# System Dynamic Tools

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**Abstract**: The problems and challenges facing organisational leaders relate to the speed and complexity of change required today. System Dynamics is an approach to understanding the behaviour of complex systems over time. System Dynamics (SD) is a methodology and mathematical modelling technique for framing, understanding, and discussing complex issues and problems. Tools used for System Dynamics modelling are mostly software – e.g. Stella, Vensim, PowerSim etc. The aim of this work is to summarise widely used system dynamic tools and models. Further to this end this paper would discuss a possible enhancement of existing models or tools.

## 1 Introduction – System Dynamics

**System dynamics** is an approach to understanding the behaviour of complex systems over time. System dynamics is a methodology and mathematical modelling technique for framing, understanding, and discussing complex issues and problems.

System dynamics was created during the mid-1950s *(1)* by Professor Jay Forrester of the Massachusetts Institute of Technology (MIT). His initial goal was to determine how his background in science and engineering could be brought to bear, in some useful way, on the core issues that determine the success or failure of corporations. Forrester's insights into the common foundations that underline engineering, which led to the creation of system dynamics, were triggered, to a large degree, by his involvement with managers at General Electric (GE) during the mid-1950s.

From hand simulations (or calculations) of the stock-flow-feedback structure of the GE plants, which included the existing corporate decision-making structure for hiring and layoffs, Forrester was able to show how the instability in GE employment was due to the internal structure of the firm and not to an external force such as the business cycle. These hand simulations were the beginning of the field of system dynamics *(2).*

During the late 1950s and early 1960s, Forrester and a team of graduate students moved the emerging field of system dynamics from the hand-simulation stage to the formal computer modelling stage. Richard Bennett created the first system dynamics computer modelling language called SIMPLE (Simulation of Industrial Management Problems with Lots of Equations) in the spring of 1958. In 1959, Phyllis Fox and Alexander Pugh wrote the first version of DYNAMO (DYNAmic MOdels), an improved version of SIMPLE, and the system dynamics language became the industry standard for over thirty years. Forrester published the first, and still classic, book in the field titled Industrial Dynamics in 1961 *(2).*

From the late 1950s to the late 1960s, system dynamics was applied almost exclusively to corporate/managerial problems. In 1968, however, an unexpected occurrence caused the field to broaden beyond corporate modelling. The Urban Dynamics model presented the book titled Urban Dynamics was the first major non-corporate application of system dynamics *(2).*

The second major non-corporate application of system dynamics came shortly after the first. In 1970, Jay Forrester was invited by the Club of Rome to a meeting in Bern, Switzerland. The Club of Rome is an organisation devoted to solving what its members describe as the "predicament of mankind" - that is, the global crisis that may appear sometime in the future, due to the demands being placed on the Earth's carrying capacity (its sources of renewable and non-renewable resources and its sinks for the disposal of pollutants) by the world's exponentially growing population. On the plane back from the Bern meeting, Forrester created the first draft of a system dynamics model of the world's socioeconomic system called WORLD1. Later Forrester refined the version of the model and published it as WORLD2 in a book titled World Dynamics.

There are different areas of business where system dynamic modelling can be applied nowadays. Next to modelling business processes system dynamics can be for example applied in manufacturing and production, supply chain, transportation, strategic planning, healthcare, military and defence, ecosystem and various urban or environmental issues.

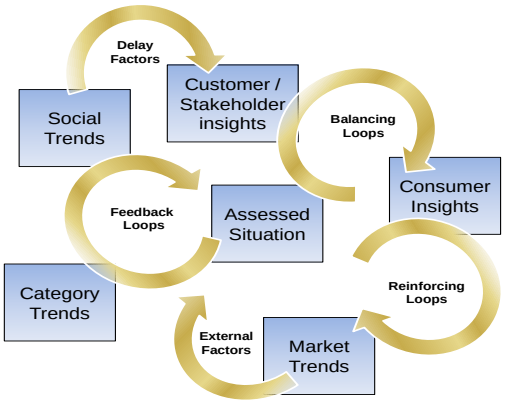
### 1.1 Methodology

This paper is organised as follow: The first section describes system dynamics tools and methods used mostly for simulation modelling. The second section lists a number of system dynamic software tools that are available on the market. The third section contains a summary of system tools features; there is also an example of valuation of listed software. The final section is a conclusion.

When preparing this paper the subject was firstly searched for in scientific libraries and databases, mostly electronically through remote access. When searched for expressions like ‘system dynamics’, ‘system dynamics tools’, tools for system dynamic’ or ‘system dynamic software’ the amount of findings in databases was significant. However, in most cases, the offered content mostly described a result of some scientific work or experiment rather than a tool used for the job. After some time the search was moved in the area of more common sources (e.g. Google or Yahoo browsers) where some information published into this paper was found. Once system dynamic software was identified a web page of software developer was visited and further details were examined.

