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Software engineering: the mandatory connection between deterministic and probabilistic engineering

Ingeniería de software: la conexión obligatoria entre la ingeniería determinista y la probabilista

MÁRQUEZ-DOMÍNGUEZ, Sergio†´, CARPIO-SANTAMARÍA, Franco Antonio´, GONZÁLEZ-LÓPEZ, Gloria Inés´´ and ZAMORA-HERNÁNDEZ, Abigail´*

´Universidad Veracruzana, Institute of Engineering Veracruz-Boca del Río región, Mexico.
´´Universidad Veracruzana, Faculty of Chemical Sciences Orizaba-Córdoba region, Mexico.

ID 1st Author: *Sergio, Márquez-Domínguez* / **ORC ID:** 0000-0002-4864-3238, **SNI CONACYT ID:** 166987

ID 1st Co-author: *Franco Antonio, Carpio-Santamaría* / **ORC ID:** 0000-0003-3383-1858, **SNI CONACYT ID:** 543314

ID 2nd Co-author: *Gloria Inés, González-López* / **ORC ID:** 0000-0002-8763-2128, **SNI CONACYT ID:** 203790

ID 3rd Co-author: *Abigail, Zamora-Hernández* / **ORC ID:** 0000-0002-2046-3104, **SNI CONACYT ID:** 277195

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Abstract

This article analyzes 13 specialized applications in structural reliability, which show the determining role of Software Engineering in the evolution of Deterministic Engineering toward Probabilistic Engineering. This transition involves stochastic analysis in decision-making based on risks and structural security, focused on reducing the gap generated by the cost-benefit binomial. Deterministic engineering bases decision-making on rigid results without considering the randomness and risks involved in the environment; Probabilistic Engineering addresses them through stochastic models, to achieve optimal designs that integrate uncertainty and its impact over time. The applications, that were analyzed, are specialized in risk prediction, decision-making, and structural reliability, considering factors such as: academic impact, type of software license (commercial or free), its applicability and focus, country of origin, release date, access type, code, platform (operating systems), and implementation language. The results show the technological dependence of our country on foreign countries concerning this type of applications.

Probabilistic engineering, Structural reliability, Risk

Resumen

Este artículo analiza 13 aplicaciones especializadas en confiabilidad estructural, que muestran el rol determinante de la Ingeniería de Software en la evolución de la Ingeniería Determinista hacia la Ingeniería Probabilista. Esta transición involucra el análisis estocástico en la toma de decisiones basada en riesgos y seguridad estructural, enfocada en reducir la brecha generada por el binomio costo-beneficio. La ingeniería determinista basa la toma de decisiones en resultados rígidos sin considerar la aleatoriedad y riesgos envueltos en el entorno; la Ingeniería probabilista los aborda a través de modelos estocásticos, con la finalidad de lograr diseños óptimos que integren la incertidumbre y su impacto a lo largo del tiempo. Las aplicaciones que fueron analizadas en este trabajo se especializan en la predicción de riesgos, toma de decisiones y confiabilidad estructural, considerando factores como: impacto académico, tipo de licencia del software (comercial o libre), su aplicabilidad y enfoque, país de origen, fecha de lanzamiento, tipo de acceso, código, plataforma (sistemas operativos) y lenguaje de implementación. Los resultados muestran la dependencia tecnológica de México en este tipo de aplicaciones.

Ingeniería probabilista, Confiabilidad estructural, Riesgo

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* Author's Correspondence (E-mail: abzamora@uv.mx)
† Contributing researcher as first author.

Introduction

Until a few years ago, civil construction applied codes and design standards that were configured according to Traditional (Deterministic) Engineering, which overvalues the experience of constructors and designers. This article glimpses Software Engineering as the determining factor in the transition from a rigorous Engineering of invariant results towards Probabilistic Engineering, which involves stochastic analysis for risk-based decision making, and structural safety, as well as the binomial cost-benefit. Deterministic engineering bases its decisions on rigid results, without considering the uncertainties (randomness) and risks involved in the environment, but they are considered by Probabilistic Engineering through stochastic models, to achieve optimal designs that integrate uncertainty and its impact over time. These analyses demand computational resources that when they exponentially evolved, triggered new user needs, that require complex and sophisticated systems, with user-friendly graphical interfaces, and compatibility between different types of file and data systems.

