Modelling and Simulation in the ERP Systems

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Abstract. The implementation of integrated ERP systems becomes a key factor for effective management of business processes. In same time the ERP systems are a huge investment, and the implementation process is a complex and expensive. The successful implementation and operation of such complex systems can be aided by the use of modern modelling and simulation methods and systems. This article presents an overview of some of the methods of modelling of a variety of processes related to the functioning of ERP systems. Examples of the using of approach of System Dynamics and modelling tool Vensim PLE in the study of the processes of data collection in ERP systems, management of vulnerabilities in information systems, management of costs for ensuring information security and modelling of the effectiveness of the implementation of an ERP system in a manufacturing company are presented.

1. Introduction

In today's globalized and hyper-dynamic business environment, companies face the enormous challenge of fluctuating markets and increasing customer demands. This forces them to optimize total operating costs, shorten lead times for orders regardless of their size, reduce resources used in manufacturing, ensure fixed delivery dates and better customer service, improve quality and effectively coordinate demand, supply and production worldwide [1].

The term ERP (Enterprise Resource Planning) was first used in 1990 by the company Gartner Group and generally replaced the term integrated management information systems. ERP systems are software packages that offer solutions for various business areas - sales, supplies, warehouse systems, accounting, and human resource management, trying to provide software technology solutions for all the main business functions of the enterprise, regardless of its specifics. ERP systems today manage both business and public organizations - up to universities and governments [2].

The decision to implement an ERP project involves a lot of complexity and risks in many directions. Implementation can bring benefits, but it can also be risky. The implementation itself can be successful, but not bring real benefits and efficiency. The ERP system is not only an information system, it also carries an integrated know-how regarding the reengineering of business processes, which leads to user resistance - overt or not, pointed or not. Countering these problems requires careful advance research and planning. In parallel, it is necessary to conduct training and engagement activities for staff.

The best approach is to pre-model and simulate the operation of the system before proceeding with the implementation of the ERP systems in the organizations. But modelling the functioning of systems during operation is also extremely important because the optimization of the functioning of management systems is a constant process caused by the restructuring of the market and legal environment.

This article reviews the methods of modelling of modern ERP systems. The modelling of development, implementation, and functioning processes using specialized modelling methods and tools is a possibility for optimization of managing systems.

2. Modelling and simulating of information systems

Modelling is a process of creating a model, in the case of information systems mathematical, virtual, digital, software, which represents a system with typical properties of the system that is the object of modelling. The model more or less resembles the real system. The purpose of modelling is to create a tool for investigation the real system. The model aims to establish the main characteristics of the system, which are defining for it from a certain aspect. Existing systems can be modelled as well as those yet to be designed and built. Individual processes, part of the system's functioning, can also be modelled. Mathematical modelling describes the object or system by creating a mathematical model, which in turn allows the use of software tools developed specifically for modelling purposes.

Simulation is a process of studying and analysing the behaviour of the system by imitating the behaviour and using the already developed model. A simulation works on the mathematical or software model that describes the system. In a simulation, one or more variables are changed and changes in other variables are studied. Simulations allow users to predict the behavior of the real system. Simulations help to optimize information systems at the stage of design, implementation, operation and update. The goal is to achieve desired and necessary changes and results without interrupting the operation of the system and without risking loss of data and functionality. Simulations help to learn and test systems in more detail in other than specified nominal modes of operation.

The model can be considered static, but the simulation is always dynamic, since it is a process of changing the input parameters of the studied object and monitoring, recording and studying the output. Nowadays, both modelling and simulations are performed using specialized computer-based systems and applications that play a major role in science and engineering.

In all modern ERPs, three parallel systems work at the same time - development, live and test. The live system is the real, live working system, the development system serves for the development of new applications and functionalities by developers, the test system is using for training new users and testing new functionalities, for example, updates caused by legal changes. This is opportunity to test new functionalities with book of data from a real system. It is also a way to optimize and scale already deployed and operational systems.