## 2 System dynamic tools

The elements of system dynamics diagrams are feedback, accumulation of flows into stocks and time delays.




*Picture 1: Example of a system dynamics software thinking tool*

The picture shows modelling of managing complex. As an illustration of the use of system dynamics one could imagine an organisation that plans to introduce an innovative new durable consumer product. The organisation needs to understand the possible market dynamics in order to design marketing and production plans.

System dynamics tools are nowadays well translated into software, especially in the business simulation area. The system dynamics approach emphasizes a continuous view. The continuous view strives to look beyond events to see the dynamic patterns underlying them. Moreover, the continuous view focuses not on discrete decisions but on the policy structure underlying decisions. Events and decisions are seen as surface phenomena that ride on an underlying tide of system structure and behaviour. (4)

Major paradigms in simulation modelling are System Dynamics (SD), Discrete Event (DE) and Agent Based (AB). SD and DE are traditional, AB is relatively new. There is also Dynamic Systems (DS) field, but it stays a bit aside as it is used to model and design “physical” systems. (3)

These SD, DE and AB paradigms (or methods) are mostly used for simulation modelling over systems. With respect to how do they approach such systems, these could be defined as:

System Dynamics - perspective and set of conceptual tools that enable to understand the structure and dynamics of complex systems over the time

Discrete Event - approximate continuous real-world processes with non-continuous events that you define

Agent Based Modelling - can be defined as an essentially decentralized, individual-centric (as opposed to system level) approach to model design.

## 2.1 Commonly identified system dynamic tools

**iThink** and **STELLA** are two names for one model development platform published by isee systems. As mentioned by developers' iThink should more comply with Policy and Business issues whereas STELLA supposed to be used for Education and Research. The software is available in different configurations under a commercial license for Windows and Macintosh computers. Educational licenses and a free runtime version of the software are available. Available is also an add-on wizard called isee NetSim. The add-on allows quickly publish STELLA and iThink models to the web. (5) By publishing models to the web one can share those with others, even if they do not own STELLA or iThink.

**Powersim Studio** is available in a number of different configurations from Powersim Software. It offers a variety if simulation tools. The software is available under commercial license and runs under Windows. Educational licenses and options for publishing standalone model packages are available. A new free version, Studio 9 Express is now available. (6)

**Vensim** is available in a number of different configurations from Ventana Systems, Inc. They describe Vensim as 'Industrial strength simulation software for improving the performance of real system' (7). The software is available under a commercial license and runs on Windows and the Macintosh. Educational licenses, including a configuration of the software that is free for educational use, and a free runtime version of the software are available.

**Anylogic** is product of XJ Technologies that supports simulation based on discrete event, agent based and system dynamics methodologies. (8) The software is available under a commercial license and runs on Windows, Macintosh and UNIX platforms.

**Dynaplan Smia**, from Dynaplan, represents a new modelling paradigm. It combines features of spread sheets, presentation software, and simulation into an integrated modelling environment. (9) It is available under a commercial license.

**GoldSim**, from The GoldSim Technology Group, is a Monte Carlo simulation software solution for dynamically modelling complex systems in business, engineering and science. The software can also support stock and flow style modelling. It is available under a commercial license.

**Berkley Madonna** uses a differential equation representation to develop models. It is available under a commercial license.

**Exposé** from Attune Group, Inc. is an Excel add- in that supports visualization of feedback within spread sheets and allows visual cause and effect editing within Excel. It engages modelling tools in build/Modify models in visual environments using systems thinking approach (10). It is available under a commercial license.

Simulistics develops and distributes **Simile**, modelling and simulation software for complex dynamic systems in the earth, environmental and life sciences. (11) They use based declarative modelling technology to

represent the interactions in these systems in a clearly structured, visually intuitive way. It is available under a commercial license.

**Simgua** is a visually based model development environment. It is available under a commercial license.

**TRUE**, from TRUE-WORLD, is visually oriented software for developing and animating models. is a tool for modelling, simulating, analysing and optimizing multi-domain dynamic applications. TRUE is a freeware since March 2013. (12)

**Forio**, from Forio Online Simulations, is a web based tool. It allows building web based interfaces to already developed models and also provides a library of interactive environments for curious users to explore. The software is web hosted, with a commercial use license, but provides a number of options for low cost and no cost publication and proliferation of models and model results.

## 2.2 Pedagogical Tools

Pedagogical tools are designed to convey important lessons and allow people to improve their understanding of a problem or undertaking. Though, in a sense, these are the goals of any successful system dynamics study, the pedagogical tools focus on the teaching part, not the analysis of novel situations.

**Sysdea**, Strategy Dynamics Ltd, replaces MyStrategy. Sysdea is an on-line, browser based, system dynamics tool. It is easy to use, has extensive documentation and has easy model sharing options.

