Vilnius University
Institute of Data Science and Digital Technologies
L I E T U V A

INFORMATICS (N009)

RESEARCH ON SIMULATION-BASED MULTI-OBJECTIVE BUSINESS PROCESS OPTIMIZATION METHODS USING EVOLUTIONARY INTELLIGENCE

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Abstract

Business process optimization (BPO) is the focus of all successful business companies. Various simulation optimization methods, which is understood as simulation-based optimization, are available. Optimization, itself, is known as the process of finding the best solution from all feasible solutions. It is not obviously clear which optimization method or group is most applicable for BPO. Simulation-based business process optimization is an instrument for detailed analysis of processes and further optimization. This paper discusses the simulation optimization methods for BPO.

Keywords: Simulation optimization, business process optimization, simulation software.

Contents

1 Introduction

Business process optimization (BPO) is the focus of all successful business companies. Various simulation optimization methods, which is understood as simulation-based optimization, are available. Optimization, itself, is known as the process of finding the best solution from all feasible solutions. It is not obviously clear which optimization method or group is most applicable for BPO. Simulation-based business process optimization is an instrument for detailed analysis of processes and further optimization. This paper discusses the simulation optimization methods for BPO.

Different simulation optimization approaches have been provided in the related papers, however evolutionary algorithms and in specific genetic algorithms are widely used for BPO. Challenging in business process simulation becomes apparent when solving problems simultaneously against multiple objectives that conflict to each other. Multi-objective optimization involves optimizing a number of objectives simultaneously. To solve multi-objective optimization problems evolutionary algorithms are successfully used. One of the objectives of the paper is to provide sufficient information how simulation optimization and with which methods is used for BPO.

In the field under discussion, it is a challenge to understand the relation between different terms, such as, Multi-objective optimization, Multi-criteria optimization, Business process optimization, Business process simulation, Simulation optimization, Evolutionary algorithms, Genetic algorithms. Due to large amount of the terms and in some case with very similar wording, is highly important to use them in proper and precisely way. For that reason, as next objectives of the paper, the explanations of such relations as well as meanings of terms are provided.

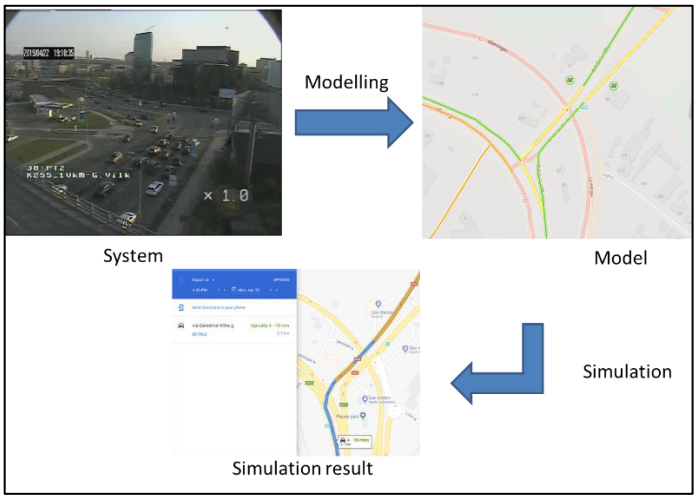
The experiments with BPO, have been conducted with simulation optimization software, will be done and the results will be described in the paper. In our days, market is suggesting a lot of simulation optimization software and it becomes challenging to pick up the most suitable one. The brief comparison of simulation optimization software is also available in the paper. Some ideas how to prepare and run simulation-based multi-objective optimization method for BPO has been presented in the paper.

In the end of the paper conclusions are listed and what assumptions might be addresses in the future studies. Nevertheless, it is necessary to continue research in the area of the simulation-based BPO to achieve all objectives and overcome all challenges.

2 Introduction to simulation

Simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behaviour of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system Shannon (1975)).

- What is the pass-through limit?
- What can be done to increase the limit?
- What restructuring would help the most?
- What is the impact of restructuring plan X?



- Mathematical models:
  - *may be complex to design;*
  - *hard to understand for end-users.*
- Real-life experiments may be:
  - *expensive to implement;*
  - *take too long to implement;*
  - *has impact on the running system.*

Business process simulation is arguably the most popular and most widely supported method for the quantitative analysis of process models. The basic idea behind the process modeling is quite simple. In fact, the process simulator generates a large number of hypothetical instances of the process, performs these instances step by step and records each step in this implementation. So, which of the available simulation software is the most appropriate software to be used?