The design of modern structures requires a clear understanding of the natural environment involving uncertainty and risk. These factors directly influence the appreciation of engineers, which usually focuses on Structural Reliability, which inevitably implies including randomness in the design. In the 17th century Blaise Pascal and Pierre de Fermat, French mathematicians, formulated the theory of probability considering gambling as mathematical problems.

An ancient origin considers Gerolamo Cardano, an Italian Renaissance mathematician of the 16^{th} century, as a pioneer of probabilistic theory for his systematic analysis of game problems, which establishes an interesting reference framework for state-of-the-art reliability that originated until XIX. In it, reliability is defined as a tool developed by insurance companies for life maritime insures, to calculate insurance rates, correlated with the prediction of death probability or risks that their clients are subject to (Choi et al., 2007). The probabilistic theory as a mathematical tool to quantify structural safety emerged in the 20th century thanks to Mayer, Streletzki, and Wierbicki. In the 50s, Freudenthal reuses it but finds it difficult to apply it due to the lack of computers and Software Engineering.

In 1961, reliability is recognized as a discipline because of the work done by Birnbaus, Esary, and Saunders. In 1969, Cornell proposed a reliability index through the second-moment method. Benjamin and Cornell (1970) state that structural engineering allows the engineer to develop decision-making skills. In 1974, Hasofer and Lind formulated the First Order Reliability Method (FORM). In 1978, Rackwitz and Fiessler proposed an efficient numerical method to calculate the reliability index.

In the 1980s, reliability methods reached maturity, becoming available for different applications in various engineering areas, such as aeronautical, offshore, oil, naval, mechanical, electrical, and civil engineering, among others. Smith (2005) approaches the relevance of reliability prediction due to computational tools development, which in the 1980s had an exponential development, establishing collaboration between Software Engineering and Structural Reliability, joined to risks prediction.

This stage launched several contributions of prominent researchers in the probabilistic engineering area, highlighting Madsen and Thoft-Christensen in Madsen (1986), Thoft-Christensen & Baker (1982), and Thoft-Christensen & Murotsu (1986). In Mexico, Emilio Rosenblueth and Luis Esteva Maraboto (Esteva, 2022; Rosenblueth, 2022) are the main referents of Probabilistic Engineering and Structural Reliability.

Specialized software

Pellissetti and Schuëller (2006), and so in El Hajj Chehade and Younes (2022), offer a complete study of the state of the art of software development for solving problems oriented related to structural reliability is addressed. Melchers (1999) mentions some computer programs available for the estimation of Structural Reliability highlighting CALREL, ISPUD/COSSAN, NESSUS, PROBAN, and STRUREL.

This document studies 13 representative specialized programs in risk prediction, decision-making and structural reliability, analyzing several characteristics such as their academic impact and cost, launch date, country of origin, platform architecture, operating system, programming language, and orientation.

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As mentioned in Zamora *et al.*, (2022), the software technological dependence in Mexico, represents a great opportunity for the creation of national products through interdisciplinary collaboration.

CalREL

CalREL is a pure structural reliability analysis program designed to function as a standalone or as an operating system interface alongside other structural analysis programs. It was written in FORTRAN 77 in the early 1980s at UC Berkeley for teaching, research, and engineering practice. This code was meant to evolve continually, but it does not offer sophisticated user interfaces typical of commercial software. It served as a model for the development of FERUM and OpenSees (Der Kiureghian *et al*., 2006).

The software is currently offered free of charge at the UC Berkeley Simcenter, but there is no guarantee of its functionality (Govindjee, 2022). CalREL incorporates several methods and algorithms for the analysis of reliability components and structural systems, highlighting the First Order Reliability Methods (FORM) and Second Order (SORM), sensitivity analysis, directional simulation, and Monte Carlo Simulation (MCS) (Der Kiureghian, 2022) (Der Kiureghian *et al*., 2006). CalREL's fusion with application programs for specific nonlinear mechanics problems allows it to interact with Finite Element codes, specifically with FEAP (Finite Element Analysis Program). CalRel operates in Windows and UNIX environments (SSC-398A, 2022).

