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Race:
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☐ Asian
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☐ Native Hawaiian or Other Pacific Islander
☒ White

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List of Suggested Reviewers or Reviewers Not To Include (optional)

SUGGESTED REVIEWERS:

Kishor S. Trivedi
Farokh B Bastani
Aditya Mathur
Gianfranco Ciardo
Ali Mili

REVIEWERS NOT TO INCLUDE:

Not Listed

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 01-2

NSF 00-126 01/22/01

FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.)

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TITLE OF PROPOSED PROJECT **Integration and Validation of Modeling Formalisms for Dependable Software**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PREPROPOSAL NO., IF APPLICABLE
$ 214,181	36 months	01/01/02	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

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CO-PI/PD				
CO-PI/PD				

Received :01/23/2001

CERTIFICATION PAGE

Certification for Principal Investigators and Co-Principal Investigators:

I certify to the best of my knowledge that:

(1) the statements herein (excluding scientific hypotheses and scientific opinions) are true and complete, and
(2) the text and graphics herein as well as any accompanying publications or other documents, unless otherwise indicated, are the original work of the signatories or individuals working under their supervision. I agree to accept responsibility for the scientific conduct of the project and to provide the required progress reports if an award is made as a result of this proposal.

I understand that the willful provision of false information or concealing a material fact in this proposal or any other communication submitted to NSF is a criminal offense (U.S.Code, Title 18, Section 1001).

Name (Typed)	Signature	Social Security No.*	Date
PI/PD **Frederick T Sheldon**		*ON FASTLANE SUBMISSIONS* **SSN's are confidential and are not displayed**	
Co-PI/PD			
Co-PI/PD			
Co-PI/PD			
Co-PI/PD			

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the individual applicant or the authorized official of the applicant institution is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, and lobbying activities (see below), as set forth in Grant Proposal Guide (GPG), NSF 01-2. Willful provision of false information in this application and its supporting documents or in reports required under an ensuring award is a criminal offense (U. S. Code, Title 18, Section 1001).

In addition, if the applicant institution employs more than fifty persons, the authorized official of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of Grant Policy Manual Section 510; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflict which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

Debarment Certification

(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

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This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

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The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

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(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME/TITLE (TYPED) **Dan Nordquist, Interim Director**		**01/23/01**

TELEPHONE NUMBER	ELECTRONIC MAIL ADDRESS	FAX NUMBER
509-335-9961	**ogrd@wsu.edu**	**509-335-1676**

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Received :01/23/2001

Proposal in Response to NSF 00-126: Information Technology Research

ITR/SY+AP: Integration and Validation of Modeling Formalisms for Dependable Software

Project Summary

Software now affects almost every aspect of personal and professional life in the nation. It manages our telephone networks and nuclear power plants; a large variety of embedded control and sensor devices, air-traffic-control systems, and the readiness of the world's most advanced military force, to mention only a few examples. Given the exponential growth curve for software use, even greater demands on software in the future are expected. Software will need to be even more dependable given the contexts of its use.

Vision statement: Complex software products and systems can be designed via computer modeling and simulations that accurately represent the physical properties of the systems being built. Designers, programmers, and end-users can therefore participate in the design process, providing immediate feedback. Multiple architectures and designs can be rapidly explored, resulting in safer products, high quality, and lower costs.

Main objectives: Apply and validate principles derived from theoretical research to enlarge the toolkit for software developers. Advance our understanding of the basic elements of computer science and the formal methods used in software engineering which are the foundations for all software construction. This research would ultimately address the "fragility" of our software infrastructure, where fragility means "unreliability, lack of security, performance lapses, errors, and difficulty in upgrading."

Roadmap: This is a three year effort designed to intensify research activities by the PI toward the goal of developing and validating methods (and supporting tools) for characterizing the logical and stochastic properties of high assurance software systems.

This project offers an innovative approach to an extensible framework for relating logical, functional, structural and stochastic properties of models derived through a rigorous mapping (i.e., proven theories of correspondence) between the formalisms that describe the models. The project will focus on developing theories of correspondence among the various formalisms (i.e., algorithms for generating bisimilar representations), including the codification and validation of such theories. The formalisms selected will support specifying properties that ensure highly deterministic behavior [i.e., robust and reliable] that is constantly available. By characterizing both logical and stochastic properties we will have added an additional mode to the methods that can be enlisted to verify (and validate) a design including:

- Models that incorporate high-level stochastic modeling formalisms (e.g., stochastic Petri nets) in a single system specification. Each (sub)model is described in a uniform environment and solved using a variety of solution techniques, including numerical methods and simulation,
- The framework will use a strategy that is open and is written in a modular way that allows researchers to perform the easy integration of new formalisms and solution algorithms.

This work will provide useful formal *representations* and *analysis methods* that can be employed to create software components and architectures that relate specifications to programs and programs to behavior. In this way, we will be able to more effectively optimize our designs on the basis of properties from both realms. Moreover, this work should increase the scientific basis of software engineering, provide a more reliable process based on such methods for building software to help us build more dependable software systems.

Keywords: Specification modeling, software design and evolution, verification and validation, safety and reliability analysis, dependable systems.

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For font size and page formatting specifications, see GPG section II.C.

Section		Total No. of Pages in Section	Page No.* (Optional)*
Cover Sheet (NSF Form 1207) (Submit Page 2 with original proposal only)			
A	Project Summary (not to exceed 1 page)	1	
B	Table of Contents (NSF Form 1359)	1	
C	Project Description (plus Results from Prior NSF Support) (not to exceed 15 pages) **(Exceed only if allowed by a specific program announcement/solicitation or if approved in advance by the appropriate NSF Assistant Director or designee)**	10	
D	References Cited	3	
E	Biographical Sketches (Not to exceed 2 pages each)	2	
F	Budget (NSF Form 1030, plus up to 3 pages of budget justification)	6	
G	Current and Pending Support (NSF Form 1239)	1	
H	Facilities, Equipment and Other Resources (NSF Form 1363)	1	
I	Special Information/Supplementary Documentation	0	
J	Appendix (List below.) **(Include only if allowed by a specific program announcement/ solicitation or if approved in advance by the appropriate NSF Assistant Director or designee)**		
	Appendix Items:		

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

Section C. Project Description

ITR/SY+AP: Integration and Validation of Modeling Formalisms for Dependable Software

1. Introduction

This proposal is submitted in response to the ITR program (NSF 00-126). The contents herein are organized on the basis of the GPG Section II.D.4, and the NSF 00-126 guidelines for submission of proposals. Table 1 gives an overview of the project description. Paragraph 4 is directed to satisfy the GPG concerning the broader issues of advances in the field of Software Engineering and the NSF 00-126 guidelines concerning the program description under Software and improved technology for software creation.

Table 1. Section C Organization.

Para	Paragraph and subparagraph title	Description of contents
1.	**Introduction**	Overall description of the project goals.
2.	**Objectives and expected significance**	Overall objectives and their significance to the greater mission of the program.
2.1	Relation to long terms goals	Objectives / long term goals.
2.2	Relation to the present state of knowledge in software engineering	Objectives / known solutions (or generally accepted practice).
2.3	Relation to work in progress here (under support) and elsewhere	How current activities provide a basis for completing stated objectives?
3.	**General plan of work**	Activities, tasks, subtasks, sequencing and deadlines.
3.1	*Broad design of activities to be undertaken*	Relation between the activities.
3.2	*Experimental methods and procedures*	Concept validation and issues specific to software engineering processes and artifacts.
3.3	*Expected results*	Based on the objectives, a discussion of how these objectives will be satisfied.
3.3.1	Preservation and documentation of results	Reporting results, access to the research infrastructure, experimental data, and repository of project artifacts.
3.3.2	Evaluation and self assessment	Measuring the correspondence between the stated objectives and the results (and unforeseen results).
4.	**Advancing discovery and understanding**	Support for fundamental research underlying the development-evolution of quality software-based systems.
4.1	Promoting teaching and learning	Integrating research and education by promoting teaching, training and learning.
4.2	Enhancement of educational infrastructure	Augmenting and intensifying the educational foundation at WSU in software engineering.
4.3	Dissemination of results	Promoting the discovery and broad dissemination of the acquired knowledge.
4.4	Collaborative opportunities	Describes the potential for collaborative activities.
4.5	Summary of prior research and education accomplishments	Describes the background of the PI
5.	**Cited references**	71 references are included.

Paragraph 2 gives the overall objectives of the proposed project concerning the broader scientific impacts. Thus, paragraphs 2–4 provide information regarding the question of what is the intellectual merit of the proposed activity? These paragraphs are developed to establish the importance of the planned work in advancing knowledge and understanding within the field of software engineering.

The ITR program emphasizes the importance of the knowledge base and the workforce needed to enhance the value of information technology for everyone, academic careers dedicated to stimulating the discovery process in which the excitement of research is enhanced by inspired teaching and enthusiastic learning. Therefore, a paragraph 4 is developed to focus on how to improve both our ability to write software and the quality of the software we write.