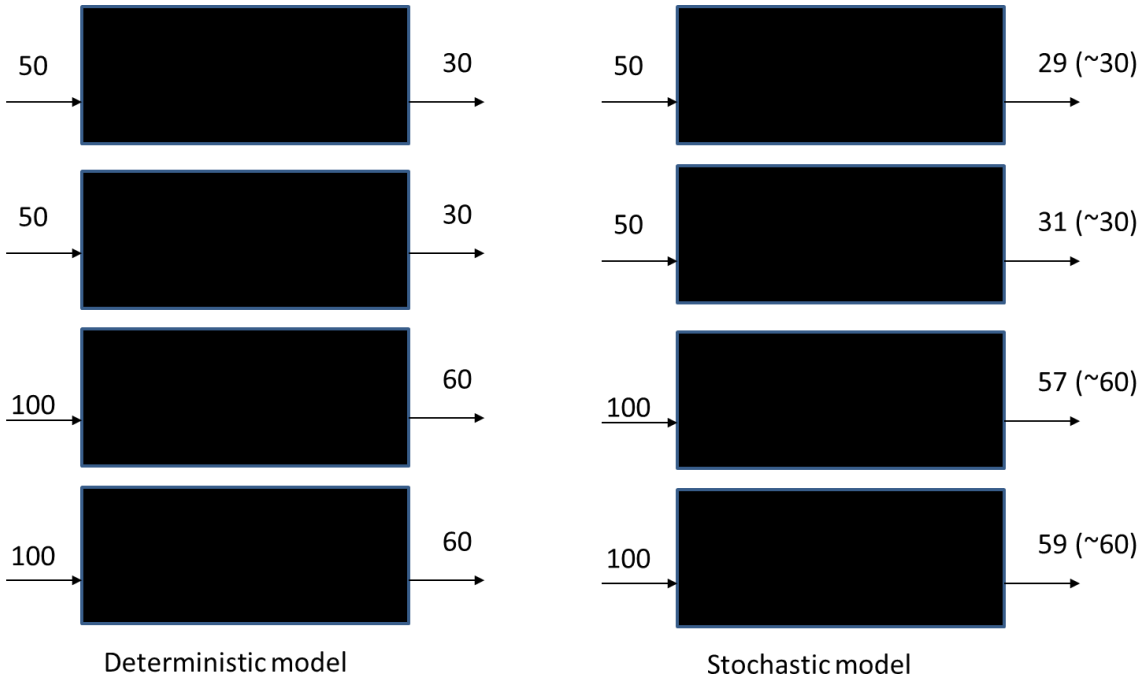
To answer formulated questions, a comprehensive state-of-art review is needed for better understanding the current state of available simulation software. Therefore, this survey draws up a systematic review of simulation software.

2.1Types of simulation

Simulation can be classified based on:

- *Results:*
  - ✓ *Deterministic;*
  - ✓ *Stochastic.*
- *Behavior:*
  - ✓ *Discrete Event;*
  - ✓ *Continuous;*
  - ✓ *Agent-based.*

(*Discrete and Continuous Simulation*)

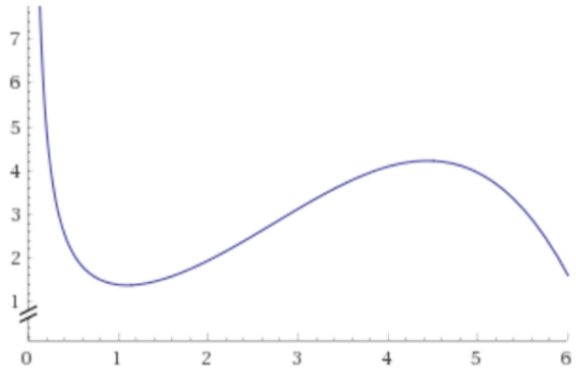


A discrete simulation model has some variables whose values vary at discrete points in time (*Discrete and Continuous Simulation*). Some examples of such models are:

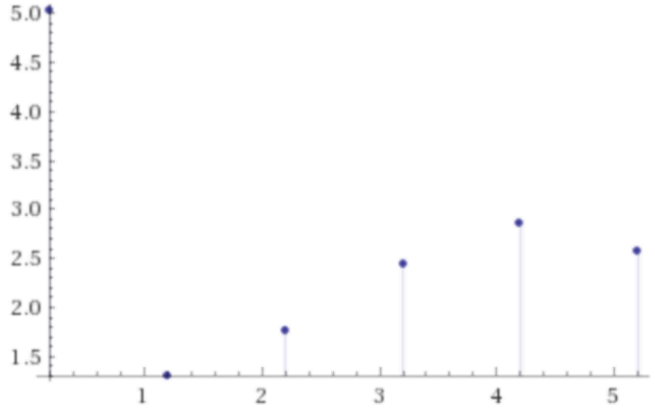
- ✓ *Bank tailoring systems*
- ✓ *Railway reservation systems*
- ✓ *Selling systems at counters in supermarkets*
- ✓ *Inventory control systems*
- ✓ *Manufacturing of discrete products*

A continuous simulation model has variables that change continuously over time. Thus, the results of such systems are taken at fixed intervals of time after the system reaches a steady state (*Discrete and Continuous Simulation*). Examples of such systems include:

- ✓ *Production of chemicals*
- ✓ *Pipeline transmissions of gaseous products*

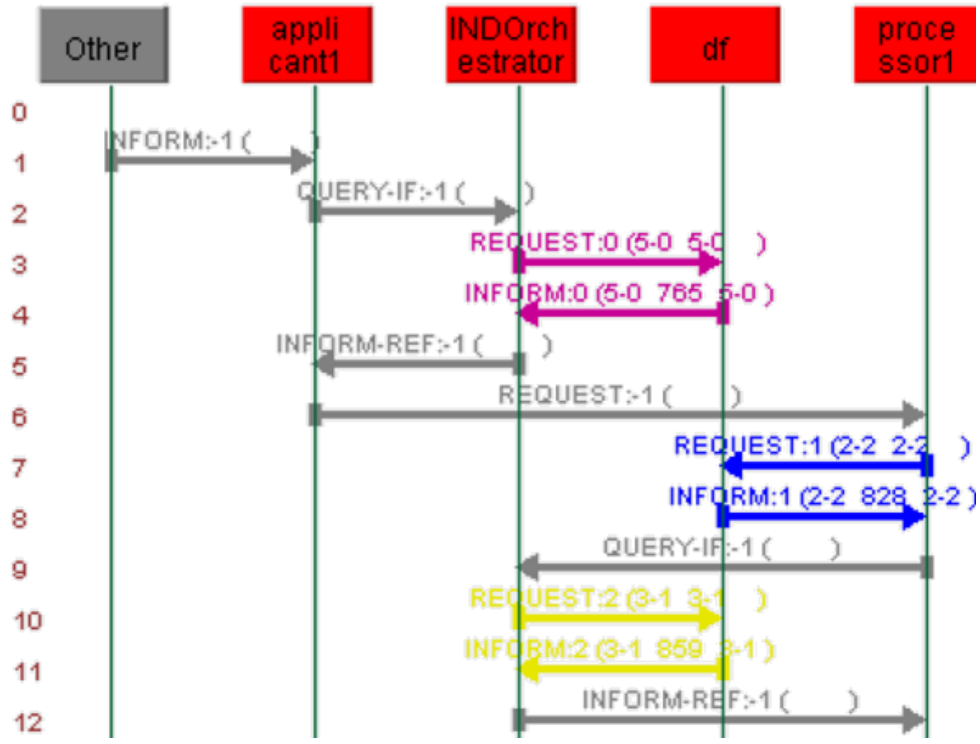


Continuous simulation exemplary output



Discrete simulation exemplary output

Agents



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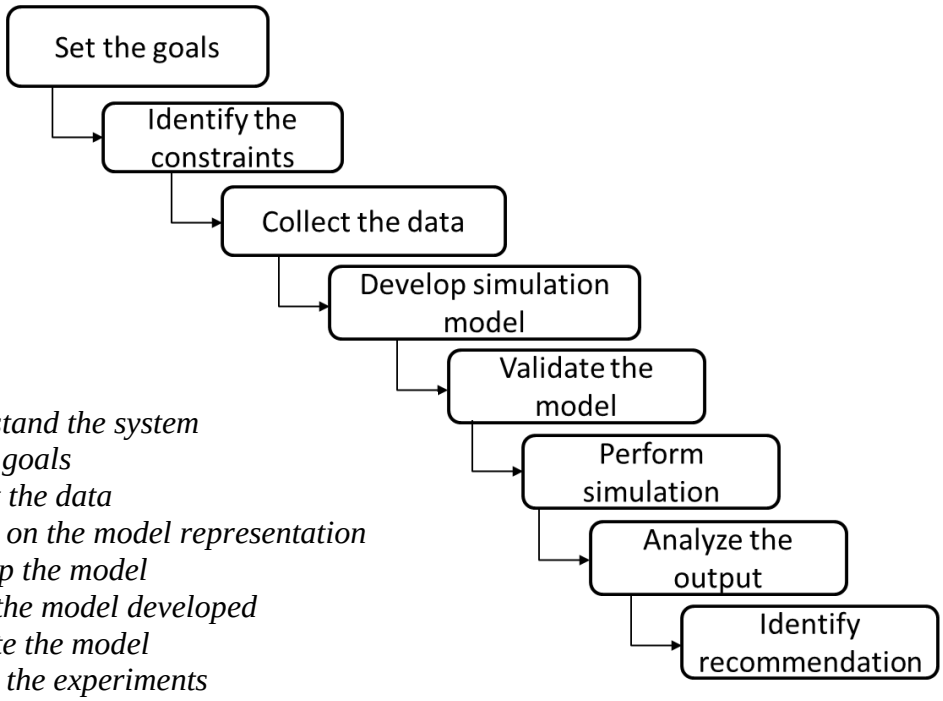
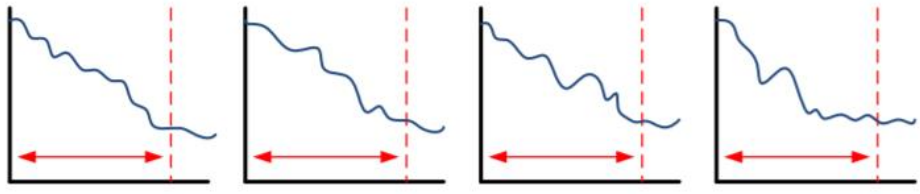
Agent-based simulation exemplary output (*Gong and M. Janssen 2010*)

2.2 Steps of simulation

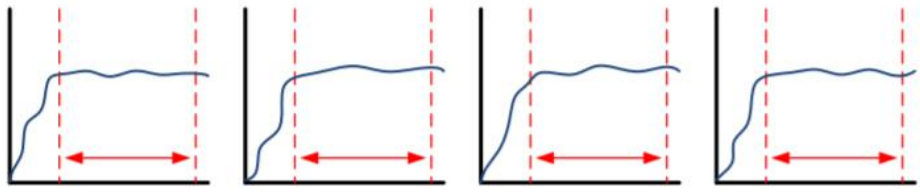


- ✓ *Understand the system*
- ✓ *Set the goals*
- ✓ *Collect the data*
- ✓ *Decide on the model representation*
- ✓ *Develop the model*
- ✓ *Verify the model developed*
- ✓ *Validate the model*
- ✓ *Design the experiments*
- ✓ *Run and analyze the simulation model*