COSSAN

Schuëller (2022) mentions that ISPUD code "Importance Sampling Procedure using Design Points" is the basis for the development of COSSAN (COmputational Stochastic Structural ANalysis), created in 1986 and based on an easy-to-use command interpreter denoted such as SLANG (Structural Language), which links its methods with third-party packages, specialized in finite elements, for the development of codes focused on solving specific problems in structural reliability (COSSAN, 2022).

It has a modular structure with object-oriented data handling. ISPUD is a multipurpose software package, based on the use of search-by-importance or adaptive sampling, with explicit or implicit limit state function as response surface, time-dependent problems are handled by an extreme value approach. ISPUD estimates the probability of failure by integrating the joint probability density function using numerical procedures, such as Monte Carlo Simulation, and particularly significance sampling around design points.

COSSAN employs third-party finite element codes and a surface response methodology, along with advanced Monte Carlo Simulation methods, such as search-by-importance or adaptive sampling methods, all of them integrated into a COSSAN programming Language Interpretation Package (Melchers, 1999). In 1990, COSSAN rapidly evolved to beta versions named COSSAN-A and COSSAN-B (Patelli, 2017).

COSSAN-A is designed as an open system, easily adjustable and expandable to include new computational tasks. Each problem solution was broken down into a set of specific commands, each of which performed a uniquely defined computational task, called a module. COSSAN-B makes possible the implementation of communication tools focused on platforms specialized in structural analysis, through finite element theory merging with stochastic analysis, applying third-party finite element codes. As of 2006, the software evolves to COSSAN-X, a dynamic version in constant development that capitalizes on advanced communication between third-party commercial programs (ABAQUS, ANSYS and NASTRAN), adding a programming language interpretation package, to accomplish a general-purpose software capable of solving a series of different problems, becoming a multidisciplinary software that satisfies the industry requirements in terms of numerical efficiency and detailed model analysis. COSSAN-X provides a friendly user interface developed in Eclipse RCP, available for operating systems such as Windows, Linux and MacOSX. Probabilistic method routines can be programmed in environments such as PERL, Matlab or C++ (COSSAN, 2022).

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The current version of the software is hosted on the Risk and Uncertainty Institute at the University of Liverpool, UK, led by Edoardo Patelli; since 2012 an open-source version of COSSAN-X is available, called OpenCossan developed in a Matlab environment. The program currently covers a wide field of applications ranging from uncertainty quantification, Meta-Modelling, Reliability-Based Optimization, fracture and damage analysis, random vibration, system identification, deterministic and stochastic Finite Element Analysis, and Monte Carlo Simulation (Schuëller and Pradlwarter, 2022).

FERUM

FERUM (Finite Element Reliability Using Matlab), originated in 1999 at the University of California at Berkeley, mainly for academic and research purposes to implement structural reliability methods and stochastic finite elements. The project was started by Armen Der Kiureghian (Der Kiureghian, 2022) and updated by Terje Haukaas, being an open-source program until 2003. FERUM is a collection of Matlab functions used to perform reliability analysis along with simple finite element models, as well as reliability analysis for prescribed limit-state analytic functions. FERUM serves as the basis for larger and more powerful codes such as OpenSees.

An improved version was developed by Professor Jean-Marc Bourinet and his colleagues at the Universite d'Auvergne Clermont, specifically at the Institut Français de Mécanique Avancée (IFMA) in Clermont-Ferrand, France. FERUM 4.1 (the latest version), is still freely available and works in synergy with Matlab (Toolbox), keeping most of the programmed methods such as FORM, SORM, raw Monte Carlo, and sampling by importance, in addition to implementing new techniques based on simulation, such as directional simulation and subset simulation; addresses global sensitivity analysis based on Sobol indexes and design optimization based on reliability (SIGMA Clermont, 2022).