2. Objectives and expected significance

In a perfect world, verification and validation of a software design specification would be possible before any code was generated. Indeed, in a perfect world we would know that the implementation was correct because we could trust the class libraries, the development tools, verification tools and simulations, etc. These features would provide the confidence needed to know that all aspects (complexity, logical and timing correctness) of the requirements were fully satisfied (i.e., everything was right). Right in the sense that we built it right (its correct with respect to its specification) and it solves the right problem. Unfortunately, it's not a perfect world, and therefore we must strive to continue to define, develop and validate useful methods and tools for the creation of safe and correct software. Therefore, given the realities of today's world, the correctness, safety and robustness of a critical system specification are generally assessed through a combination of rigorous specification capture and inspection; formal modeling and analysis of the specification; and execution and/or simulation of the specification (or possibly a model of such). Such activities are conducted to ensure the confidence and quality of certain key attributes (i.e., correctness, reliability, availability, safety, security and timeliness).

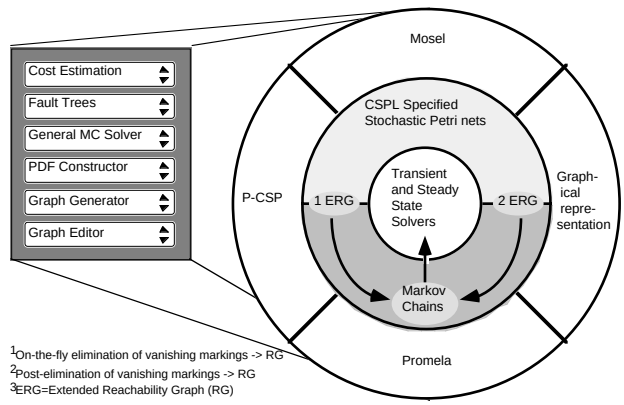

Figure 1. OpenDUO will integrate model description languages and analysis techniques.

2.1 Relation to long terms goals of the project

The long-term goal for this effort is to develop and validate methods and tools for the creation of safe and correct software based systems by investigating mechanisms to assess those key attributes. This goal is apparent in the name *Software Engineering for Dependable Systems* (SEDS) which targets application domains that can benefit from the use of formal and rigorous methods and technology. Given this goal, the general project objective is to create a framework (see Figure 1) that is open and extensible for composing, analyzing, verifying and validating software system models. The framework will address important issues in the field of software engineering: performance and reliability modeling (Petri nets, process algebras, model checking), scalability and the limitations of current methods and technology used for verification and validation. This objective will provide a foundation and framework for investigation, and experimentation within the realm of an academic setting.

It is important that this goal and its objectives be significant in terms of the broader impacts to the state of the practice in software engineering. In light of this, consider the following scenarios. System designers are often confronted with the *verification* problem, i.e., checking that a specification is correct with respect to some requirements, the *implementation* problem, i.e., deriving an executable realization of a correct specification, and the *performability* problem i.e., under specified conditions (e.g., degraded operation) determining the probability of performing the necessary operation(s) on time. In these areas, the use of automated tools to assist human work is highly desirable [Gar90a]. Formal description techniques (e.g., CSP, Promela, Lotos, Petri nets, Task graphs) are a prerequisite for the development of automatic methods of reasoning and of analysis.

This effort addresses these scenarios. The PI is experienced in developing models, methods and tools specifically for stochastic analysis, performability evaluation, and solution methods suited to systems with low latency requirements and rare events. In this vein, the sub-objectives will (1) furnish theories of correspondence among the various formalisms (i.e., algorithms for generating bisimilar representations), (2) including the codification and validation of such theories, (3) develop and

demonstrate compositional techniques for the specification, analysis and design of embedded systems (e.g., guidance control software), and (4) provide interoperability among logical and stochastic representation forms by adding translation capabilities from Promela to Stochastic Petri Nets (see Figure 3). In summary, the objectives will support the development and enhanced automation of an *open framework* for modeling (via CSP, Promela, Mosel, and Stochastic Petri nets [using CSPL as the meta representation][1]) and analysis [Hol93,97, Cha96, Kav96, She96,98,99 Gre98, 95a,b Cia92a,b].

Each objective will be satisfied by demonstrating how a particular example (case study) demonstrates that it satisfies its (functional/non-functional) requirements. The actual and specific needs will be fixed during a requirements elicitation process.

2.2 Relation to the present state of knowledge in software engineering

First, lets consider the basic modeling philosophy which begins by identifying the essential components of the system and the different ways they interact. This means that many assumptions will be introduced. In making these assumptions we must keep in mind the following three basic modeling considerations: (1) simplicity, (2) ease of evaluation, and (3) adequacy of measurements [Laz84]. The key to a successful modeling examination is the skill to introduce assumptions. The principles of the modeling cycle are shown in Figure 2.

Today's real life systems are typically very complex. This fact prevents us from making a direct analysis. Therefore a series of abstraction steps (two basic steps described here) are necessary to obtain system measures from the real system. All these steps together give the modeling cycle. Initially, the system model is created at an abstract level (i.e., abstract model) that specifies the system at a relatively low level.2 To do an analysis of the system we need measures of the system using some type of measurement technique (i.e., we start at the Real System place, top of Figure 2). The Proposed System place is without a real system to compare to and thus, a great deal of work is needed to explore the parameter space.

The data collected from system measurements are used to parameterize the abstract model. However, usually the system model will still contain too many details that prevent an efficient system analysis. In a second abstraction step the computational model is created (relatively high level) which allows an easier and more efficient system analysis. The computational model can be considered to be the highest level of model abstraction. The process of refining the computational model is a matter of building confidence in the model. Thus, in Figure 2 the process of operational validation is performed that results in a modified system with modified system input parameters/data. This step can be repeated until the computed performance measures fulfill the requirements.

If there exists no way to gather system measurements for the purpose of parameterizing the system model then there may be a great deal of more work to do. In addition, the stopping rule for performing operational validation is now based on relative comparisons from one iteration to the next. Different model parameterizations are used to compare the different design (or implementation) candidates with the goal of making architectural design decisions. In simple terms, using a technique commonly known as sensitivity analysis to optimize the model's structure toward achieving critical functional and non-functional requirements [Bla88; Hei88; Cho93; Mai93].

Part of the discovery process that is envisioned concerns gaining experience with tools that support generally accepted practice. The process of developing this project proposal has identified a small set of available tools (i.e., both commercial COTS and academic research based ARB). These tools were selected because (1) the PI had industrial experience using or evaluating the particular tool in the context of complex embedded systems development, or (2) they were encountered in the process of conducting the PI's research agenda. Acquiring, and using such tools will promote educational objectives. In addition, these activities will provide a way to better understand the limitations and in answering such questions as, how can these approaches be improved?

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[1] Mosel is a modeling language for describing state transition systems which are solved using the Markov analyzer MOSES [Gre94a,b]. CSPL is a C-based Stochastic Petri net [SPN] description Language [Cia89,94].

[2] Five hundred-foot level is a terminology used here to assign a number to the degree of abstraction employed. It's a relativistic term, so if you think of ground level (or zero feet), that is at a very low (e.g., the bare machine) system level. The thousand-foot level is more abstract than say the five hundred-foot level. The thousand-foot level here roughly corresponds to employing additional simplifying assumptions.

Some commercially available tools that deal with object oriented (UML) analysis (including design and implementation) are Rational Rose (Rational Inc.) and Rapsody (I-Logix Inc.). In addition, Statemate MAGNUM (I-Logix Inc.) provides graphical modeling, behavior analysis, and software synthesis targeted to complex embedded systems. Yet another is SES/workbench (SES Inc.) for analysis using discrete event simulation based approach (i.e., resource utilization, throughput, and response times). In general these products provide a robust environment for developing a visual specification and an executable model, and in the case of Statemate, code generation[3]. However, these tools provide a narrowly focused paradigm and are limited in the size and kinds of problems with which they can deal.

2.3 Relation to work in progress here (under support) and elsewhere

How do current activities provide a basis for completing stated objectives? The current work by the PI encompasses the development and refinement of a framework called DUO. Figures 2 and 3 show a general architecture for DUO (so called to indicate interoperability [↔]) which defines an architecture that promotes interoperable use of various formalisms (including at least one language