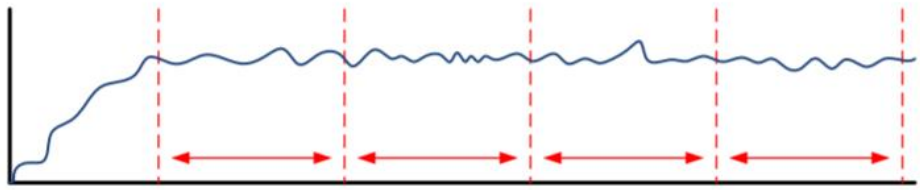
Hlupic & Robinson, 1998



(a) transient analysis (no warm-up period, initial state matters, bounded timeframe)



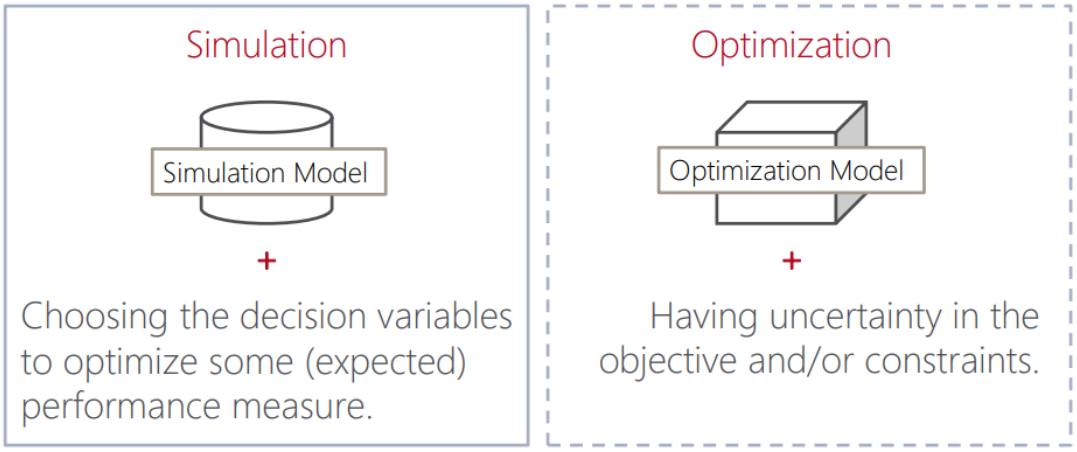
(b) steady-state analysis (separate runs each with warm-up period)



(c) steady-state analysis (long run with one warm-up period split into smaller subruns)

For transient analysis, the initial state and the first part of the simulation are relevant. For steady-state analysis, the initial state and warm-up period are irrelevant and only the behavior after the warm-up period matters. Each graph shows one simulation run. The X-axis denotes time whereas the Y-axis represents the state of the process. For steady-state analysis one can take separate simulation runs (each with a warm-up period) or one large simulation run cut into smaller subruns (*Business process simulation survival guide, van der Aalst, Wil*).

Different simulation optimization approaches have been provided in the related papers, however evolutionary algorithms and in specific genetic algorithms are widely used for BPO.



Other names: "Simulation-based Optimization" or "Optimization via Simulation".

3 Systematic review of simulation software

3.1. Research question

In this step, review questions are defined. So, this study was conducted to answer a research question as follows:

RQ1: What are vendor and applications?
RQ2: What is the technical compatibility?
RQ3: How model building is realized?
RQ4: What are the animation opportunities?
RQ5: What are support and training possibilities?
RQ6: What is the price of student version?

Table 1. RQ1 results

Name	Vendor	Typical applications	Primary markets	Vendor's other software
ANYLOGIC https://www.anylogic.com/	AnyLogic North America	Multimethod general- purpose simulation tool. Discrete event, agent-based, and system dynamics modeling.	• Supply Chains • Transportation • Warehouse operations • Rail logistics • Mining • Oil and gas • Road traffic • Passenger flows • Manufacturing and material handling • Healthcare • Business processes • Asset management • Marketing • Social processes • Defense	anyLogistix — supply chain simulation and optimization software. AnyLogic Cloud – web service that allows AnyLogic users run and access models from a web browser on any device, compare results, create custom dashboards, and perform various experiments
ARENA https://www.arenasimulation.com/	Rockwell Automation	Used for simulating and analyzing existing and proposed systems as well as operational analysis.	• Manufacturing • Supply chains • Government • Healthcare • Logistics • Food and Beverage • Packaging • Mining • Call Centers	N/A
ENTERPRISE DYNAMICS https://www.incontrolsim.com/software/enterprise-dynamics/	INCONTROL Simulation Solutions	Manufacturing, logistics, and material handling simulation	• Warehouses • Distribution centers • Airports and harbors • Healthcare and pharmaceuticals • FMCG	Pedestrian Dynamics — a crowd simulation software application, designed for the creation and execution of large pedestrian simulation models in complex infrastructures.
EXTENDSIM PRO https://extendsim.com/	Imagine That Inc	Professional level tool for modeling and analyzing complex discrete rate,	• Consumer products • Healthcare • Energy	ExtendSim DE — entry-level general-purpose, discrete event and continuous simulation tool.