The main application of modelling and simulation of processes related to ERP systems are:

- At the stage of preliminary research and formation of a reasoned decision for implementation;
- At the implementation stage of the selected system;
- Modelling economic aspects of the implementation and exploitation stage;
- Modelling of individual functionality of the systems, for example, the process of data collection and transfer;
- Improving existing processes, exploring the possibility of adding new functionalities.

Various methods and software tools can be used to model and simulate the functioning of ERP systems. We will present some of them. Along with the development of information technology and management theory, ERP systems and models for their implementation are also changing. In parallel with the development of ERP systems, supplier and implementing companies also develop methodologies and modeling tools supporting implementation processes.

Before the modern cloud technologies, the ERP system was deployment on premise and relatively similar deployment models were used ASAP from SAP [4], Application Implementation Method (AIM) from Oracle [5]. The processes were grouped into several main stages that defined the implementation activities step by step.

Many other companies offer their own implementation methodologies and models [6]. Most of them are used all over the world and have proven the effectiveness of their use. Which model will be used depends mainly on the business model of the organization and the ERP system to be implemented.

3. Specialized software tools for modelling and simulation of modern ERP systems

In parallel to the development of ERP systems, specialized tools are also being developed - software systems for preliminary simulation of the work of the system at the stage of research and selection of the functionalities of the selected ERP system, for parallel study of the work in the implementation process and for optimizing the work of the already implemented a working ERP system. Major suppliers of management information systems develop their own tools for simulating the operation of ERP systems, which are widely used to train students and users of the systems.

Examples of this type of systems are SAP's ERPsim [7] and Oracle's Oracle Project Management [8]. The ERPsim tool developed by SAP is a unique product that allows modelling the management system, to optimize already implemented systems by predicting the functioning of business processes, to train users of ERP systems, as well as students and project engineers. ERPsim is a simulation tool for SAP ERP and SAP S/4HANA in which users play a real ERP system to run a virtual business in a competitive environment. Users improve their knowledge of business processes and understanding of how ERP systems work in a playful, stress-free way. Real transactions in a real live SAP system as well as custom transactions are used, which is similar to the daily work of ERP users.

The company ERPsim Lab, HEC Montréal, Canada [9], provides training of specialists and users of ERP systems from all over the world and students from more than a hundred universities. It’s provides access to a real SAP HANA system covering all processes in the business organization. ERPsim supports real-time analytics, from SAP Fiori analytical applications to OData (from Open Data Protocol) services for migrating from older to newer versions of the ERP system, as well as many of the BI tools available on the market, including SAP Lumira and Power BI.

Together with the development of the cloud ERP systems (ERP II), the web services supporting the customers in choosing the specific functionalities of the ERP system are also developing.

An example of such applications is the SAP Best Practice and SAP Rapid Deployment Solutions sites developed by SAP [10]. SAP Best Practices is used to accelerate customer’s SAP cloud and on-premises implementation projects. There is uploaded lots of excellent examples and content on the benefits and value of using them in SAP implementations. SAP Best Practice contains a catalog called SAP Best Practices Explorer showing the company's entire portfolio. It can be searched by selecting a business or technology area, searched alphabetically or by keywords in the search box. Using provided models is easy to understand the scope of packaged solutions and get more details on already implemented projects. There are also a lot of links to download the entire package or individual documents, such as hardware and software requirements. Access to this content is free after registration.

4. System Dynamics. Dynamical modelling tool Vensim PLE

The system dynamics approach was developed by Forrester [3] and his colleagues at MIT (Massachusetts Institute of Technology) for modelling of management of industrial processes. System dynamics is based on the theory of nonlinear dynamics and control developed in mathematics, physics, and engineering. Mathematically, the basic structure of the system dynamics model is a set of linear or nonlinear, related equations for first-order differentiation. Using the system dynamics approach to analyse specific problems consists of three steps:

- Creating a model for presenting the studied structure.
- Establishing the functional relationships between the variables in this dynamic structure. These relationships can be analytical, empirical, or numerical in nature.
- Starting from a set of initial values, calculating all variables simultaneously with a given iteration step for a predefined period of time.