NESSUS

NESSUS (Numerical Evaluation of Stochastic Structures Under Stress) is a general-purpose tool that allows linking traditional and advanced probabilistic algorithms with analytical equations, also using external computer programs including commercial finite element codes (ABAQUS, ANSYS, NASTRAN, NASA_GRC_FEM, PRONTO), and to create general combinations of both. Eleven probabilistic algorithms and 15 probability distribution models are available, including non-parametric modeling, via kernel density estimation, in addition to traditional methods such as Monte Carlo Simulation and the First and Second Order Reliability Methods (FORM/SORM), and some other sampling methods such as that of mean value and for adaptive importance (Riha *et al.*, 2022). It was initially developed by a team led by the SwRI (Southwest Research Institute, San Antonio, Texas) for the National Aeronautics and Space Administration or NASA (National Aeronautics and Space Administration). It is available for Windows 10 and Linux operating systems (CENTAUR, 2022).

NESSUS defines random variables and many reliability algorithms through the CENTAUR (Collection of ENgineering Tools for Analyzing Uncertainty and Reliability) package. CENTAUR is defined as a software library that contains an important variety of methods for reliability analysis, distribution adjustment, uncertainty quantification, and numerical optimization, among others. SwRI has used CENTAUR to develop custom software tools and solutions using: FORTRAN, C/C++, MATLAB, Python, and Microsoft Excel (CENTAUR, 2022).

OpenSees

OpenSees (Open System for Earthquake Engineering Simulation) is an open-source system for earthquake engineering simulation, developed by researchers at the PEER (Pacific Earthquake Engineering) research center (OpenSees, 2022). It implements the nonlinear finite element technique through modules for sensitivity analysis, uncertainty propagation, reliability evaluation, and determination of measures of variable importance.

The program code in C++ on an object-oriented architecture is able of performing Direct Differentiation Method (DDM) sensitivity analysis, First Order Second Moment Method (FOSM) uncertainty propagation analysis, as well as reliability analysis by the First Order Reliability Method (FORM), significance sampling, and Monte Carlo Simulation (Der Kiureghian, 2022).

OpenSees is a software framework that allows to implementation of computer applications: it works as a collection of activated components, using the Tcl (Telephone Communication Limited) coding language, an interface that allows for the creation of modeling components and adding analysis tools. Tcl supports multiple programming paradigms, including object-oriented, commonly used with applications developed in C. Before entering any of the commands, the “reliability” module must be activated, which “plugs in” the reliability and sensitivity commands by loading them into the interpreter or Tcl code (Der Kiureghian *et al.*, 2006). OpenSees enable the integration of models to investigate soil-structure-foundation interaction. In addition to improved models for reinforced concrete structures, shallow and deep foundations, and liquefiable soils, OpenSees is designed to take advantage of the latest developments in databases, reliability methods, scientific visualization, and high-level computing (PEER Center, 2022).

OpenTURNS

It is the result of a proposal from four companies, EDF R&D, Airbus Group, and Phimeca Engineering in a collaboration at the beginning of 2005; IMACS is incorporated in 2014 to define itself as OpenTurns *“Open source Treatment of Uncertainty, Risk 'N Statistic”* (OpenTURNS, 2022). It is open-source software under LGPL license, which is presented as a C++ library and a Python GUI, it works under Linux and Windows environments. The initiative had the firm objective of making an open access code that would address reliability issues, such as: FORM and SORM approximation methods, Monte Carlo Simulation, Quasi-Monte Carlo, Importance Simulation, Directional and Latin Hypercube, and some others (Baudin *et al.*, 2017).

PHIMECA-SOFT

The development of this software is achieved in the French Institute of Advanced Mechanics and the PHIMECA engineering company which develops the commercial version. For 25 years, the Clermont-Ferrand scientific team has researched both the field of structural materials engineering and probabilistic methods. Therefore, it is important to know the evolution from RYFES to PHIMECA. RYFES *(Reliability with Your Finite Element Software),* is software made by Mohamed and Suau in 1996 within an academic context. With experience and knowledge of several years, they built the software core, which later became a commercial project through a university-industry partnership, resulting in the PHIMECA-SOFT project in 2002 (Lemaire and Pendola, 2006).