**InsightMaker**, from Give Team, is a free System Dynamics modelling tool that runs completely in the browser. It enables to build, run and share System Dynamics models without downloading or installing a single program.

**NetLogo**, from Northwestern University, is a multi-agent programmable modelling environment. It has the ability to build system dynamics models. It also powers HubNet participatory simulations.

### 2.3 Documenting and Explaining Models

Documenting models is fundamental to both their credibility and on-going use. Documentation can also provide deep understanding of model structure, especially if it is structured as a linked web page allowing the user to browse in any directions.

**SDM-Doc**, developed at Argonne National Labs, takes a text format Vensim models and creates html based documentation. It is an open source project. Though currently configured to run under windows, because it is open source it may be possible to adapt it to different environments.

**Automated Eigenvalue analysis of SD models, Identifying Dominant Behavior Patterns, Links and Loops Automated Eigenvalue Analysis of System Dynamics Models** uses a Powersim Constructor parsed file to generate a model analysis.

### 2.4 Model Analysis Tools

The "**Tool set for Loop Eigenvalue Elasticity Analysis**" by Christian Kampmann and Rogelio Oliva is a set of tools to convert the dynamics matrix of a Vensim model to Mathematica and perform the analysis in that and Excel. The supporting tools are available free of charge but Vensim, Mathematica and Excel are all provided under commercial licenses.

### 2.5 Open Source Tools

A number of people working in System Dynamics find R from the R project to be very useful. It is general purpose software for doing statistical analysis and graphing of data.

## 3 Summary

The table below summarise features of above described system dynamics tools. There is also an example of valuation that suggests a view of looking on the described software. However, the suggested valuation should be viewed individually depending on the outcome and expectation of the software.

When analysing software author used following criteria:

- Operating system – every analysed software could operate in Windows environment, however a successful one may need to support work also in other environment
- Purchasing - the way software can be purchased
- Single license price – many of analysed software offer variety of license policy, license bundles etc. To have a common approach for valuating price availability author selected a single license price
- Free license option – an attractive option of getting software
- Academic discount – supporting education, research or non-profit institutions
- Courses offered – a possibility to learn and practice software off-line
- Business cases available – feature that supports understanding of software and that can also fasten process when one is looking for solution of a business case
- On-line courses – easy way how to learn software without travelling to an off-line training
- Free demo – to get acquaint with software features
- Supporting content of web site – well designed web side can help a lot in learning or working with software

| Validation (Example of Item Value) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Operating system | | | Purchase | | | | | | Web Page | | | | |
| Software name | Company | Win | Mac | Other | Web | Off-line | Single licence (EUR) | Free licence | Academic Discount | Courses offered | Business cases available | On-line courses | Free demo | Supporting content | |
| Stella | isee sysems | Y | Y | N/A | Y | Y | 1 407 | N | Y | Y | Y | Y | Y | Y | |
| iThink | isee sysems | Y | Y | N/A | Y | Y | 1 407 | N | Y | Y | Y | Y | Y | Y | |
| Powersim Studio | Powersim Software | Y | N/A | N/A | Y | Y | 5 333 | N | Y | Y | Y | N | Y | Y | |
| Vensim | Ventana Systems | Y | Y | N/A | Y | Y | 1 478 | N | Y | Y | Y | N | Y | Y | |
| Anylogic | XJ Technologies | Y | Y | Y | N | Y | 4 592 | N | Y | Y | N | N | Y | Y | |
| Dynaplan Smia | Dynaplan | Y | N/A | N/A | N | Y | N/A | N | N/A | N/A | N | N | N | N | |
| GoldSim | GoldSim Technology Group | Y | N/A | N/A | Y | Y | 2 926 | N | Y | N/A | Y | Y | N | Y | |
| Berkley Madonna | | Y | Y | N/A | Y | N | 221 | N | Y | N/A | Y | N | N | Y | |
| Expose | Attune Group | Y | N/A | N/A | N | Y | N/A | N | N/A | Y | N | N | Y | Y | |
| Simile | Simulistics | Y | Y | Y | Y | Y | 637 | N | Y | Y | Y | Y | Y | Y | |
| Simgua | | Y | Y | N/A | Y | N | 885 | N | Y | N/A | Y | N | Y | Y | |
| TRUE | TRUE-WORLD System Dynamic | Y | N/A | N/A | N | Y | 0 | Y | Y | N/A | Y | Y | Y | Y | |
| Forio | Forio Online Simulations | Y | Y | Y | Y | N | 355 | N | Y | Y | Y | Y | Y | Y | |
| Sysdea | Strategy Dynamics | Y | N/A | N/A | Y | N | 160 | N | N/A | N/A | Y | Y | Y | Y | |
| InsightMaker | Give Team | Y | Y | Y | Y | N | 0 | Y | Y | N/A | Y | Y | Y | Y | |
| NetLogo | Northwestern University | Y | Y | Y | Y | N | 0 | Y | Y | N/A | Y | Y | Y | Y | |
| SDM-Doc | Argonne National Labs | Y | Y | Y | N | N | N/A | N | N/A | N/A | N | N | N | N | |
| R | R project | Y | Y | Y | Y | N | 0 | Y | Y | N/A | N | N | Y | Y | |