There are many dynamic modelling systems, but in recent years Vensim (www.vensim.com) has become increasingly popular. Vensim is an object-oriented system for modelling and researching complex dynamic systems, developed by Ventana Systems, founded in 1985 in Harvard, Massachusetts. Ventana Systems develops simulation models that integrate both business and technical elements to solve difficult management problems. To reduce the development time of the model, Ventana Systems began to create its own simulation language. This language, called Vensim, was originally developed as an extension of Pascal, so models developed in Vensim are translated into an execution program [11]. Over the years, the system has been constantly evolving to become a popular modelling environment used by professionals and beginners. Ventana Systems offers both - licensed and free version of Vensim for academic purpose.

Vensim PLE (Personal Learning Edition) is a version of Vensim that has been designed to the beginning system dynamics modeller. In same time PLE is fully functional system dynamics software that is free for personal and educational use and comes complete with sample models and help engine. Vensim, the Ventana dynamical simulation environment, is an interactive software environment that allows the development, exploration, analysis, and optimization of simulation models. A models created with this software are simpler and more understandable than models created with typical modelling programming languages.

5. Dynamical model of data collection in the ERP systems

Vensim PLE models are built as causal diagrams [11]. The stocks are represented by rectangles (variables in the field), and the processes are represented as arrows with valves that can control the change of the studied quantities. The clouds at the end represent sources or vice versa, absorbers, of the quantity being transported. On Figure 1 is presented simple model of data collection.

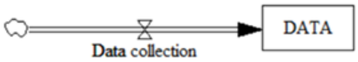

FIGURE 1. Simple model of data collection using Vensim.

Data stocks are also called integral or state variables. The rates are time derivatives. Or it's model of the following process:

$$D(t) = D_0 + \int_{t_0}^{t} DC\, dt,$$

where D is Data, D_0 is start quantity of data, DC is rate of data collection, t_0-t is working interval.

The sources of data collection and methods of data transfer can be divided into three main groups – users of information system, intelligent sensors and external information systems [12]. The Figure 2 illustrates the process of data collection in ERP systems, covered the three data sources.

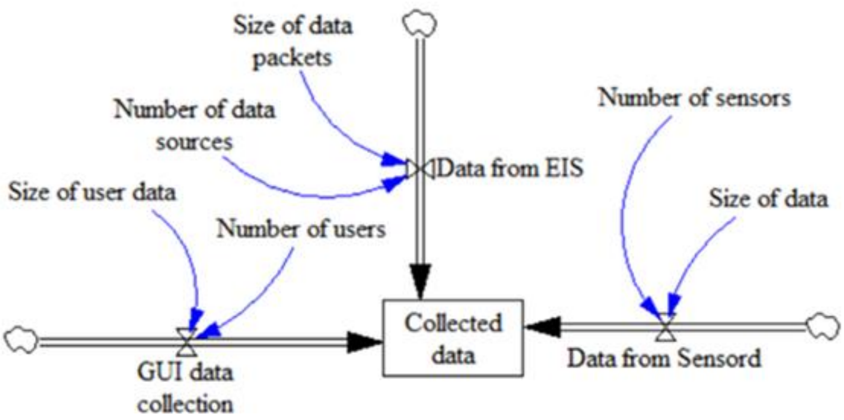

FIGURE 2. Simple model of data collection process using Vensim PLE.

Two important simplifications are made in building this model - the first is that the data sources generate a constant value of data over time, and the second is that there is no loss in the collection and transfer of data to the database. Therefore, a more complex model of this process is presented in Figure 3.

This model accounts for the non-uniform generation of data because of user activity. For example, it is known from practice that the peak load of the information system is at the beginning of the work shift. This is the result of authenticating users and reading initial information. In this model, the peak of the work shift, the period of peak load and the maximum volume of generated data - load are taken into account. This model also includes the processes of data transfer to the data center and their verification. Also shown are the processes of using data and generating new ones from the application layer, as well as the processes of optimizing the database according to criteria that are outdated and not used for a long time.