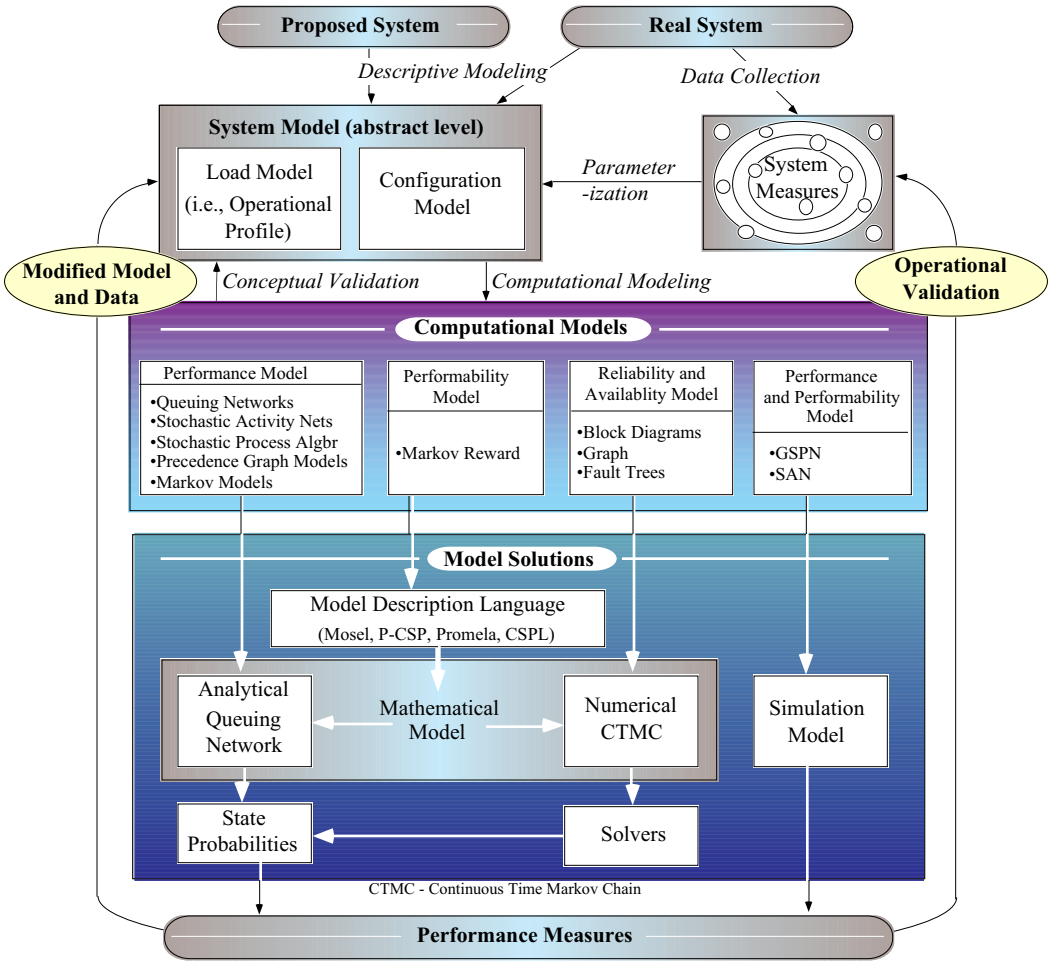

Figure 2. The modeling cycle shows the principle modeling steps (to be formalized and codified in

used in very powerful model checking programs) [Bur92; Hol93; Hol97]. The meta-language used as an intermediate canonical representation form is CSPL (C-based Stochastic Petri net Language) [Cia94]. This environment will facilitate the modeling process and will provide an interface for common techniques and method interoperation. DUO aims to provide greater *orthogonality* (by

[3] Non-COTS ARB tools include SPNP, SPIN, CSPN (developed by PI) and a host of others as shown in Figure 2

adding Promela-to-CSPL) among the formal description techniques, a robust and efficient *analytic solver* (in addition to SPNP and MOSES) and enhanced *automation* [Gre94b]. By the end of the 2001 it is expected that work by students at the University of Erlangen (and at WSU under the direction of the PI) will complete a field data analysis tool (FTA) for generating PDFs (Probability Density Functions), a Warranty cost analysis tool (GUK), a complete database connection, and a state space generator and solver (either analytically or by simulation), and a simulator for fluid (real valued tokens) stochastic Petri nets. Additional efforts are planned to permit the use of non-exponential PDFs in the CSPL file and further extending CSPL to allow for fluid stochastic PNs constructs. Also, the process of porting CSPN from C to C++ is underway.[4]

In addition, the results of the safety and reliability analysis of a braking, anti-slip/traction control and stability system (Brake-safe) will be completed by the PI. It will be interesting to compare the fidelity of this analysis against models using any one of the proposed COTS paradigms. All of these functionalities will be incorporated into OpenDUO.

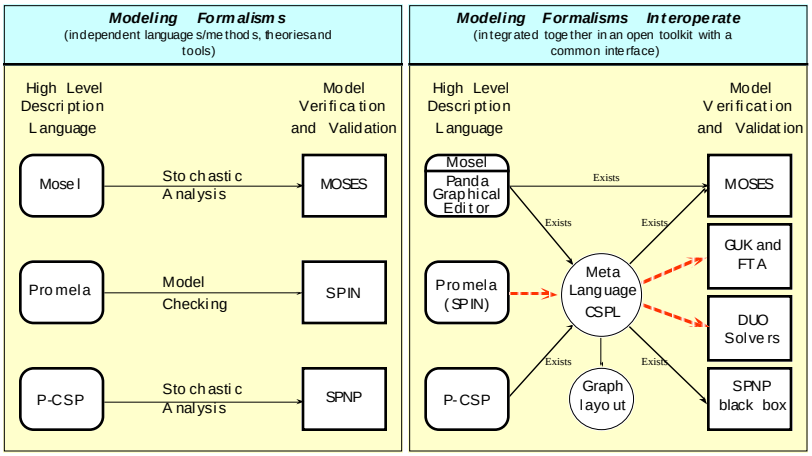

Figure 3. Open DUO Framework (arrows: dashed -underway, solid -exist).

3. General plan of work

The plan of work will develop several example models using different paradigms or languages (Workbench, Statemate, Promela and CSP/ SPNs) to demonstrate system-level specification and analysis. The approach will conduct stochastic and performability evaluation using techniques previously developed by the principal investigator [She96, She98, She99]. Various case studies will be developed to understand and demonstrate the benefits and limitations within each paradigm (e.g., Statemate, SES/workbench, and academic research based). The results of the analysis from each of the different paradigms will be compared to develop a strategy for overcoming known limitations. Industrial participation will be invited from the School of EECS Industrial Advisory Council (http://www.eecs.wsu.edu/~corporat/corprel.htm) to help refine and prioritize the strategy and case studies.

Foundation: Develop theories and algorithms for generating Bisimilar representation forms

- √ Define canonical translation rules (CTR) and evaluate their correctness
- √ Installation of COTS and Academic Research Based (ARB) tools
- √ Develop baseline (case study) examples on COTS tools and define assessment criteria
- √ Migrate baseline examples to ARB tools and refine/define assessment criteria
- √ Establish guidelines for experimentation

Framework: Develop an extensible framework

- √ Integrate popular text editors (e.g., emacs) and develop an extensible graphical HLDL[5] editor
- √ Investigate drawing large SPNs and defining net properties in the visual environment
- √ Define reuse strategy to capture well defined mini-models, how to implement multi-level (or hierarchical) models and facilitate building models from a library of reusable components

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[4]The CSPN tool (developed by the PI) translates the CSP (communicating sequential processes) process algebra into SPNs (i.e., CSPL) to explore the specification/analysis of stochastic properties for concurrent systems. The functional system description (using a CSP-based language, P-CSP) is translated into the information needed to predict behavior as a function of observable and stochastic parameters (topology, timeliness, communications and failure categories).

[5] High Level Description Language (HLDL)

Buildup: Refining translators and integrating solvers.

- √ CTR refinements (augment and integrate the automation that permits the specification and translation between formalisms (e.g., Promela and SPNs))
- √ Further define the Promela-to-CSPL[6] translations and refine the existent prototype translator
- √ Compare the state space generated from the different formalisms
- √ Refinement of the state space generator (using on-the-fly and post elimination algorithms)
- √ Integrate solvers (*SOR* [Successive Over Relaxation] and *Gauss Seidel* for steady state analysis, *Uniformization* for transient analysis, and the *Multilevel method* for Stiff DTMC and steady state analysis)

Finishing: Demonstrate/assess benefits of the OpenDUO against COTS based paradigms. Build (or insert into SERC repository) web-based access point to the tools, papers and case study example(s).

3.1 Broad design of activities to be undertaken

The activities described in Figure 4 relate to the plan of work provided in paragraph 3 above. These activities provide the primary research focus. To conduct this research the software engineering tool set and workstations are needed to provide the underlying infrastructure. This infrastructure will additionally support a software engineering environment that will benefit the software engineering degree programs. Together, both the research and the academic programs will be greatly enhanced.

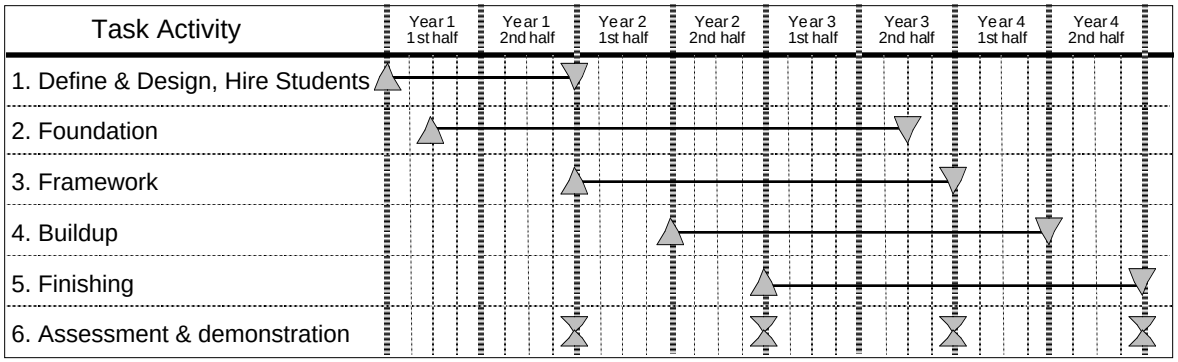

Figure 4. General schedule of activities.

3.2 Experimental methods and procedures

The OpenDUO toolset will provide a basis for both collaboration within the EECS department among students and outside collaborative activities among invited industrial partnerships and the NSF SERC. The development of features and refinements will be conducted based on a software engineering model (much like the spiral model), from requirements elicitation/specification, modeling analysis and architecture, design and implementation to testing configuration and risk management.