| Validation (Example of Item Value) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Value | | 3 | 3 | 2 | 2 | 1 | 3 | 2 | 1 | 1 | 2 | 2 | 3 | 1 | Sum |
| Stella | isee sysems | 3 | 3 | 0 | 2 | 1 | 2 | 0 | 1 | 1 | 2 | 2 | 3 | 1 | **21** |
| iThink | isee sysems | 3 | 3 | 0 | 2 | 1 | 2 | 0 | 1 | 1 | 2 | 2 | 3 | 1 | **21** |
| Powersim Studio | Powersim Software | 3 | 0 | 0 | 2 | 1 | 0 | 0 | 1 | 1 | 2 | 0 | 3 | 1 | **14** |
| Vensim | Ventana Systems | 3 | 3 | 0 | 2 | 1 | 2 | 0 | 1 | 1 | 2 | 0 | 3 | 1 | **19** |
| Anylogic | XJ Technologies | 3 | 3 | 2 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 3 | 1 | **15** |
| Dynaplan Smia | Dynaplan | 3 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **4** |
| GoldSim | GoldSim Technology Group | 3 | 0 | 0 | 2 | 1 | 1 | 0 | 1 | 0 | 2 | 2 | 0 | 1 | **13** |
| Berkley Madonna | | 3 | 3 | 0 | 2 | 0 | 3 | 0 | 1 | 0 | 2 | 0 | 0 | 1 | **15** |
| Expose | Attune Group | 3 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 3 | 1 | **9** |
| Simile | Simulistics | 3 | 3 | 2 | 2 | 1 | 3 | 0 | 1 | 1 | 2 | 2 | 3 | 1 | **24** |
| Simgua | | 3 | 3 | 0 | 2 | 0 | 3 | 0 | 1 | 0 | 2 | 0 | 3 | 1 | **18** |
| TRUE | TRUE-WORLD System Dynamic | 3 | 0 | 0 | 0 | 1 | 3 | 2 | 1 | 0 | 2 | 2 | 3 | 1 | **18** |
| Forio | Forio Online Simulations | 3 | 3 | 2 | 2 | 0 | 3 | 0 | 1 | 1 | 2 | 2 | 3 | 1 | **23** |
| Sysdea | Strategy Dynamics | 3 | 0 | 0 | 2 | 0 | 3 | 0 | 0 | 0 | 2 | 2 | 3 | 1 | **16** |
| InsightMaker | Give Team | 3 | 3 | 2 | 2 | 0 | 3 | 2 | 1 | 0 | 2 | 2 | 3 | 1 | **24** |
| NetLogo | Northwestern University | 3 | 3 | 2 | 2 | 0 | 3 | 2 | 1 | 0 | 2 | 2 | 3 | 1 | **24** |
| SDM-Doc | Argonne National Labs | 3 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **8** |
| R | R project | 3 | 3 | 2 | 2 | 0 | 3 | 2 | 1 | 0 | 0 | 0 | 3 | 1 | **20** |

**Validation rules**

N/A = 0

N = 0

Single license criteria

< 999 = 3

There were following criteria used for the valuation:

- Every analysed feature received a value from 3 to 1. For this example the features considered as most important received value 3, the less important value 2 and the least value 1
- When software contains analysed feature the table shows Y and a software receives value of the feature
- When software does not contain analysed feature (or author was not able to figure it out) the table shows N (or N/A) and software receives 0 value
- Single license price was valued according following criteria:

- Price < 999 => value 3
- 999 > Price < 1.999 => value 2
- 1.999 > Price < 2.999 => value 1
- Price > 2.999 => value 0

- The last column in the table summarise received values (points)

## 4 Conclusions

As one can conclude from system tools listed in this paper there is already a variety of software available on market. Majority of them is available for relatively reasonable price with single license fee counting mostly in hundreds or thousands EURO. Majority of software can work both in Windows and Macintosh environment, some of them also in UNIX or other operational systems. Software's can support various languages and units (metric or others).

Some of the web pages offer ample amount of information that is related either to software itself or to a method used for building software, to business cases and to tutorials and supporting courses.

There are 3 methods mostly used for simulation, those are: agent-based, discrete event and system dynamic methods.

From geographical origin of software one can conclude that United States are the most developed country as regards system dynamic and simulation tools.

## Literature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