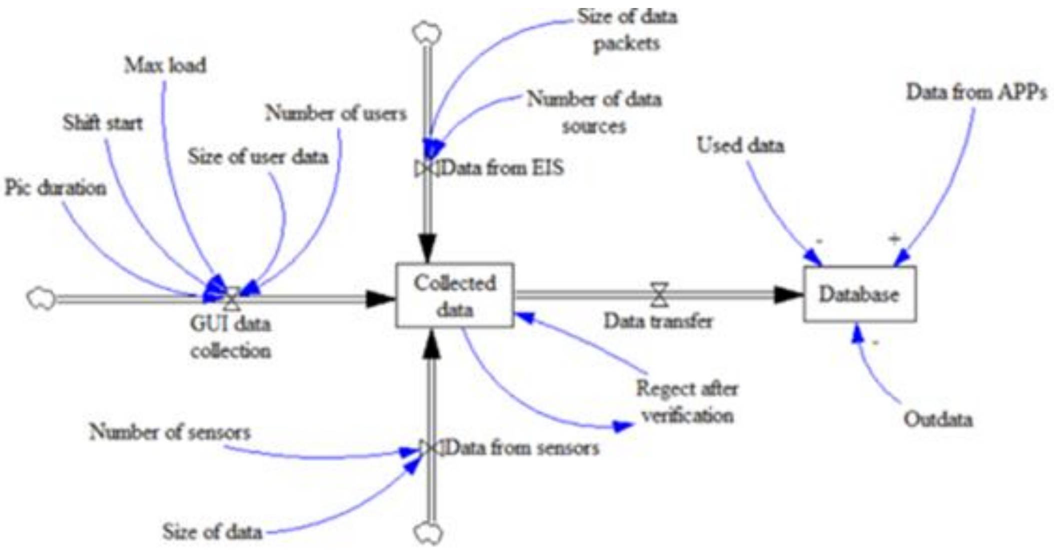

FIGURE 3. Model of data collection, transfer, and processing.

The process of data collection can be simulating using tool Simulate or SyntheSim. The SyntheSim is a very useful tool from Vensim PLE for online step by step simulation of processes, an example of simulation is shown in Figure 4.

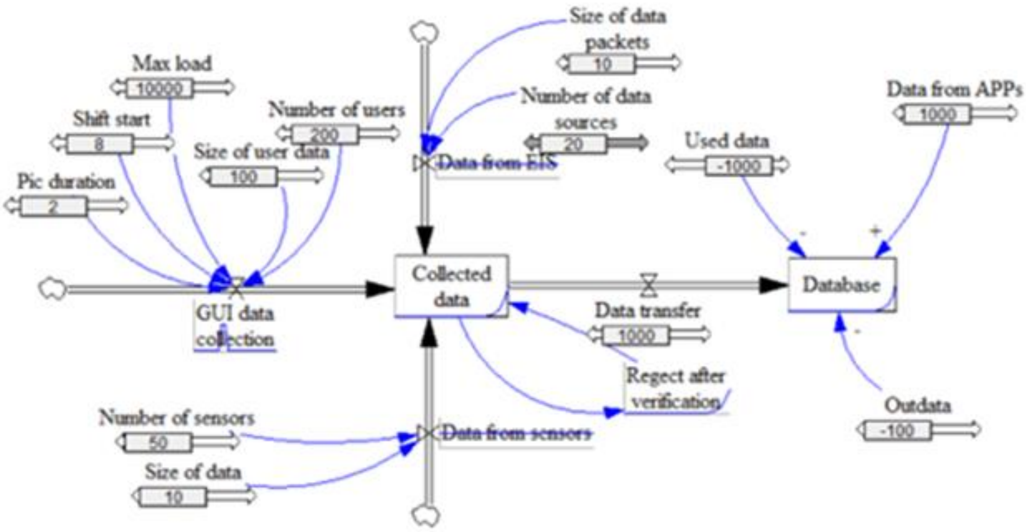

FIGURE 4. Simulation of the model using SyntheSim function of Vensim for 24 hours working time.