Name	Vendor	Typical applications	Primary markets	Vendor's other software
		continuous, agent-based, and hybrid systems.	• Petro-chem • Pulp/Paper • Transportation • Pharmaceuticals • Semiconductors • Military and Government • Mining	
FLEXSIM https://www.flexsim.com/	FlexSim Software Products, Inc.	Simulation and modeling of any process, with the purpose of analyzing, understanding, and optimizing that process.	• Manufacturing • Packaging • Warehousing • Material handling • Supply chain • Logistics • Healthcare • Factory • Aerospace • Mining	FlexSim Healthcare — simulation and modeling to analyze, optimize, and better understand healthcare systems.
PROMODEL OPTIMIZATION SUITE https://www.promodel.com/products/ProModel	ProModel Corporation	Process optimization and Improvement, Resource utilization, System capacity and throughput, Constraint analysis, LSS	• DoD and Government • Manufacturing • Pharmaceutical • Logistics • Warehouse and DC	Enterprise Portfolio Simulator — web-based simulation analysis of multiple, simultaneous project plans FutureFlow Rx — ADT Decisioning, Patient Flow and Bed Management MedModel — a dynamic, animated computer simulation of clinical environment Process Simulator — flowcharts and process diagrams simulator
SAS SIMULATION STUDIO https://www.sas.com/en_us/software/simulation-studio.html	SAS	Discrete-event simulation: supply chains, resource management, capacity planning, workflow analysis, and cost analysis.	• Manufacturing • Banking • Pharmaceuticals and healthcare • Energy • Government agencies • Retail • Education • Transportation	N/A
SIMUL8 PROFESSIONAL https://www.simul8.com/products/	SIMUL8 Corporation	Assembly Line, Line Balancing Strategic planning, Operations, Healthcare Systems, BPMN, Lean, Shared Services, Capacity Plan	• Manufacturing • Healthcare • Education • Engineering • Supply chains • Logistics • Government • BPMN • Lean • Automotive • Call centers	N/A
SIMIO ENTERPRISE EDITION	Simio LLC	Ideal product for professional modelers and researchers. Powerful object-oriented	• Academic • Aerospace & defense • Airports • Healthcare	N/A

Name	Vendor	Typical applications	Primary markets	Vendor's other software
https://www.simio.com/software/enterprise.php		modeling and integrated 3D animation for rapid model	• Manufacturing • Mining • Military • Oil and gas • Supply chains • Transportation	
PLANT SIMULATION https://www.dex.siemens.com/plm/plant-simulation	Siemens Product Lifecycle Management Software Inc.	Discrete-event simulation, visualization, analysis and optimization of production throughput, material flow, and logistics	• Automotive OEM and supplier • Aerospace and defense • Consumer products • Logistics • Electronics • Machinery • Healthcare • Consulting	N/A
WITNESS https://www.lanner.com/en-gb/technology/witness-simulation-software.html	Lanner	Fast, productive predictive simulation desktop software for professional modelling and application development.	• Business planning • Process optimization • Decision making	N/A

Table 2. RQ2 results

Name	Supported operating systems	Compatible software to perform specialized functions	Being controlled or run by an external program	Multiprocessor CPU support
ANYLOGIC	Windows, Mac, Linux	• Excel, Access, and any database • OptQuest • Stat::Fit • Any Java / DLL library e.g. for bayesian or neural networks.	AnyLogic models can be exported as standalone Java applications that can be run from/by any other application. They could be also run online via AnyLogic Cloud web service.	YES
ARENA	Windows	OptQuest	Visual Studio for the purpose of automation as well as VB	YES
ENTERPRISE DYNAMICS	Windows	N/A	N/A	YES
EXTENDSIM PRO	Windows, Mac	• Excel, Oracle, Access, SQL Server, MySQL • Stat::Fit • JMP • Minitab • any custom DLL	Any Windows application that can be configured as an Automation controller, such as Excel or Access, can control and communicate with ExtendSim as a COM Automation Server.	YES
FLEXSIM	Windows	• Excel and other database software • C++ applications	OLE and ActiveX	YES
PROMODEL OPTIMIZATION SUITE	Windows	• Excel and Access • Stat:Fit • MiniTab	• Excel and Access, • C# • VB and VBA	YES

Name	Supported operating systems	Compatible software to perform specialized functions	Being controlled or run by an external program	Multiprocessor CPU support
SAS SIMULATION STUDIO	Windows, Linux	SAS and JMP software, either run externally or embedded via SAS Program block.	Any program that can launch a Java application.	YES
SIMUL8 PROFESSIONAL	Windows	• Excel • Stat::Fit, • OptQuest • SQL Databases	Microsoft Excel and any COM enabled IDE	YES
SIMIO ENTERPRISE EDITION	Windows	• Microsoft Azure • Wonderware • OptQuest • .Net Programs (over 60 languages supported) • Excel, Access, SQL Server, MySQL	• Wonderware • OptQuest • .Net Programs (over 60 languages supported)	YES
PLANT SIMULATION	Windows	• Matlab • Excel • SAP • Simatic IT • Teamcenter • Autocad • Microstation	• Parameterizing from MS Excel • Siemens PLCSIM Advanced • OPC, OPC UA, ODBC • MS Windows • Oracle	YES
WITNESS	Windows	N/A	N/A	YES