PHIMECA-SOFT runs on the Microsoft Windows platform (2000 and higher) with a graphical user interface and Linux without the graphical interface and employing macro commands. The software architecture is based on high modularity, only object-oriented programming procedures in C++: for physical and probabilistic models, limit state formulation and analysis options. Its syntax is based on the language FORTRAN. The user builds his program in any type of programming environment (C++, FORTRAN, etc.) and compiles it into a library (for example, into a .dll file in the Windows environment). The program offers communication with finite element software for which a special interface has been created: ANSYS, ABAQUS, CODE_ASTER, CASTEM, ZEBULON, I-DEAS, SAMCEF. PHIMECA-SOFT has 22 density functions and is based on numerical methods such as FORM/SORM. Simulations can even be performed by choosing between crude Monte Carlo or conditional Monte Carlo (Lemaire and Pendola, 2006).

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ProbAn

The Probability Analysis software (Probability Analisys), created in Norway by Det Norske Veritas (DNV, 2022) at late 1980s, complements the hydrodynamic and structural analysis functions and is part of the powerful Sesam suite of programs for marine and offshore engineering analysis. It has a graphical user interface and can receive Finite Element codes from third parties, allowing the user to encode their own functions in FORTRAN to estimate reliability at both component and system levels. In Sesam (2022), it is mentioned that the latest version (5.1-01) has been updated to Intel FORTRAN 11, with compatibility on the Windows platform (Tvedt, 2006).

ProbAn implements several methods such as FORM, SORM, adaptive response surface, nested reliability analysis, and simulations such as Monte-Carlo (adjusted), stratified, directional, design point, orthogonal axis, and Latin hypercube. It also offers a graphical user interface that maintains models in a database, recording commands in a work file for possible rereading, and displays, plots, and prints the model and results (Tvedt, 2006).

ProFES

ProFES *(Probabilistic Function Evaluation System)* is a system that enables designers to perform probabilistic Finite Element Analysis (FEA) in a completely familiar 3D graphical environment, similar to modern deterministic FEA. ProFES is based on an innovative software architecture that seamlessly integrates state-of-the-art probabilistic mechanics techniques with commercial CAD and CAE software to make practical and feasible all probabilistic analyzes of complex structural components. Thus, engineers may use powerful probabilistic techniques to solve challenging problems such as probabilistic High Cycle Fatigue (HCF) analysis, with no need for extensive training in probabilistic mechanics techniques. Industry partners which participated in the development of ProFES are GE, Pratt & Whitney, Allison Engine, General Motors, and commercial FEA providers ANSYS and MSC/NASTRAN (Cesare & Sues, 1999).

ProFES offers a set of standard probabilistic methods including First-Order Reliability (FORM) and Second-Order Reliability (SORM), First-Order Second-Moment Method (FOSM), Monte Carlo, and Significance Sampling (Wu *et al.*, 2022. It is designed to facilitate the fast development of probabilistic models from existing deterministic models. Its graphical user interface (GUI) allows you to build probabilistic models by examining finite element (FE) models and specifying and defining random variables, response functions, limit states, analysis methods, etc. (Wu and Shin, 2022). El Hajj Chehade & Younes (2022), mention that ProFES is disabled from the network.

Rt

Rt which stands for "Risk Tools" abbreviation is a free software implemented with the object-oriented programming language C++. Rtx, a derivative of Rt, is developed at the Infrastructure Resilience and Sustainability Research Center (INSURER), at the Sharif University of Technology, under the supervision of Mojtaba Mahsuli. Rt was developed in 2012, during Mojtaba Mahsuli's doctoral studies at the University of British Columbia, Vancouver, Canada, under the supervision of Professor Terje Haukaas (Mahsuli, 2012). The development of Rt is now carried out both at the Sharif University of Technology under the name Rtx, and at the University of British Columbia by Professor Terje Haukaas under the name Rts. (Mahsuli & Haukaas, 2013).