This presented model was set for simulation of 24 ours working period, using statistical data from middle size plant, for example, with 200 user, 10 EIS, 50 sensors. Moving the sliders of the variables, the model of the process of data collection and transfer to database can be specified to concrete plant and respectively ERP management system – structure, data sources (quantity and size of information packages), methods of security data transfer, database, and data processing. On the simulation is visible pic load at the beginning of shift (rate GUI data collection).

The results of the simulation can be useful at the stage of designing the structure of the information system for sizing the channels for data transfer and predicting the required volume of the database. Also, can be used for troubleshooting and reengineering of implemented systems. It can also be useful for diagnosing data transfer problems, for example using a specialized device to consolidate data before transferring it to the database, especially for cloud web based ERP systems.

6. Dynamical model of vulnerability discovering and patching of information systems

ERP systems are designed for integrated management of complex business processes and are subject to attempts to block competitive business on the one hand and attempts to acquire sensitive information on the other. Therefore, information security is extremely important. Vulnerability management [13], [14] is a general term used to describe tasks such as technical cyber security, scanning for possible vulnerabilities, finding possible solutions to eliminate attacks through these vulnerabilities, testing these tools and applying them to information systems. These are vulnerability management practices with a focus on the positive action of identifying specific systems affected by known (post-disclosure) vulnerabilities and reducing the risks they pose by applying mitigation or remediation measures such as patches or configuration changes to methods and systems for data transfer.

The vulnerability management process involves several phases, usually sequential in time. The phases are based on the ISO/IEC 3011 Standard [15] expanded in the CERT Guide for Coordinated Vulnerability Disclosure and can be summarized below:

- Finding vulnerability. Much of vulnerabilities are reported to be fixed, but there are also malicious researchers looking for them in order to destroy systems.
- Informing service providers of service providers.
- Vulnerability analysis and prioritization by the service provider. Similar signals from other customers are usually checked as well.
- A fix or fix plan - ideally software patch.
- Public awareness – the vulnerability and the plan to fix it are disclosed to the public and specialized organizations.
- Applying the fix is applied to deployed systems.

The System Dynamics approach and Vensim PLE is a perfect method for analysis of the cybersecurity vulnerability management process [14]. There is presented detailed examples of modelling of all phases of this process. For example, process of vulnerability discovery and fixing process.

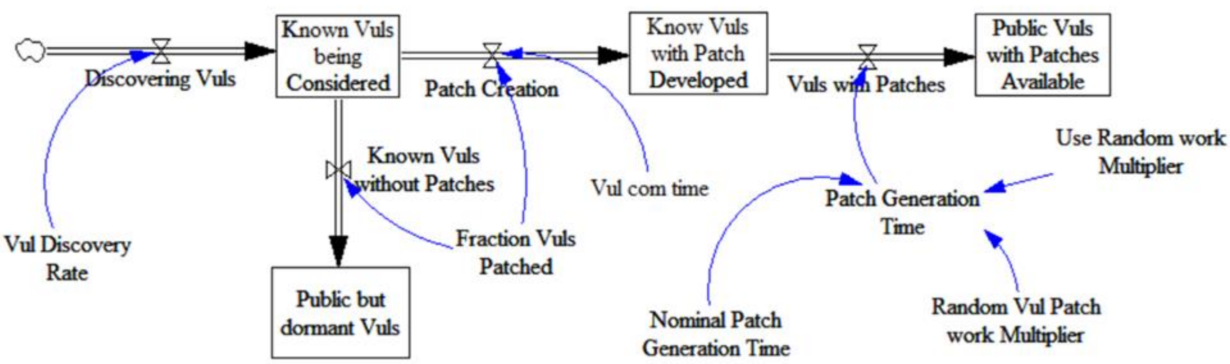

FIGURE 5. Model of vulnerability discovery and patching process [14].