This effort is expected to enable deeper understanding into pedagogic style based on the integrated research and education activities (i.e., classroom-laboratory experience). This experience will help students evaluate how effective an experimental method is compared to a more traditional method. This method also seeks to understand, within the context of an experimental setting, the major factors that contribute to the efficiency and effectiveness of the methods being applied, the factors that contribute to experiential learning versus more traditional pedantic learning and the factors that detract from learning.[7] Another issue is, what relevant data exists that can be useful for

[6] C-based Stochastic Petri net Language

[7] One issue from an educational perspective is discovering the differences between collaborative group or team learning and individual or isolated learning. Are the best (more highly skilled) programmers (or S/E practitioners) better on the basis of being self taught or visa versa?

characterizing software content, complexity and form? Comparing the results of products developed from classroom project assignments from one team to the next and from semester to semester will facilitate insight and understanding with respect to the efficacy of experimental tools, methods and teaching [Hal77, McC76, Van93].

In general, the experiments may involve a control group (using a traditional method, COTS) and a shadow group (using an experimental method, ARB). Another method may compare historical data (trends and changes) with data obtained from current experiments. It is expected that the industrial partners will provide problems and data for evaluating the results obtained from this effort. For example, the PI has used the Software Requirements Specification for the Guidance Control Software (GCS) of the Viking Mars Lander for various class projects in Requirements Engineering, Software Design and Formal Methods (made available by NASA LaRC). For example, last spring 2000, in CptS 580.1 Software Specification and Analysis a complete Zed specification of the GCS system. The research at SERC will also be monitored for insights into new technology and educational resources that may contribute to teaching effectiveness.

3.3 Expected results

It is expected that this effort will provide a very productive basis for improving and firmly establishing a strong software engineering program within the WSU EECS department. In addition, the project will have established an appropriate agenda for the purpose of experimentation using the OpenDUO framework for *composing, analyzing, verifying and validating software based system models*. These results will be devoted to investigating software technology, as well as for the development and assessment of tools and methods for improving productivity and software quality throughout the life cycle.

3.3.1 Preservation and documentation of results

The primary method of preserving and documenting the results will be via publications in scholarly journals and conferences. In addition, the artifacts from the student projects will be collected both in electronic and hard copy media. Annual progress reports as specified in the NSF GPG (VII.G.1 and 2) will be supplied and will include an update to other external support.

The results from achieving the long term goal of the project will be made accessible via publications and dissemination via a specialized web site (http://www.eecs.wsu.edu/~sheldon). In addition, this work is expected to align well with the NSF sponsored SERC (Software Engineering Research Center) and VirtualSERC (the SERC web site http://www.serc.net). The PI is currently developing a strategy for making WSU an affiliate of SERC. He has met with the director of SERC in this regard at WSU (April 14, 2000). SERC is devoted to investigating the development and assessment of tools and methods for improving productivity and software quality throughout the life cycle. The SERC program is structured to improve the management of the software engineering process, the productivity of software engineers, and the quality of software engineering products.[8]

3.3.2 Evaluation and self assessment

Evaluation and self assessment measures the correspondence between the stated objectives and the results (and perhaps recognizes the value of unforeseen results). This is primarily dependent on (1) making the solution (results) effective, affordable and repeatable, (2) understanding and evaluating how well we have hit the target of our objectives, (3) our ability to optimize human resources (students and external collaborators), (4) determining the marketability of our framework [technology transfer], (5) establishing research alliances and a concomitant symbiotic vision (i.e., quality and relevance matter most). These factors will be assessed and reported as described in paragraph 3.3.1.

Self assessment will also address the issue of relevance from the standpoint of scholarly achievements (published work) and industrial participation. Assessment will be conducted with

[8] Members ($30,000/affiliate) benefit via direct involvement in a highly leveraged, sponsor-guided research program; early access to research results applicable to sponsor needs; technology transfer via personnel exchange programs, and seminars, talks, and short courses; opportunities to influence directions in software engineering educational developments; a world wide window on new software engineering technology; and additional specific research under separate "contracts."

respect to current industrial practice. For example, today, commercial software comes packaged in various levels of granularity, from complete applications to components libraries. Access to much of the functionality is changing the software landscape. Thus, access to COTS utilities decreases the need for developers to rewrite functionality that they can license, but it increases the need for analysis, integration and testing resources. Bad COTS components may be embedded in the applications that cause widespread failures [Voa99]. How effectively is this issue addressed by our work? What role can such formal methods and tools play in software certification? What are the five main issues surrounding software engineering environments?

This last question was discussed by Anthony I. Wasserman in his recent article in IEEE Software: *Toward a Discipline of Software Engineering* (Nov. 1996) where he claims that the main issues include platform integration (the ability of tools to interoperate on a [potentially heterogeneous] network); presentation integration (commonality of the user interface among tools); process integration (linkage between tool usage and the software development process); data integration (the ways in which tools share data); control integration (the ability for tools to notify and initiate actions among one another. Probably the most important two issues are data and control integration. This is evidenced by the commercial ventures that have focused on those aspects. Yet one may argue that platform integration is also very important because of the investment in such. However, by solving the first two there would be a considerable easing on the problem of heterogeneous environments. The big win may eventually come from the development of an open environment that supersedes the platform problem. These issues will be important questions in our assessment of OpenDUO.

4. Advancing discovery and understanding

This paragraph indicates how the project will integrate research and education to advance the process of discovery and understanding. To accomplish this vision, the PI recognizes the need to focus attention in the following areas of activity. These areas are actually linked and even co-dependent in many ways. Further, these areas of focus cannot succeed without a strong foundation of support in terms of people, infrastructure and other resources to ensure that learning and discovery can prosper.

- √ *Undergraduate Learning Environment:* Generate innovation in an undergraduate learning environment in ways that promote a sense of discovery and lifelong learning, develop skills in critical thinking, and prepare students for citizenship and leadership.
- √ *Research and Graduate Education:* Develop a leadership role in advancing knowledge and understanding through research and graduate education with appropriate links to government, business and other institutions through outreach and technology transfer.
- √ *Diversity:* Nurture a climate of inclusion, knowledge, understanding and appreciation of the full range of the human experience in order to foster a better society.
- √ *Technology:* Situate the Software Engineering program at WSU to be exceptional in providing state of the practice tools and challenges to enable its graduates to compete in the world market.

4.1 Promoting teaching and learning

This paragraph indicates how the project will integrate research and education by promoting teaching, training and learning. This effort will enrich the PI's and EECS department's ability to offer curriculum using state of the practice facilities for undergraduate and graduate education in software engineering. The idea is to investigate and experiment with popular methods and tools within a classroom laboratory context working on pertinent problems from the industrial domain (e.g., embedded systems used in avionics, aerospace, transportation systems) contributed by way of industrial partnerships. These methods and tools will offer a baseline state of the practice approach to sharing and solving complex, yet academic sized, software engineering challenges.

It has been the experience of the PI that students can realize their creative talents and improve their technical skills by participating in group projects that have industrial relevance. For example, the PI (summer 98) provided two student stipends for weeklong visits to NASA Ames Research center where the students made presentations about their projects. The PI also secured an international

scholar visitation stipend at Ames to support collaborative work and promote the exchange of ideas among colleagues there.[9]

In general terms, it is important to establish opportunities for the students to explore their creative and analytical abilities:

- developing guidelines for practical, challenging and innovative group projects,
- sending outstanding project reports to local conferences,
- recruiting students by sponsoring high school or junior college projects,
- developing new courses related to the PI's areas of research,
- collaborating with internal and/or external faculty on cross-disciplinary courses and projects, or bringing in industry to motivate and sponsor class topics and semester projects.

4.2 Enhancement of educational infrastructure

This effort will integrate research and education by enhancing the infrastructure for research and education (e.g., facilities, networks and partnerships). The general project objective will provide a foundation and framework for investigation, experimentation and teaching (classroom project labs, and graduate project, thesis and dissertation undertakings) as discussed above. For example, many of the project classes (e.g., Software Architecture and Design, or Requirements Specification and Analysis) could benefit from a floating license for SES/workbench ($2,000 for 20 and no maintenance fees). For example, the PI has developed a SES model that represents an embedded architecture for the Guidance and Control Software of the Viking Mars Lander (see http://www.eecs.wsu.edu/~sheldon/cs580.html). A Statemate ($2,000 for 20 floating licenses and no maintenance fee) model could be developed and for the same type of system given as a class project. The students would need to reverse engineer the Workbench model and forward engineer the Statemate model. This kind of example could be used as a basis for comparison of other methods over the duration of the class. This scenario will be made possible by NSF funding.

4.3 Dissemination of results

This paragraph indicates how the project will integrate research and education to enhance scientific and technological understanding. In addition there are potential benefits from the project that will impact the society at large through discovery and implementation of new and advanced approaches to characterizing the logical and stochastic properties of high assurance software systems. As mentioned above, dissemination of the results will proceed through the normal channels discussed above (paragraph 3.3.1) and through the establishment of a specialized web site. In addition, the results will provide an *excellent* source and basis for teaching software engineering and other related (project oriented) classes.