Table 3. RQ3 results

Name	Output Analysis support	Optimization	Support of model packaging	Batch run / experimental design	Mixed discredit / continuous modeling (levels, flows, etc.)
ANYLOGIC	• Reports • Model execution logs • Charts • Output to the built-in database or any external data storage (databases, spreadsheets, text files)	OptQuest is included, additionally, users can employ any custom optimization algorithms.	Models can be exported as standalone Java applications or shared online via AnyLogic Cloud web service.	Flexible user interface to create the following experiments: Parameter Variation, Compare Runs, Monte Carlo, Sensitivity Analysis, Calibration, and custom.	YES
ARENA	Arena Output Analyzer and Process Analyzer to review results and users may use external products as well	OptQuest for Arena	Arena Runtime	Process Analyzer to run a series of different model runs in a batch	YES
ENTERPRISE DYNAMICS	Experiment Wizard – an internal feature	By providing support for various third-party optimizers	By providing a free Viewer License of the software	By providing Experiment Wizard and Scenario Manager	YES
EXTENDSIM PRO	• Output to charts & reports	Evolutionary Optimizer is included in all	Trial version runs any model built in	Users choose to store run results in the internal database or	YES

Name	Output Analysis support	Optimization	Support of model packaging	Batch run / experimental design	Mixed discredit / continuous modeling (levels, flows, etc.)
	• Integrated Scenario Manager with dialog or database factors and responses, sensitivity analysis, confidence intervals, Gantt charts, and quantile and interval statistical analysis. • Export to external analysis applications is also available.	versions of ExtendSim.	ExtendSim. Analysis RunTime version allows for further model analysis.	export to an external application. DOE includes manual, full factorial, and two options each for JMP custom design and Minitab optimal design.	
FLEXSIM	A full suite of charts and graphs in the Dashboard, as well as extensive Excel output options.	An optimization engine, powered by OptQuest, is available as an add-on.	The free trial version of FlexSim is capable of running any simulation model built with FlexSim.	An experimentation engine is built into the software.	YES
PROMODEL OPTIMIZATION SUITE	• Output Viewer • Minitab • Excel	SimRunner	N/A	Scenario Manager	YES
SAS SIMULATION STUDIO	Output analysis via SAS software products. Steady state analysis included.	Via data transfer to SAS/OR software; can be embedded in a simulation model via SAS Program block.	N/A	Experimental design; manual in the Simulation Studio interface or automated (with interactive modifications) via JMP or SAS software integration.	NO
SIMUL8 PROFESSIONAL	N/A	OptQuest	SIMUL8 Studio and SIMUL8 Web Technology	Multiple replications and scenario management	YES
SIMIO ENTERPRISE EDITION	SMORE Plots for risk analysis, sensitivity analysis, custom dashboards, comprehensive data in pivot tables, export summary or details to external packages	OptQuest (option) takes full advantage of all processors. Featuring Multi-Objective and Pattern Frontier optimization	Requires Team Edition or above to package model	Run manual scenarios with multiple replications. Concurrent full use of all processors. Built-in ranking and selection	YES
PLANT SIMULATION	• Datafit • Charts • Sankey	Genetic Algorithm, Layout	Built-in Pack and Go functionality	Experiment Manager supporting distributed simulation	YES

Name	Output Analysis support	Optimization	Support of model packaging	Batch run / experimental design	Mixed discredit / continuous modeling (levels, flows, etc.)
	• Bottleneck analyzer • Energy Analyzer • Neural networks	Optimizer, Neural networks, Hill Climbing, Dynamic Programming, Branch and Bound			
WITNESS	N/A	N/A	Cloud Deployment, Experimentation, Optimization	N/A	YES

Table 4. RQ4 results

Name	Animation	Animation export	Real - time viewing	3D animation	CAD drawings import
ANYLOGIC	YES	YES	YES	YES	YES
ARENA	YES	YES	YES	YES	YES
ENTERPRISE DYNAMICS	YES	YES	YES	YES	YES
EXTENDSIM PRO	N/A	YES	YES	YES	YES
FLEXSIM	YES	YES	YES	YES	YES
PROMODEL OPTIMIZATION SUITE	N/A	YES	YES	YES	YES
SAS SIMULATION STUDIO	N/A	YES	YES	N/A	N/A
SIMUL8 PROFESSIONAL	N/A	YES	YES	YES	YES
SIMIO ENTERPRISE EDITION	YES	YES	YES	YES	YES
PLANT SIMULATION	YES	YES	YES	YES	YES
WITNESS	YES	YES	YES	YES	YES

Table 5. RQ5 results

Name	Consulting available	User support / hotline	User group or discussion area	Training courses	On-site training
ANYLOGIC	Provided by company's partners	YES	YES	YES	YES
ARENA	YES	YES	YES	YES	YES
ENTERPRISE DYNAMICS	YES	YES	YES	YES	YES
EXTENDSIM PRO	N/A	YES	YES	YES	YES
FLEXSIM	YES	YES	YES	YES	YES
PROMODEL OPTIMIZATION SUITE	N/A	YES	YES	YES	YES