Rtx is a free program available for Windows, Linux and Mac with an easy-to-use native interface for reliability, risk, and resiliency analysis with a library of probabilistic models. It has as goal to promote advanced probabilistic analysis in the engineering community. It is able to perform structural reliability analysis, hazard and risk analysis, community resilience analysis, importance, and sensitivity analysis, as well as design optimization (Nasrazadani and Mahsuli, 2020). Rtx performs probabilistic analyzes using other software applications, such as: ABAQUS, SAP2000, ANSYS, Matlab, EME and USFOS (UBC, 2022).

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STRUREL

Programs for the analysis of the reliability of structures (Structure Reliability Analysis Programs) have specialized programs to determine the reliability of individual component levels, as a system or set of elements. The project started in 1976 at Technical University of Munich; in 1987, it was managed by RCP Consult GmbH (Reliability Consulting Programs Gesellschaft mit beschränkter Haftung (RCP & ERACONS, 2022). ERACONS GmbH is a consulting company that works in probabilistic modeling, risk analysis, reliability analysis, and data analysis. This company was founded in 2013 by Daniel Straub and Dr. Iason Papaioannou, as a by-product of the Technical University of Munich (Eracons, 2022). The complete collection of programs for Strurel probabilistic modeling is described below.

The purpose of Comrel-TV and Comrel-TI is for the reliability analysis of components whose characteristics may vary or not over time, they estimate the failure probability of individual components through specialized methods such as FORM and SORM, implementing several algorithms to determine the probability of failure, including a free gradient algorithm for non-differentiable failure criteria. It has complementary options such as the Mean Value First Order Method (MVFO: Mean Value First Order), Monte Carlo Simulation, adaptive sampling, spherical sampling, and several importance samplings schemes (RCP, 2022).

Sysrel specializes in system modeling that includes the representation of parallel or serial systems, and the case of conditional events (RCP, 2022).

Costrel optimizes the performance (cost, weight, volume) under a reliability constraint, as well as a performance constraint (RCP, 2022).

Statrel is a useful tool for statistical data analysis that offers 44 models in the present day, its menus are designed to perform basic descriptive statistics with many graphical functions, such as histograms, cumulative frequencies, bivariate graphs, bar graphs, and probability plots (RCP, 2022).

Permas-RA is a powerful finite element program coupled to Comrel and Costrel, that includes nonlinear analysis and access to non-differentiable state functions via response surfaces (Gollwitzer *et al.*, 2006). All Strurel modules are genuine 32-bit Windows applications, compatible with Windows 9x or Windows Me, Windows NT-4, Windows 2000, and Windows XP. It has a powerful online scripting language that allows entering analytic expressions directly by means of the GUI. Educational versions of Comrel-TI and Sysrel are available for students. The computational cores of the professional versions of Comrel, Costrel, and Sysrel are compiled into object libraries, but by default, these libraries are packaged for Compaq Visual FORTRAN 32-bit compiler v. 6.x, and some other compilers (RCP, 2022).

SAPHIRE

In 1992, the US Nuclear Regulatory Commission (NRC) created and sponsored IRRAS *(Integrated Reliability and Risk Analysis System)* (Russell *et al.*, 2022), now SAPHIRE *(Systems Analysis Program for Hands-On Integrated Reliability Evaluations)*, developed in conjunction with the Idaho National Laboratory (INL). This application introduced an innovative way of drawing, editing, and analyzing graphical fault trees, decreasing the magnitude of analysis time. Some of its features are final state analysis, modules focused on fires, floods, and seismic events. In 1997, SAPHIRE for Windows is released with a user interface that eases learning. The new "add-on" feature allows analysts to extend the built-in probability calculations. The use of this program requires a license payment.

The coding languages used were MODULA-2 and Delphi, which simulate recursive procedures by mean of arrays to save parameters passed to the procedure, which SAPHIRE exploit in its environment (Smith & Wood, 2022).

The purpose of SAPHIRE is to create and analyze probabilistic risk assessments (PRA), primarily for nuclear power plants. This development process started in 1987 at the request of NRC; INL participated in software development of user interface and training and technology transference (SAPHIRE, 2022).