4.4 Collaborative opportunities

There is a substantial collaborative potential envisioned from the proposed project. Currently the PI has been working with DaimlerChrysler and the University of Erlangen in developing the definition of the OpenDUO framework. One of the PI's students (Shane Holloway) has been offered a job at DaimlerChrysler in Stuttgart after he delivered his State Space Generator. This international relation is expected to remain very strong over the duration of the award. In addition, some fresh new contacts have been established with Boeing and Lockheed (lmtas in Fort Worth). Also, refer to paragraph 2.1 for plans involving the NSF sponsored SERC.

4.5 Summary of prior research and education accomplishments

The dissertation title *Specification and Analysis of Stochastic Properties for Concurrent Systems Expressed Using CSP* was completed in May of 1996. The PI was awarded the 1995-6 University of Texas at Arlington, School of Engineering, Computer Science Engineering Outstanding Research by

[9] Undergraduate Shane Holloway [ph. 719-471-4370] and Graduate Chuck Rodacker [ph. 719-5987367] and Ph.D. Candidate Stefan Greiner [ph. 011-49-711-17-41038] from the University of Erlangen- Nürnberg all participated.

a Ph.D. Student Award and the Sigma Xi Outstanding Dissertation award (at UTA). He also received the 1996 IEEE Second Place Graduate Technical Paper Contest (Fort Worth Section) award. Additionally, in late 1995 he received a prestigious National Research Council Research Associateship Award at NASA/Langley Research Center. He has been teaching part-time since 1993 until he began his full-time tenure track appointment at UCCS shortly after his graduation.

Sheldon was the technical lead for a $2 million contracted R&D project funded by WPAFB to define a generic Integrated Diagnostics Software Development Process to address problems associated with functional deficiencies of avionics software and software maturation using as a basis, the Software Development Integrity Program MIL-STD-1803 (including Mil-Std-2167A, 2168, 1815 and 800-xx Series). This project developed a software engineering process model to specify, develop and verify diagnostic software and made recommendations to the USAF for Mil-Std-1814 updates. In addition, he authored the first draft of the General Dynamics Software Risk Management Practices (required by SPWG), collaborated in developing the YF-22 Software/System Engineering Environment's prime requirements document (System Segment Specification) and in writing the software requirements specification (SRS) for the YF-22 Vehicle Management Kernel.

Sheldon's dissertation at The University of Texas at Arlington (UTA) was funded by a NASA GSRP fellowship. He attended UTA from 1985 while working in industry full time except during the last 3 years while supported by the fellowship. Sheldon has investigated software engineering methods and technology (i.e., specification, modeling, simulation, mathematical analysis, theory and methods) for analysis and verification of concurrent real-time systems. In support of his dissertation research he has developed analytical models for (1) predicting timing failure probability, (2) 3-dimensional cost analysis for optimizing safety critical design parameters, and (3) explored performability analysis based on task dependency graphs in conjunction with CSP-based specifications. His publications and technical reports beginning about 1988 cover the following topics: (1) software reliability modeling, (2) real-time systems design and analysis, (3) simulation based performance analysis, (4) specification based modeling for the purpose of reliability analysis, and (5) software engineering environments. Sheldon spent the last two summers at NASA Ames as an ASEE Research Associate in the Automated Software Engineering group working issues associated with verification and validation.

The following is a list of the courses that Sheldon has taught at UTA, UCCS, and WSU: CptS 580.1/483.1 Software Specification and Analysis (Spr. '00, '01), CptS 422 Software Engineering Principles (Fall '99, '00) Requirements Specification and Analysis (CS531 – Spr. '99), Software Engineering Principles (CS 330 - Spr./Fall '98), Computer Architecture (CS 520/420 - Spr. '97, Fall '97), Formal Methods: Software Systems Engineering (CS 533 - Spr. '97, Spr. '99), Software Design (CS 532 - Fall '96, '97, '98), Discrete Structures in Computer Sci. (CSE 2315/3315 was CSE 1442 - Fall 93, Spr. 94, Fall 94, Spr. 95), Formal Methods: Software Systems (CSE 5312 substitute lectures - Fall 95, Spr. 96)Fundamentals of Software Engineering (CSE 3310 - Spr. '93).

5. References Cited

(† - indicates a cited reference)

Balbo, G., "On the Success of Stochastic Petri Nets," *Int'l Wkshp on Petri Nets and Performance Modeling*, IEEE CS Press, Los Alamitos, CA, pp. 2-9, 1995.

Blake, J. T., Reibman, Andrew L. and Trivedi, Kishor S. (1988), "Sensitivity Analysis of Reliability and Performability Measures for Multiprocessor Systems," *SIGMETRICS*, ACM, New York, NY, pp. 177-186.

Burch, J. R., Clarke, E.M., and McMillan, K.L., "Symbolic Modeling Checking: 10^{20} States and Beyond," *Information and Computation, 98*, 42, 142-170, 1992.

Bolch, G., Greiner, S., deMeer, H., and Trivedi, K.S., *Queueing Networks and Markov Chains: Modeling and Performance Evaluation with Computer Science Applications*, John Wiley & Sons, New York, 1999.

Chan,† T.S. and Gorton, I., "Formal Validation of a High Performance Error Control Protocol Using SPIN," *Software Practice and Experience 26:1*, pp. 105-24, Jan. 1996.

Chiola, G. (1985), "A Software Package for the Analysis of Generalized Stochastic Petri Net Models," *Int'l Wkshp on Timed Petri Nets*, IEEE CS Press, Los Alamitos, CA, pp. 136-143.

Choi,† H., Mainkar, Varsha and Trivedi, Kishor S., "Sensitivity Analysis of Deterministic and Stochastic Petri Nets," *MASCOTS'93 International Workshop on modeling, Analysis and Simulation of Computer and Telecommunication Systems*, pp. 271-276, 1993.

Ciardo, G. (1987), "Toward a Definition of Modeling Power for Stochastic Petri Net Models," *Int'l Wkshp on Petri Nets and Performance Models*, IEEE CS Press, Los Alamitos, CA, pp. 54-62.

Ciardo, G., Marie, R., Bruell, S., and Trivedi, K., "Performability Analysis Using Semi-Markov Reward Processes," *IEEE Transactions on Computers, 39*, 10, 121-1264, 1992b.

Ciardo, G., Muppala J. and Trivedi, K.S., "On the Solution of GSPN Reward Models," *Performance Evaluation 12*, North-Holland, pp. 237-253, 1991.

Ciardo, G., Trivedi K.S., "A decomposition approach for stochastic reward net models," *Performance Evaluation, 18:1*, pp. 37-59, July 1993.

Ciardo,† G., Blakemore A., Chimento P.F., Muppala J.K., Trivedi K.S., "Automated Generation and Analysis of Markov Reward Models Using Stochastic Rewards Nets," in: *Linear Algebra, Markov Chains and Queuing Models*, eds. C. Meyer and R.J. Plemmons, IMA Volumes in Mathematics and its Applications, Vol. 48 (Springer, Heidelberg, Germany), 1992a.

Ciardo,† G., Fricks, R., Muppala J. and Trivedi, K.S., "SPNP Users Manual Version 4.0," *Dept. of EE, Duke Univ., PO Box 90291* (Durham, NC, 27708) Mar. 1994.

Ciardo,† G., Muppala J. and Trivedi, K.S., "Analyzing Concurrent and Fault-Tolerant Software Using Stochastic Reward Nets," *Jr. of Parallel and Distributed Comp*., pp. 255-269, 1992b.

Ciardo,† G., Muppala J. and Trivedi, K.S., "SPNP: Stochastic Petri Net Package," *IEEE Proceedings 3rd Int'l Workshop on Petri Nets and Performance Models*, (Kyoto), pp. 144-151, Dec. 1989.

Davies, Jim and Schneider, Steve, "Real-Time CSP," Theories and Experiences for Real-Time Sys. Dev., *AMAST Series in Comp: Vol. 2*, T. Rus and C. Rattray Eds., Wrld Sci., NJ, pp.31-82, 1994.

Delisle, N., and Swartz, M., "A Programming Environment for CSP," *ACM SIGPLAN Notices 22, No. 1*, pp. 34-41, Jan. 1987.

Delisle, Norman, and Garlan, David, "A Formal Specification of an Oscilloscope," *IEEE Software*, pp. 29-36, Sept. 1990.

Donatelli, S., Ribaudo, M. and Hillston, J., "A Comparison of Performance Evaluation Process Algebra and Generalized Stochastic Petri Nets," *IEEE Proc. 5th Int'l Wkshp PNPM* (Durham), pp. 158-168, Oct. 1995.

Dugan, J.B., and Lyu, M.R., "Dependability Modeling for Fault-Tolerant Software and Systems," *Ch. 5 In Software Fault Tolerance*, Lyu, M., Ed. (John Wiley, NY), 1995.

Fernandez, A., Garavel, H., Mounier, L., Rasse, A., Rodriguez, C., "A Toolbox for the Verification of LOTOS Programs," *Proc. of the 14th Int'l Conf. on Software Engineering*, pp. 246-259, 1992.

Garavel,† H. and Sifakis, H., "Compilation and verification of Lotos Specifications," *Proc. 10th Int'l Symp. on Protocol Specification, Testing and Verification* (Ottawa) Elsevier, June 1990a.

Garavel,† H., "Compilation of LOTOS Abstract Data Types," *Formal Description Techniques II*, Elsevier, pp. 147-162, 1990b.

