig, Germany, June 2000.

Stamatiadis, C., Gartner, N.H.: "Progression Optimization in Large Scale Urban Traffic Networks: A Heuristic Decomposition Approach", *Transportation and traffic Theory*, Proceedings of the 14th ISTTT, Jerusalem, Israel, 1999.

Stamatiadis C., Gartner, N.H., Winn, J., Bond, R.: "Evaluation of the Massachusetts Motorist Assistance Program; An Assessment of Congestion and Air Quality Impacts", Transportation Research Record, No 1634, Washington, D.C., 1998.

Gartner, N.H., Stamatiadis, C.: "Integration of Dynamic Traffic Assignment with Real Time Traffic Adaptive Control," Transportation Research Record, No1635, Washington, D.C., 1998.

Gartner, H.N., Stamatiadis C.: "Adaptive Traffic Control Strategies for Dynamic Traffic Assignment," Triennial Symposium on Transportation Analysis, San Juan, Puerto Rico, June 1998.

Gartner, H.N., Stamatiadis C.: "Simultaneous Progressions on Traffic Grid Networks," Institute of Transportation Engineers Annual Meeting, Toronto, Canada, August 1998.

Gartner, H.N., Stamatiadis C.: "Traffic Assignment and Control Models for Dynamic Traffic Management," 8th World Conference on Transport Research, Antwerp, Belgium, July 1998.

Lee K. Jones
University of Massachusetts Lowell
Department of Mathematical Sciences

a. Education

B.S. Physics and Mathematics, Tufts University 1965

M.S. Mathematics, Stanford University 1968 Ph.D. Mathematics, Stanford University 1970

b. Professional Positions and Contracts

Professor of Mathematical Sciences, University of Massachusetts Lowell, September 1986-present

Graduate Coordinator for Statistics and Optimization and Doctoral Program in Computational Mathematics

Massachusetts Highway Department/Federal Highway Administration Grant with University of Massachusetts Dartmouth 2004-2005

National Science Foundation Grants, 1992, 1993, 1995, 1996, 1997, 1999

German Research Foundation Visiting Professorship, summer semester 1991, University of Bielefeld

c. Publications Relevant to the Research Proposed

1 Jones, L., On a Conjecture of Huber Concerning the Convergence of Projection Pursuit Regression, Annals of Statistics. 1987, pp. 880-882.

2 Jones, L., A Simple Lemma on Greedy Approximation in Hilbert Space and Convergence Rates for Projection Pursuit Regression and Neural Network Training, Annals of Statistics, Vol. 20, No. 1, 1992, 1.608-613.

3 Jones, L. On Local Greedy Approximation For Nonlinear Regression and Neural Network Training, Annals of Statistics Vol. 28**,** No. 5, 2000, pp. 1379 – 1389.

4 Jones, L. K. and O'Neil, P. J., On Markov chain Monte Carlo algorithms for computing conditional expectations based on sufficient statistics, Journal of Computational and Graphical Statistics, Vol. 11, Number 3, Sept. 2002, pp. 660-677.

5 Jones, L. K., Local Minimax Function Approximation and Estimation with Optimal Finite Sample Error Bounds : Applications to Linear Regression, Tree Learning, Kernel Machines and Inverse Problems, UML Comp. Sci. Tech. Rep., 2006, accepted subject to revision by I.E.E.E. Trans. On Information Theory

d. Other Significant Research Publications

1 Jones, L. On Uniform Generation of Two-way Contingency Tables and the Conditional Volume Test of Diacons and Efron (with R. B. Holmes), Annals of Statistics, Vol. 24, No. 1, 1996**,** pp. 64-68.

2 Jones, L. The Computational Intractability Of Training Sigmoidal Neural Networks, I.E.E.E. Trans. On Information Theory. Vol. 43-1, 1997, pp. 167-173

3 Jones, L. Good Weights and Hyperbolic Kernels for Neural Networks, Projection Pursuit, and Pattern Classification: Fourier Strategies for Extracting Information from High-Dimensional Data, I.E.E.E. Trans. on Info. Th., Vol. 40, No. 2, March 1994, pp. 439-454.

4 Jones, L. Inferring Balking Behavior from Transactional Data, Operations Research,Vol.47,No. 5, Sept.-Oct., 1999, pp. 778-784.

5 Jones, L. A Revised Approach to Queue Inference from Transactional Service Data, , UML Comp. Sci. Tech. Rep. , 2006.