The Figure 5 is the illustration of the process of vulnerability detection and patching process. Vulnerabilities are discovered, patches are created for most of them. After creation of patches and testing, they are implemented and made publicly available for public access. This model can be run using average patch generation time as a constant the model and using a random time-averaged vulnerability patch multiplier. Based on a analysis of the vulnerability operating factor, a multiplier is chosen from an exponential distribution. Some passive vulnerabilities remain passive only until they are used in an attack, in which case they are becomes an urgent need to block.

The corrections are generated in the same way, but there is an acceleration factor due to the urgency of the correction. This factor is a parameter of the model, as we do not yet have reliable data on the increased patch rate for urgent vulnerabilities. Some of the vulnerabilities are never fixed; they are called public eternal vulnerabilities. Vulnerabilities become public knowledge the day they are discovered and remain dormant until an emergency patch is generated.

This model can run in one of two modes: one that uses an average patch-generation time as constant in the model and one that uses a random vulnerability patch work multiplier of that average time. In the same study, this model is upgraded and simulated using statistical data. Comparison of the simulation-derived data with consolidated reports from blocked cyber-attacks demonstrates the fidelity and utility of the proposed approach and the model built with dynamic modeling tool Vensim [14].

7. Dynamical model of information security investments.

Information security management is an increasingly serious challenge to business especially after implementation of cloud ERP systems and using of Internet as the business platform. Because of the complex nature of the information systems and the large number of variables and processes but in same time limited resources information security problems are area of permanent investigations.

The system dynamics is approach to security analysis, with the help of an information security life cycle model [16]. By identifying the objects of attacks, effectivity of the attack, quantity of attacks, is possible to develop a system dynamics model for analyzing the effect of security investments.

Figure 6 shows system dynamics model for the attack stage from external hackers [16].