Gerber,† R. and Lee, I., "A Proof System for Communicating Shared Resources," *IEEE Proc. Real-Time Systems Symp.*, pp.288-299, 1990.

Gomaa, Hassan, "Software Design Methods for the Design of Large-Scale Real-Time Systems," *Jr. of Systems Software, Vol. 25*, pp. 127-146, 1994.

Greiner,† S. and Bolch, G., "Generation and Solution of Markov Chains Using MOSES," *TR-I4-94-11, IMMD IV, Univ. of Erlangen*, June 1994b.

Greiner,† S. and Bolch, G., "The Markov Analyzer MOSES," *TR-I4-94-10, IMMD IV, Univ. of Erlangen*, June 1994a.

Greiner,† S., "An Analytical Model for the Operating System BS2000," *MS thesis at Computer Science - IMMD IV, Univ. Erlangen*, Mar. 1995b.

Greiner,† S., "Performance Evaluation of Dynamic Priority Operating Systems," *IEEE Proc. 5th Int'l Wkshp PNPM* (Durham), Oct. 1995a.

Greiner,† S.A., "New Analytical Methods for the Analysis of Dependable Real-Time Systems," *Ph.D. Dissertation, Computer Science Dept., Univ. of Erlangen*, May 1998.

Halstead,† M.H., *Elements of Software Science*. New York: Elsevier, 1977.

Heidelberger,† P., and Goyal, Ambuj, "Sensitivity Analysis of Continuous Time Markov Chains Using Uniformization," *Computer Performance and Reliability. Proc. of the 2nd Int'l MCPR Wkshp*, North-Holland, Amsterdam, pp. 93-104, 1988.

Hillston, J., "A Compositional Approach to Performance Modeling," *Ph.D. Thesis, Univ. of Edinburgh*, Mar. 1994.

Hillston, J., "PEPA: A Performance Evaluation Process Algebra," *Proc. of PAPM'93*, (Edinburgh), pp. 21-29, May 1993b.

Hoare, C.A.R., *Communicating sequential processes*, Prentice-Hall Int'l, London, 1985.

Holzmann,† Gerard J., "Design and validation of protocols: a tutorial," *Computer Networks and ISDN Systems, Vol. 25*, pp. 981-1017, 1993.

Holzmann,† Gerard J., "The Model Checker SPIN," *IEEE Trans. on SE, 23:5*, May 1997.

Jones, Robert L. III, "Predicting Fault Coverage Using Stochastic Activity Networks," *Personal Communication and NASA Tech. Memorandum*, July 1995.

Kavi,† K.M., Sheldon, F.T. and Reed, S.C., "Specification and Analysis of Real-Time Systems Using CSP and Petri Nets," *Int'l Jr. of SE and Knowledge Engineering*, June 1996.

Lazowska,† E.D. , Zahorjan J. , Graham G.S. , Sevcik K.C., *Quantitative System Performance - Computer System Analysis Using Queuing Network Models*, Prentice Hall , 1984.

Lee, Insup and Gerber, Richard, "A Process Algebraic Approach to the Specification and Analysis of Resource-Bound Real-Time Systems," *Proc. of the IEEE, 82:1*, pp. 158-171, Jan. 1994a.

Levenson, N. G., and Stolzy, J.L., "Safety Analysis Using Petri Nets," *IEEE Trans. on Software Engineering, SE-13*, 3, 386-397, 1987.

Mainkar V., "Solution of Large And Non-Markovian Performance Models," *Ph.D. Dissertation at Dept. of Electrical Engineering, Duke University*, pp.113-130, May 1994.

Mainkar,† V., Choi, Hoon and Trivedi, Kishor, "Sensitivity Analysis of Markov Regenerative Stochastic Petri Nets," *5th Int'l Wkshp on Petri Nets and Performance Modeling*, IEEE Computer Society Press, Los Alamitos, CA, pp. 180-189, 1993.

Malhotra, M., and Trivedi, K.S., "A Methodology for Formal Expression of Hierarchy in Model Solution," *Fifth Int'l Wkshp on PNPM*, IEEE CS Press, Los Alamitos, CA, pp. 258-267, 1993.

Marie, R., and Jean-Marie, Alain, "Quantitative Evaluation of Discrete-Event Systems: Models, Performance and Techniques," *Fifth Int'l Wkshp on Petri-Nets and Perf. Modeling*, IEEE CS Press, CA, pp. 2-11, 1993.

Marsan, M. A., Balbo, G. and Conte, G, "A Class of Generalized Stochastic Petri Nets for the Performance Evaluation of Multiprocessor Systems," *ACM Trans. on Comp. Sys., 2*, 1, 93-122, 1984.

McCabe,† T.J., “A Complexity Measure,” IEEE Trans. Software Eng. SE-1(3):312-327, 1976

Meyer, J.F., "On Evaluating the Performability of Degradable Computing Systems," *IEEE Transactions on Computers*, Vol. C-22, pp. 720-731, Aug. 1980.

Meyer, J.F., "Performability: A Retrospective and some pointers to the future," *Performance Evaluation*, pp. 157-196, February, 1992.

Moller, F. and Tofts, C., “A Temporal Calculus of Communicating Systems,” *CONCUR '90, LNCS 458*, Springer-Verlag, pp. 401-415, 1990.

Molloy, M. K., “Performance Analysis Using Stochastic Petri Nets,” *IEEE Transactions on Computers*, *C-31*, 9, 913-917, 1982.

Moore, Andrew P., “The Specification and Verified Decomposition of System Requirements Using CSP,” *IEEE Trans on Software Engineering, 16:9*, pp. 932-948, Sept. 1990.

Muppala, J. K., Ciardo, Gianfranco and Trivedi, Kishor S., “Stochastic Reward Nets for Reliability Prediction,” TR-1994-12, Duke Univ., EE Dept., Durham, NC, 1994.

NASA95 “Formal Methods Specification and Verification Guide Book for Software and Computer Systems - Volume I: Planning and Technology Insertion,” *NASA-GB-002-95*; July 1995.

NASA97 “Formal Methods Specification and Verification Guide Book for Software and Computer Systems - Volume II: A Practitioner's Companion,” *NASA-GB-001-97*; May 1997.

Olderog, E.R., “TCSP - Theory of communicating sequential processes,” *LNCS-255*, S-Verlag, 1986.

Olszewski, Jacek, “CSP Laboratory,” *SIGCSE Bulletin, 25:1*, pp. 91-95, Mar. 1993.

Ostroff, Jonathan S., “Formal Methods for the Specification and Design of Real-Time Safety Critical Systems,” *Journal of Systems Software, Vol. 18*, pp. 33-60, 1992a.

Ostroff, Jonathan S., “Verification of Safety Critical Systems using TTM/RTTL,” *Proc. of the REX Wkshp: Real-Time: Theory in Practice, LNCS 600*, Springer-Verlag, pp. 573-602, 1991.

Peleska, Jan, “Design and Verification of Fault Tolerant systems with CSP,” *Distributed Computing*, 5:2, Springer-Verlag, pp. 95-106, 1991.

Sahner, R. T., K. and Puliafito, A. (1996), *Performance and Reliability Analysis of Computer Systems - An Example-Based Approach Using the SHARPE Software Package*, Kluwer, Boston, MA,.

Sheldon, F.T., and Kavi, K.M., "Position Statement: Linking Software Failure Behavior to Specification Characteristics II," *IEEE Proc. Int'l Workshop on Evaluation Techniques for Dependable Systems*, (San Antonio), Oct. 1995a.

Sheldon, F.T., Kavi, K.M, and Kamangar, F.A., "Reliability Analysis of CSP Specifications: A New Method Using Petri Nets," *AIAA Proc. Computing in Aerospace 10*, pp. 317-326, March 1995b.

Sheldon, F.T., Mei, Hsing, and Yang, S.M., "Reliability Prediction of Distributed Embedded Fault-Tolerant Systems," *IEEE Proc. Int'l Symp. on Software Reliability Eng.*, pp. 92-102, Nov. 1993.

Sheldon,† F.T. and Greiner, S.A., "Composing, Analyzing and Validating Software Models to Assess the Performability of Competing Design Candidates," To appear in *Annals of Software Engineering –Special Volume on Software Reliability, Testing and Maturity*, 84 Refs., 36 pages.

Sheldon,† F.T., "Specification of Stochastic Properties with CSP," *Ph.D. Dissertation, Computer Science and Engineering Department., Univ. of TX at Arlington*, May 1996.

Sheldon,† F.T., "Analysis of Real-Time Concurrent Systems Models Based on CSP Using Stochastic Petri Nets," *SCS Proc. 12th European Simulation Multiconference*, pp. 776-783, June 16-19, 1998.

Vander,† Wiel, S.A. and Votta. L.G. “Assessing software designs using capture-recapture methods,” *IEEE Trans. Software Engineering*, SE-19(11):1045-1054, 1993.

Voas,† Jeffrey, “Certification: Reducing the Hidden Costs of Poor Quality,” *IEEE Software*, pp. 22-25, July, 1999.

Wang, Chang-Yu and Trivedi, Kishor, “Integration of Specification for Modeling and Specification for System Design,” *EE Dept., Duke Tech. Rpt.*, 21 pgs., 1994.

Wang, Chang-Yu, “Some Problems in the Specification and Analysis of Computers and Networks," *Ph.D. Dissertation, Dept. of CS, Duke University*, 218 pgs, 1995.