SAS SIMULATION STUDIO	N/A	YES	YES	N/A	N/A
SIMUL8 PROFESSIONAL	N/A	YES	YES	YES	YES
SIMIO ENTERPRISE EDITION	YES	YES	YES	YES	YES
PLANT SIMULATION	YES	YES	YES	YES	YES
WITNESS	YES	YES	YES	YES	YES

Table 6. RQ6 results

Name	**Student version**	**Major new features (since 2015)**	**Vendor comments**
ANYLOGIC	Free AnyLogic Personal Learning Edition	•AnyLogic Cloud, a web service for sharing models and running them online on any device. •The Road Traffic Library for detailed modeling of vehicle movement on roads. •The Material Handling Library for the simulation of manufacturing systems and operations	The only simulation tool that supports combining Discrete Event, Agent-Based, and System Dynamics simulations in one model.
ARENA	Free version available	N/A	N/A
ENTERPRISE DYNAMICS	Free version available	•Improved Support for BIM, CAD •Improved animation and debugger, etc.	N/A
EXTENDSIM PRO	$25 download for ExtendSim Adopters; $50 for other students. Research grants are available to use the full version of ExtendSim in research projects for advanced degrees.	•App overhaul plus new UI, charts & reports •Advanced Resource Mgmt •Improved source editing environment •New import/export capabilities.	Unified modeling architecture with powerful internal relational DB & flexible framework to represent widely different systems
FLEXSIM	Free to $ 100	•A new graphical tool for process definition (Process Flow) •Support for virtual reality (Oculus Rift, HTC Vive)	FlexSim is committed to help answer questions relating to any process in the most intuitive, easy-to-use interface possible.
PROMODEL OPTIMIZATION SUITE	$ 30	•Resource distance traveled statistics •Identify captured resource units •In-process resource utilization statistics •Programmatic export of statistics •UI enhancements	N/A
SAS SIMULATION STUDIO	N/A	•Linux support •Enhanced controls on order of execution for blocks and block ports •Extended queueing controls.	Included with SAS/OR. Integrated with SAS and JMP analytical capabilities. Models can incorporate any SAS or JMP code.
SIMUL8 PROFESSIONAL	$ 1995	• SIMUL8 Studio • Power & Free Conveyors	N/A

Name	Student version	Major new features (since 2015)	Vendor comments
		• Work Item tracking • Create custom interfaces, Overtime • Financial Input Summary	
SIMIO ENTERPRISE EDITION	Free and a $25-versions are available	N/A	Patented innovations, designed by the Dr. C. Dennis Pegden team, takes Flexibility and Rapid Modeling to new levels.
PLANT SIMULATION	Free version available	• Enhanced worker, robot, mixer, motion paths and visualization • New Simtalk, OPC UA and Siemens PLCSIM Advanced connections	N/A
WITNESS	Free version available	N/A	N/A

The most simulation software vendors are providing similar functionalities to each other. However, the answer which simulation software is more applicable is depends on what is actually will be simulated and further optimized. For the business process optimization – very sophisticated simulation software must be chosen. It is because the human resources must be simulated in such processes. For the industry processes any of representing simulation software could be selected.

After the analysis of the answers to the research questions defined in section we pick up three simulation software to be tested in computer environment. They are: ANYLOGIC, SIMIO and WITNESS.