UNIPASS

According to Lin & Khalessi (2006), UNIPASS *(UNIfied Probabilistic Assessment Software System)* is a unified probabilistic assessment system developed by PredictionProbe (PredictionProbe, 2022). It is a general proposal probabilistic program with an easy-to-use Graphical User Interface (GUI) which allows defining the limit state function with code with FORTRAN -style syntax (Lin *et al.*, 2001). It can be used on UNIX and Windows 98, 2000, and NT operating systems. It has 23 types of distributions to model four classes of random variables. It includes 59 mathematical functions to model any complex event, and three types of function analysis: Probability Analysis and Inverse Probability Analysis, plus four different problem types, including Component, Serial, Parallel, and General Systems. It can process several probabilistic methods, such as First and Second-Order Reliability Methods (FORM/SORM), simulation, importance sampling, response surface methods, and those methods based on mean values. It offers generic and customized interfaces for easy integration with internal and commercial codes or with MSC/NASTRAN finite element code (Noor, 2022).

Results

Origin country

The analysis shows that countries with the highest production of software applications are: the United States (E.U.) with 40%, France with 20%, Germany, England, and Austria with 10% each, and Norway and Canada with 10% for both. Figure 1 shows the international contributions to this software area, and obviously, the absence of Mexico is evident. The study considers only countries where software development occurs, because some applications were created in one country, but continued in another.

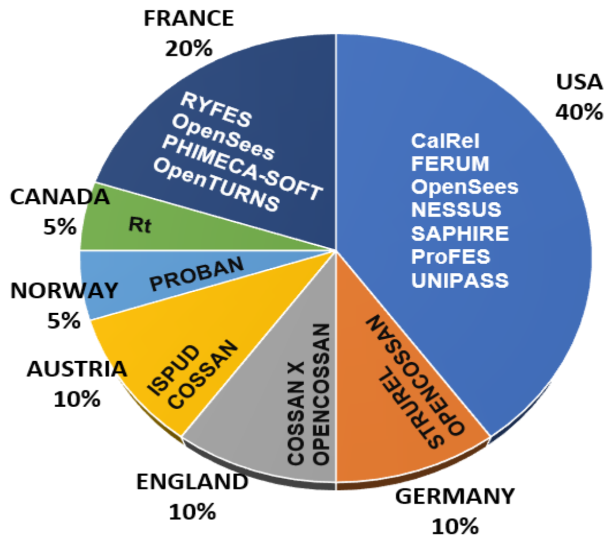

Figure 1 Origin country for reliability software

Release date

Table 1 shows three application characteristics: release date, operating system, and programming language. Strurel in 1976 leads the development of programs for structural reliability and risk, and it is in the 80's that technologies development oriented to risk prediction and reliability estimation increased, due to all favorable conditions to migrate from deterministic to probabilistic engineering.

Software category

Most of the applications were developed for academic purposes, which is why some of them offer free access and use, and allow contributions to improving them. Some of these are: CAlREL, FERUM, OpenSees, OPENCOSSAN, and Rx. An exceptional case is represented by OpenTURNS, despite it being designed for professional use, after the merging of four French companies, they developed it as free access and non-profit program. Of analyzed applications, 38.46% of them are free accessible (freeware) and charge-free. The licensed software category includes those that migrated from the academic to the commercial scope and those designed for commercial purposes that demand a license payment, such as: STRUREL, ISPUD, COSSAN, COSSANX, PROBAN, IRRAS, RYFES, SAPHIRE, NESSSUS, UNIPASS and PHIMECA, which correspond to 61.54% of the total. For this group, only some companies provided technical data and prices of their products, others only do so in case there was a real interest in product purchasing.

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NESSUS offers commercial licenses with costs ranging from $500 USD per year for academic use to $5,000 USD for common use; a perpetual license costs $12,500 USD but its cost increases due to updates and mandatory maintenance (SWRI, 2022). ProbAn costs about $30,000 USD (El Hajj Chehade & Younes, 2022) and it is possible to download version 5.1-01 from Sesam portal; the last ProbAn update was in 2011 and it is available in the 32-bit version for Windows (Sesam, 2022). Strurel cost, as a complete package that includes all its modules, for commercial use is €6,300 and for academic use, it is €3,800. These prices may vary if individual modules or add-ons are purchased (RCP & ERACONS, 2022).