Wasserman,† A. I., “Toward a Discipline of Software Engineering,” *IEEE Software*, pp. 23-31, Nov. 1996

Biographical Sketch Frederick T. Sheldon

785 Ridgeview, Pullman, Washington 99163

PROFESSIONAL BEARING

Research to develop / validate methods and supporting tools for the creation of safe and correct software.

EDUCATION

University of Texas at Arlington, College of Engineering

Ph.D. in Computer Science (Mjr. Prof. Krishna M. Kavi) May 1996

MS in Computer Science (Mjr. Prof. Krishna M. Kavi) August 1988

University of Minnesota, Institute of Technology

Bachelor of Science in Computer Science December 1983

University of Minnesota, College of Biological Science

Bachelor of Science in Microbiology July 1977

EXPERIENCE

Washington State University, College of Engineering and Architecture From/To: 06/99 - present

Assistant Professor, School of Electrical Engineering and Computer Science

University of Colorado, College of Engineering and Applied Science From/To: 08/96 – 06/99

Assistant Professor, Computer Science Department

National Research Council, NASA Langley Research Center From/To: 06/96 - 08/96

Postdoctoral Research Associate, Flight Electronics Technology Division: Formal specification of stochastic properties for an integrated air/ground system to support low visibility landing and surface operations at commercial airports. Investigated advanced design techniques for ensuring that high-performance computing systems are produced in a timely fashion and meet stringent real-time reliability and fail-safe requirements.

University of Texas at Arlington, College of Engineering From/To: 01/93 - 05/96

Assistant Instructor, Computer Science and Engineering: Taught Methods in Software Engineering, Discrete Structures in Computer Science (+ Pascal lab) and Formal Methods. Dissertation title: Specification and analysis of stochastic properties for concurrent systems expressed using CSP. Developed a CSP-to-Stochastic Petri net translator and studied simulation techniques for dependability analysis and verification. Received NASA fellowship and School. of Engineering (CSE Dept.): Outstanding Research by a Ph.D. Student award.

General Dynamics, Fort Worth Division From/To: 10/88 - 01/93

Engineering Specialist (promoted 1992 from Senior Engineer) Avionics R&D: Technical lead for $2million project to define a generic Integrated Diagnostics Software Development Process to address problems associated with functional deficiencies of avionics software and software maturation. We developed a software engineering process model (specify, develop and verify diagnostic software) and recommendations to the USAF for Mil-Std updates. Authored F-22 Software/System Engineering Environments prime requirements document. Lead for YF-22 Vehicle Management System Distributed Kernel and author of it's software requirements specification.

Texas Instruments, Defense Systems and Electronics Group From/To: 7/84 -10/88

*Test Engineer (promoted 1988 from Software Design Engineer), Test Automation Department: D*esigner for built-in-test software on the VHSIC Multipurpose Interface module (YF-22) Mission Display Processor using DoD-STD-2167 and Ada. *Software Design Engineer, Avionics Systems/Radar Division:* Designer for hardware fault diagnostic, built-in-self-test, calibration and acceptance test software for the Tornado Nose Radar.

AWARDS AND RECOGNITION

- 1997-98 ASEE Fellowship: Stanford/NASA Ames Summer Faculty Research Associate
- 1996-97 Outstanding UTA Ph.D. Dissertation Award from UTA Chapter for the Society of Sigma Xi
- 1995-6 UTA School of Engineering, Dept. of CSE: Outstanding Research by a Ph.D. Student
- 1996 IEEE First Place Graduate Technical Paper Contest (Ft. Worth Sec) IEEE Region 5 cash award
- 1996 National Research Council Associateship Award at NASA/LaRC
- 1994 University of Texas at Arlington's ACM Programming Contest Team Coach
- 1993 Runners-Up Best Paper at the Fourth Int'l Conf. on Applications of Software Measurement
- 1993-95 NASA Graduate Student Researchers Fellowship Recipient at LaRC
- 1993-95 Member of UTA's Autonomous Aerial Vehicle team for the Aerial Robotics Competition
- 1992 Scholarship for 2 week NATO ASI on Real-time Computing (St. Maarten NL Antilles)
- 1992 Theme Article for *IEEE Software* special issue on Applications of Software Reliability Models
- 1988 Member of Upsilon Pi Epsilon honor society in the computing sciences
- 1986 Member of Tau Beta Pi international engineering honor society

REFEREED JOURNAL ARTICLES

Sheldon, F.T., Kim, H.Y. and Zhou, Z, "Specification and Analysis of a Real Time Schedule for an Embedded Spaceborn System," Submitted *IEEE Mirro (Spec. Issue on* Embedded Fault-Tolerant Systems) December 2000.

Sheldon, F.T. and Greiner, S.A., "Composing, Analyzing and Validating Software Models to Assess the Performability of Competing Design Candidates," *Annals of Software Engineering –Special Volume on Software Reliability, Testing and Maturity*, Vol. 8, 49 pages, 1999.

Kavi, K.M., **Sheldon, F.T.** and Reed, S.C., "Specification and Analysis of Real-Time Systems Using CSP and Petri Nets," *Int'l Journal of Software Engineering and Knowledge Engineering –Special Issue on Software Engineering Practices and Tools for Real-Time Systems*, 24 Refs., June 1996.

Sheldon, F.T., Kavi, K.M., Everett, W.W., Brettschneider, R., Yu, J.T., and Tausworthe, R.C., "Reliability Measurement: From Theory to Practice," *IEEE Software - Special Issue on Applications of Software Reliability Models*, pp. 13-20, 10 Refs., July 1992.

REFEREED PROCEEDINGS (selected)

Sheldon, F.T. and Kim, H.Y., "Software Requirements Specification and Analysis Using Zed and Statecharts," Submitted [Oct. '00] *Proc. Fundamental Approaches to Software Engineering (in European Joint Conferences on Theory and Practice of Software [ETAPS 2001])*, Genova Italy, Apr. 2-6, 2001.

Sheldon, F.T. and Kim, H.Y., "Hybrid Approach to System Level Validation and Component Verification for Reactive Systems," Submitted [Oct. '00] *ACM Proc. Sigmetrics*, Cambridge, MA, June 17-20, 2001.

Sheldon, F.T. Greiner, S.A., and Benzinger, M., "Specification, Safety and Reliability Analysis Using Stochastic Petri Net Models," *ACM Proc. Tenth Int'l Wkshp on Software Specification and Design*, pp. 123-132 Nov. 5-7 2000.

Sheldon, F.T. "Analysis of Real-Time Concurrent Systems Models Based on CSP Using Stochastic Petri Nets," *SCS Proc. 12th European Simulation Multiconference*, pp. 776-783, 22 Refs., June 16-19, 1998.

Sheldon, F.T., "Specification and Analysis of Stochastic Properties for Concurrent Systems Expressed Using CSP," Ph.D. Dissertation, *Computer Science and Engineering Dept., Univ. of TX at Arlington*, 260 Refs., May, 1996 (Sigma Xi Scientific Research Society Outstanding Ph.D. Dissertation Award).

Kavi, K.M., and **Sheldon, F.T.**, "Specification and Analysis of Real-Time Systems Using CSP and Petri Nets," *IIT Proceedings 1st Conf. on Fault-Tolerant Systems (FTS'95)*, Madras, India, Dec. 20-22, 1995.

Sheldon, F.T., and Kavi, K.M., "Linking Software Failure Behavior to Specification Characteristics II," *IEEE Proc. Fourth Int'l Wkshp on Evaluation Techniques for Dependable Systems*, San Antonio, 27 Refs., Oct. 1995.

Sheldon, F.T., Mei, Hsing, and Yang, S.M., "Reliability Prediction of Distributed Embedded Fault-Tolerant Systems," *IEEE Proc. 4th Int'l Symp. on Software Reliability Engineering*, pp. 92-102, 27 Refs., Nov. 1993.

AWARDED PROPOSALS (selected)

Brake-Safe, *Proposal to Daimler-Benz AG*, Model-based Specification and Analysis (safety and reliability) Using CSP and Stochastic Petri Nets, (PI: **F.T. Sheldon**: $10,850 requested, $10,850 awarded) Dec. 1998.

Technical Distance Learning Courseware, *Proposal to the Changing the Learning Paradigm through Technology Initiative (Source: Univ. of Colorado's Office of the President)*, (PIs: J. Alspector, **F.T. Sheldon** and J. Haefner: $15,500 requested, $11,100 awarded) Mar. 1998.

A Novel Approach to Model Based Validation of Fault Tolerant Systems: *DARPA SBIR Proposal*, (PI: F.T. Sheldon: $99,000 awarded) September 1996.

GIMADS (Task 29) Defining a Generic Integrated Diagnostics Software Development Process (PI: **F.T. Sheldon** $2.1M Awarded, *General Dynamics FWD* 1992).