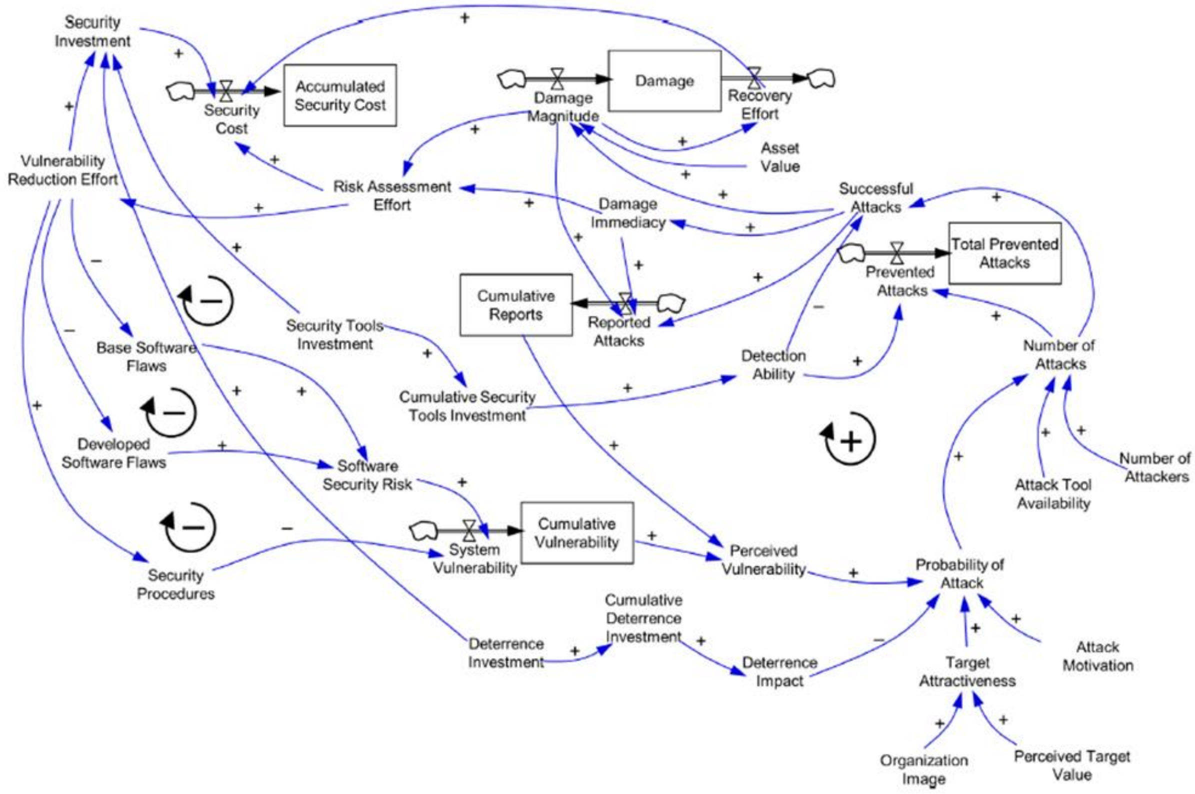

FIGURE 6. System Dynamics Model of the Attack Stage [16].

The information security investments increase the costs of attack, reduce the benefits of attack, and add to the difficulty of attack. In this model, investments in this stage take several forms:

- Human resources policy.
- Detection technologies.

- Attack deterrence technologies and procedures.
- Vulnerability information value reduction.

The last category includes such actions as parsing corporate data into small clusters, removing sensitive information from vulnerable servers, and segmenting objects using neutral indexes, all aimed to reduce the value of information and information systems to potential attackers. The other investment categories should be self-explanatory. These investments are the controllable variables in the model; all other variables are either directly or indirectly influenced by them. The uncontrollable variable that is of particular interest is the total number of attacks on the information system of the target firm, which is expected to be reduced to the extent possible with the above investments.

The embedded logic of the model in Figure 6 is as follows. The total number of attacks predicates on the total number of attackers, internal and external, and the availability of hacking tools, which increases the productivity of attackers. The number of external attackers is an exogenous, uncontrollable variable, while the number of internal attackers is represented as a percentage of the total number of employees in the firm and can be reduced by the investments in human resource policies that the firms undertake to minimize the incentive for attacks from within. The number of attacks is also a function of the probability that a potential attacker would actually attack. This attack probability is a feedback variable from the reinforcing causal loop.

Attacks are known to the firm only when they are detected, and the extent of detection increases with the investment in intrusion detection technologies. The detection of attacks has two effects.

As the number of detected attacks increases, the number of identified vulnerabilities also increases. The more identified vulnerabilities there are, the more attractive the firm’s information systems are to the attackers, and the more incentive for the firm to invest in reducing the vulnerability. On the other hand, the need for deterrence increases with the number of detected attacks, and the investment in deterrence would reduce the attractiveness of the target.

In summary, while the attractiveness of the target increases with identified vulnerabilities, it is diminished by investments that reduce vulnerability and increase deterrence. The attractiveness of the information target is also influenced by the perceived value of the target, which can be reduced with appropriate investments. The probability of attacks is a function of the attractiveness of the information target to the attacker. The model closes and completes the causal loop by connecting the attack probability as a functional argument of the total number of attacks.

The results, based on a few scenarios, show that the common security approach concentrating security investments in the technical areas such as intrusion detection and vulnerability reduction is less effective in reducing the number of attacks than a simplistic approach, where investments are equally divided among all the available security measures. The sensitivity analysis validates the stability and logical structure of our model.

This model presented in this study serves as a proof of concept for the system dynamics approach in the field of information security. This model offers interesting practical implications. The most important conclusion is that each element of security protection systems has its own importance, and directing investments in several directions, neglecting others, cannot give positive results. Even huge investments, if not properly allocated, will simply turn into big expenses without a significant improvement in cyber security.

8. System dynamical model in manufacturing with implemented ERP system

A system dynamics approach is also used to illustrate how manufacturing processes and efficiency are changes after implementation of ERP system. For example, the performance changes under different scenarios using real case data in the textile and garment industry [17]. The results of simulating highlight the role of the ERP system in interaction with the production system. In this paper is presented model of textile production on the base of system dynamic model. The model of the manufacturing process of custom textiles products is built based on the popular Sterman model [18].