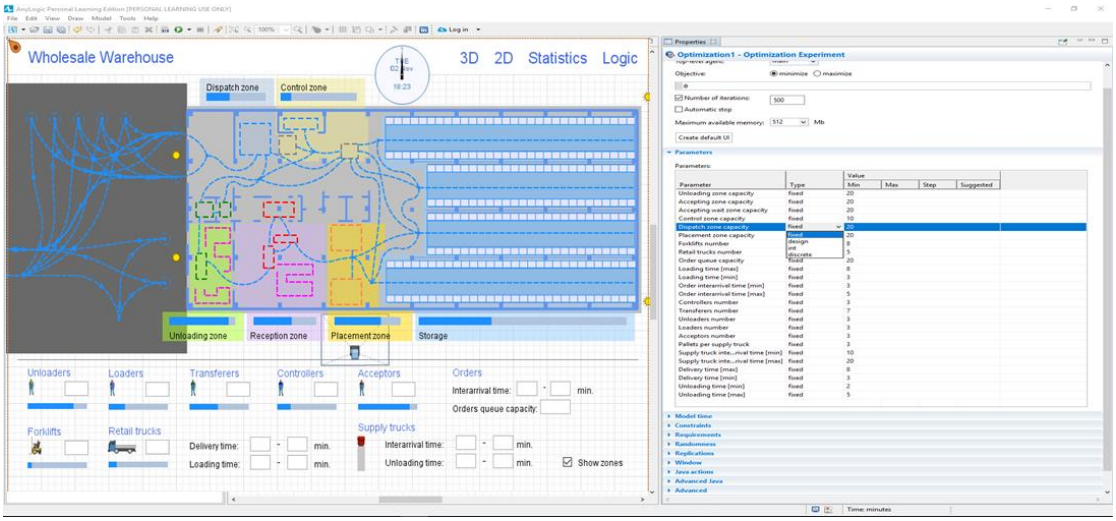


Figure 1. ANYLOGIC software environment

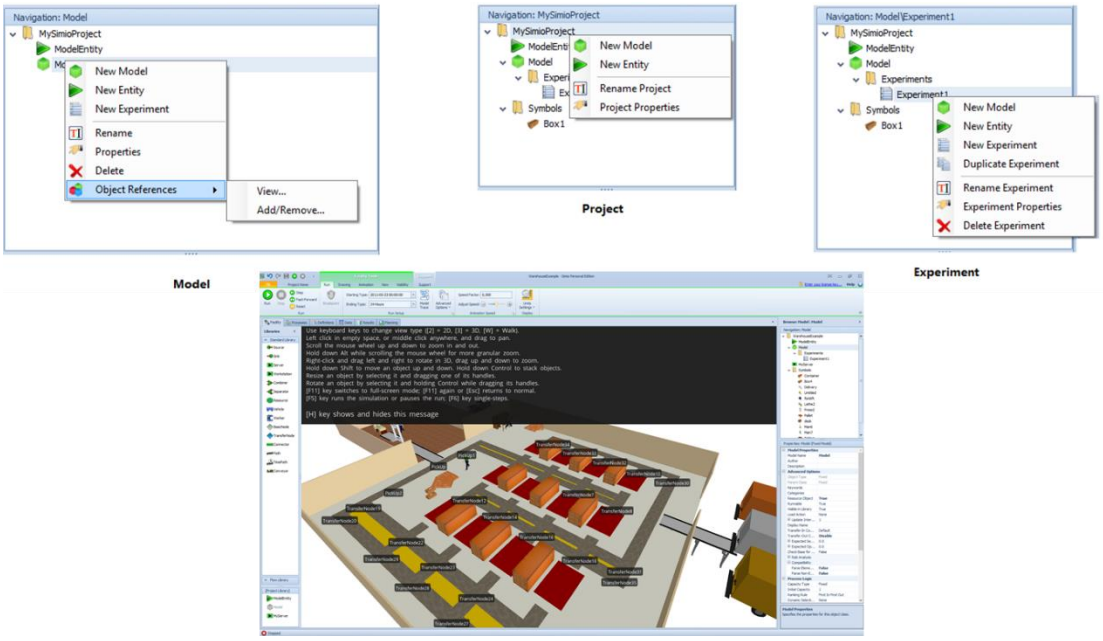


Figure 2. SIMIO software environment

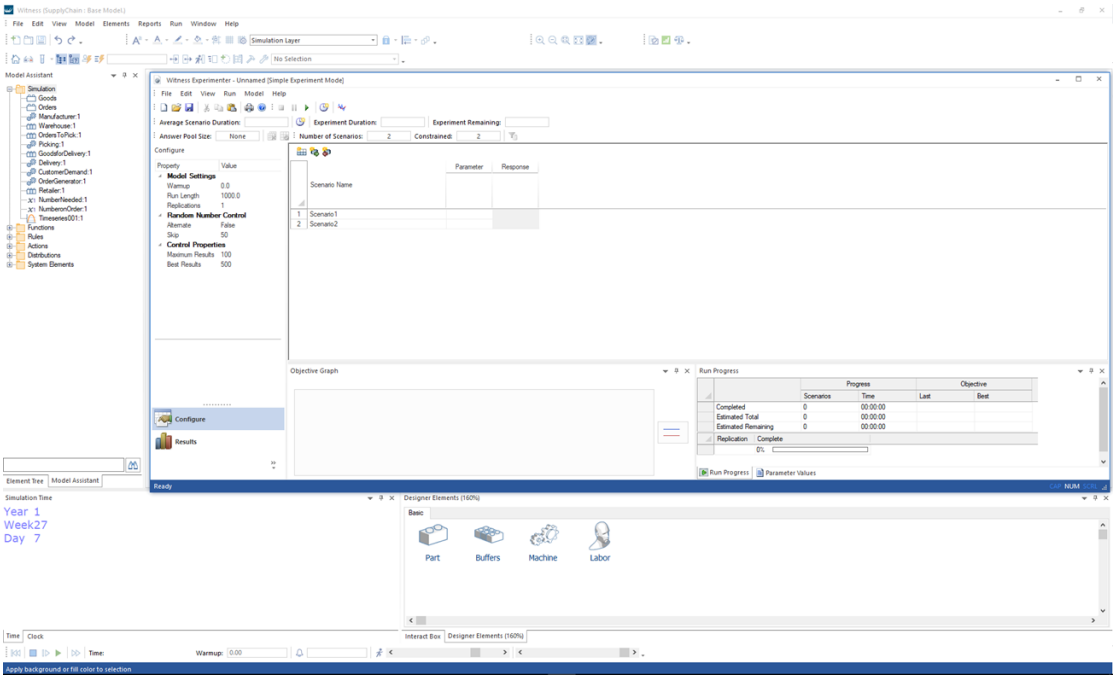


Figure 3. WITNESS software environment

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Arena
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Enterprise Dynamics
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Extendsim Pro
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Flexsim
https://www.flexsim.com/
Promodel Optimization Suite
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