Cost information about COSSAN, COSSANX, ISPUD, IRRAS, RYFES, SAPHIRE, UNIPASS, and PHIMECA, is not available to the public in any information source. This study's results make clear the high acquisition cost for most of the applications oriented to risk prediction, decision making, and structural reliability. This makes evident the prevailing need for developing specialized software in these areas for our country. Even after 40 years of some applications emergence, only those that are free or open source are the competitive alternatives for education, research, and industry.

	Program	Software Release	Operating System	Programming Language
1	STRUREL	1976	Windows	COMPAQ Visual FORTRAN 32 bits v. 6.x
2	CalREL	1989	Windows UNIX	FORTRAN 77
3	NESSUS	1989	Windows 10 Linux	(FORTRAN, MatLab, C/C++ PYTHON, EXCEL)
4	COSSAN	1990	Windows, GNU/Linux Mac OSX	Slang / PERL, MatLab, C++
	OPENCOSSAN	2012	Windows	Toolbox - Matlab
5	PROBAN	1991	Windows	Intel FORTRAN 11
6	OpenSees	1997	Windows	C++ / Tcl
7	SAPHIRE	1997	Windows	MODULA-2 Delphi
8	FERUM	1999	Windows	Toolbox - Matlab
9	ProFES*	1999	Not available	
10	UNIPASS	2001	UNIX Windows	FORTRAN style code
11	PHIMECA-SOFT	2002	Windows	Python code GUI C++, FORTRAN
12	OpenTURNS	2004	Windows Linux	C++ / Python library
13	Rt	2012	Windows Linux MacOSX	C++

Table 1 Application architecture

Operating system and programming language

Table 1 shows the architecture type, operating system, and programming language for the development of software applications.

It is evident personal computers are the most used type because 100% of applications can use Windows environment. Figure 2 shows that there are four applications compatible with Linux operating system (33%), two for the MacOSX environment (17%) and only one shows UNIX compatibility (8%).

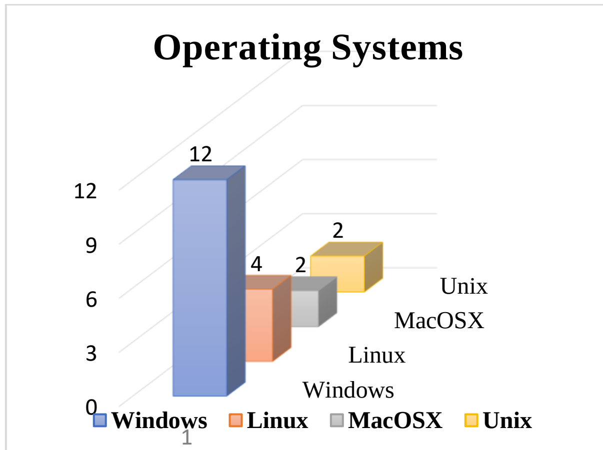

Figure 2 Operating system for applications

Concerning programming language for development, specialists with both probabilistic and stochastic knowledge implemented their algorithms in convenient and available programming languages, such as different FORTRAN versions or C/C++. For modern versions, it was necessary for graphical user interfaces, and more complex modules, which is why some applications incorporated functions or libraries created in other languages such as Matlab, Python, Visual Basic, or PERL. This also shows that it is essential for the intervention of specialist computer teams to fulfill the demands of both processing and software accessibility.

Conclusions

50 years ago, engineers in different areas should propose mathematical solutions to problems they faced, but also develop software programs in programming languages that they barely knew or used.

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The explosive development of computational processing favored that more people were able to use applications, but then they demanded better features, greater potential, superior precision, error reduction, and simplified graphical interfaces. This caused it mandatory for the participation of computer specialists to speed up the development of this type of application. Mexico is highly dependent on software applications for different areas, from other countries and the development of software applications for engineering is an area in which there is much to be done.

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