ITEM C: Collaborators:
Alspector, Joshua, and Haefner, Jeremy, Univ. of Colorado at Colorado Springs
Bolch, Gunter, Univ. of Erlangen and Greiner, Stefan, DaimlerChrysler
Boyd, Mark and Lowry, Michael NASA ARC
Jones, Robert L. III, and Young, Steve D., NASA LaRC
Everette, William W., Software Process & Reliability Engineering

ITEM D:
Bill Zhou – PhD: OpenDUO: An Open Toolkit for Characterizing Logical and Stochastic Props. (TBD)
Shuren Wang – MS: PCX A Tool for Translating PROMELA Specified Models into SPNs (Sum01)
Hye Yeon Kim – MS: Case Study: Specification/Analysis of a Reactive Fault-Tolerant Sys (Fall01)
D. Dugan – MS: SPNs and DES: A Comparative Study of Two Formal Description Methods (Fall01)
Wen Wei – MS: The CSPL Graphic Editor: Impl. of Graph Layout Algs. and CSPL Parser (Spr01)
Stefan Greiner – PhD: Univ. of Erlangen, Germany, SW Performance Modeling (Wtr00) -Co-advisor
Charles Rodacker – MS: Translation of Promela Specified Models into Stochastic Petri Nets (Wtr99)
Norb Gravelle – MS: Petri Net Graphical Editor for C-Based Stochastic Petri net Lang. (CSPL) (Spr98)
David Owens – MS: Design for Data Integrity for a Distributed Database System (Spr98)

ITEM E: Graduate advisors: Krishna M. Kavi (UAH), and Bill D. Carroll (UTA)
Postdoctoral advisor: Dave E. Eckhardt, Jr. (NASA LaRC)

SUMMARY PROPOSAL BUDGET

YEAR 1

ORGANIZATION **Washington State University**				FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Frederick T Sheldon**				AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Frederick T Sheldon - Dr.	0.00	0.00	2.00	$ 16,178	$
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	2.00	16,178	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (1) GRADUATE STUDENTS				15,734	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				31,912	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				11,858	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				43,770	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) Computers $ 5,000					
TOTAL EQUIPMENT				5,000	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				2,500	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				2,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				0	
TOTAL OTHER DIRECT COSTS				2,000	
H. TOTAL DIRECT COSTS (A THROUGH G)				53,270	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) MTDC (Rate: 45.0000, Base: 42077)					
TOTAL INDIRECT COSTS (F&A)				18,935	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				72,205	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 72,205	$
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $				

PI / PD TYPED NAME & SIGNATURE* Frederick T Sheldon	DATE	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date Of Rate Sheet	Initials - ORG

SUMMARY PROPOSAL BUDGET

YEAR 2

ORGANIZATION **Washington State University**				FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Frederick T Sheldon**				AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Frederick T Sheldon - Dr.	0.00	0.00	2.00	$ 16,825	$
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	2.00	16,825	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (1) GRADUATE STUDENTS				16,363	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				33,188	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				12,394	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				45,582	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				2,500	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				2,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				0	
TOTAL OTHER DIRECT COSTS				2,000	
H. TOTAL DIRECT COSTS (A THROUGH G)				50,082	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **MTDC (Rate: 45.0000, Base: 43579)**					
TOTAL INDIRECT COSTS (F&A)				19,611	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				69,693	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 69,693	$
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $				

PI / PD TYPED NAME & SIGNATURE* **Frederick T Sheldon**	DATE	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date Of Rate Sheet	Initials - ORG

SUMMARY PROPOSAL BUDGET

YEAR 3

ORGANIZATION **Washington State University**				FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Frederick T Sheldon**				AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Frederick T Sheldon - Dr.	0.00	0.00	2.00	$ 17,498	$
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	2.00	17,498	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (1) GRADUATE STUDENTS				17,018	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				34,516	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				12,954	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				47,470	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				2,500	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				2,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				0	
TOTAL OTHER DIRECT COSTS				2,000	
H. TOTAL DIRECT COSTS (A THROUGH G)				51,970	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **MTDC (Rate: 45.0000, Base: 45142)**					
TOTAL INDIRECT COSTS (F&A)				20,314	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				72,284	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 72,284	$
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $				

PI / PD TYPED NAME & SIGNATURE* **Frederick T Sheldon**	DATE	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date Of Rate Sheet	Initials - ORG

SUMMARY PROPOSAL BUDGET

Cumulative

ORGANIZATION **Washington State University**				FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Frederick T Sheldon**				AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Frederick T Sheldon - Dr.	0.00	0.00	6.00	$ 50,501	$
2.					
3.					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	6.00	50,501	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (3) GRADUATE STUDENTS				49,115	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				99,616	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				37,206	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				136,822	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) $ 5,000					
TOTAL EQUIPMENT				5,000	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				7,500	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				6,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				0	
TOTAL OTHER DIRECT COSTS				6,000	
H. TOTAL DIRECT COSTS (A THROUGH G)				155,322	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				58,860	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				214,182	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 214,182	$
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $				

PI / PD TYPED NAME & SIGNATURE* **Frederick T Sheldon**	DATE	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date Of Rate Sheet	Initials - ORG

Budget Justification

Frederick T. Sheldon

Year 1:

A. 2.0 months PI summer salary

B. Yearly salary for one graduate research assistant (GRA)

C. Standard fringe benefits:
- PI Salary @ 26%
- GRA med aid @ 1.5%, GRA health and GRA qualified tuition reduction

D. Permanent equipment:
- 1 PC (Pentium III 256MB 30GB, 19" monitor)
- 1 Software tool set (see page 2 of justification)
- 1 extra SW tool set for the PI's office machine [Sun Ultra10]

E. Travel: One week NASA Langley Research Center (Hamptom, VA in Spring)

F. Participant Support Costs: None

G. Other Direct Costs:
- Materials and supply expenses associated with 2 computers

I. Indirect costs at 45% MTDC

K. Total amount requested for year 1: $72,205

M. Cost sharing: None other than office space and network connections

Year 2:

A. 2.0 months PI summer salary

B. Yearly salary for one graduate research assistant (GRA)

C. Standard fringe benefits:
- PI Salary @ 26%
- GRA med aid @ 1.5%, GRA health and GRA qualified tuition reduction

D. Permanent equipment:
- 1 Server class workstation (Ultra10 256MB 12GB, 19" monitor)
- 1 Standard workstation added to the compliment of EECS Dept. supplied machines
- 1 complete software tool set(s) for the
- Additional software tool subsets to be installed on classroom laboratory machines

E. Travel: One week NASA Langley Research Center (Hamptom, VA in Spring)

F. Participant Support Costs: None

G. Other Direct Costs:
- Materials and supply expenses associated with 2 computers

I. Indirect costs at 45% MTDC

K. Total amount requested for year 2: $69,693

M. Cost sharing: None other than office space and network connections

Year 3:

A. 2.0 months PI summer salary and one-half course offload during academic year

B. Yearly salary for one graduate research assistant (GRA)

C. Standard fringe benefits:
- PI Salary @ 26%
- GRA med aid @ 1.5%, GRA health and GRA qualified tuition reduction

D. Permanent equipment:
- 2 Standard workstation added to the compliment of EECS Dept. supplied machines

- Additional software tool subsets to be installed on classroom laboratory machines

E. Travel: One week NASA Langley Research Center (Hamptom, VA in Spring)

F. Participant Support Costs: None

G. Other Direct Costs:

- Materials and supply expenses

I. Indirect costs at 45% MTDC

K. Total amount requested for year 3: $72,284

M. Cost sharing: None other than office space and network connections

GRA:

Setup, maintenance, experimentation and reporting. Also, 20% will be dedicated to supporting classroom laboratory activities. WSU waives tuition and fees.

Computer Hardware/Software:

PC will be needed to host common development tools (e.g., Visual Studio). PI has 2 Unix workstations that will be used the first two years for evaluating various software tools (SESworkbench, Statemate, SPIN, SPNP, etc.). Actually, many of the tools are only available to run on a UNIX platform. Hence, the plan will be to develop a laboratory of Unix based platforms running the software engineering toolkit environment. PCs will be also used to the greatest extent possible.

Software toolset composition (approximate):

1 SESworkbench
2 iSPNP (Visual Stochastic Petri Net Package)/ SMART
3 Sun Scholar Pack + JDK 1.2
4 Statemate Magnum (from Ilogix)
5 Rapsody (from Ilogix)
6 MS Visual Studio
7 Metrowerks Codewarrior
8 Test Center/Purify
9 MS Office
10 Adobe Acrobat
11 Various free tools (e.g., UltraSan, DSPNExpress, etc.)

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Frederick Sheldon**

Other agencies (including NSF) to which this proposal has been/will be submitted.
NASA LaRC

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: **None**

Source of Support:
Total Award Amount: $ **0** Total Award Period Covered: **01/01/00 - 01/01/00**
Location of Project:
Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **0.00**

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Facilities, Equipment and Other Resources

Frederick T. Sheldon, NSF 00-126

Laboratory:
Facilities will be provided by Washington State University, School of EECS located in the Electrical and Mechanical Engineering Building.

Clinical: Not Applicable

Animal: Not Applicable

Computer:
Year 1: One powerful PC, one sever class workstation and one standard workstation (PI currently has the a standard). Also, three copies of software tool sets described in the project description and budget justification).
Year 2-5: 2 additional standard workstations per year (8 total) including the requsite software tool sets.

Office:
PI's office is located in the Electrical and Mechanical Engineering Building.

Other:

Major Equipment:
Currently, there is one Sun/Solaris Ultra1 with minimal software available and is located in the PI's office. There is also a Powerbook G3 400Mhz loaded with professional development tools and business solutions.

Other Resources:
Computer systems support provided by WSU, EECS.

SUPPLEMENTARY DOCS

None