The model again is build using Vensim PLE. This is the typical model of a make-to-order system with basic functions to manage the supply and movement of materials and production processes. The simulation model is modified for the specific type of production - textile manufactured goods by orders. Stock and flow diagrams reflecting the dynamic structure of the model and the interrelationship between variables are presented in Figure 7.

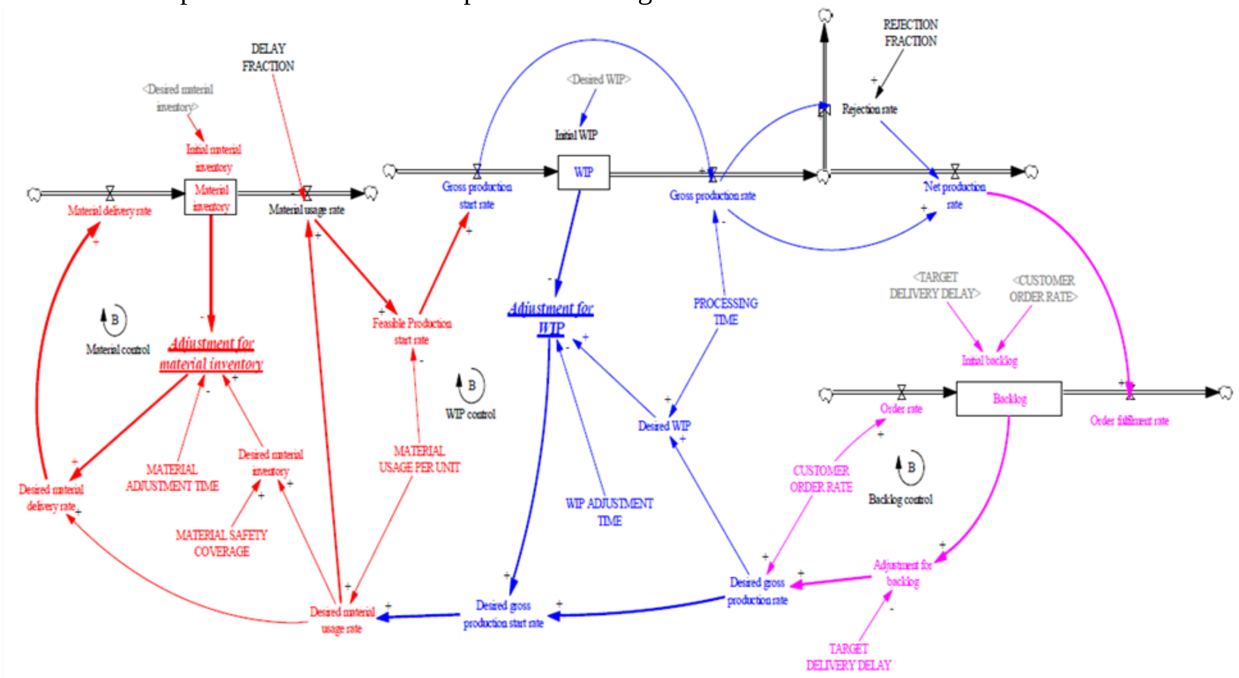

FIGURE 7. System Dynamics Model of the textile manufacturing [17].

This model presents the manufacturing process with three modules: order execution, material management and production. Stock variables are illustrated by rectangles. Flow rates are pipes with valves that lead into or out of stocks. The arrows also present the relationship two variables. Auxiliary variables in upper case letters show constant input and those in lower case letters are converters.

The auxiliary input variables include:

- Customer Order Rate.
- Rejection Fraction.
- Delay Fraction.
- Material Usage Per Unit.
- Material Adjustment Time.
- Material Safety Coverage.
- Processing Time.
- Work in progress (WIP) Adjustment Time.
- Target Delivery Delay.

A Figure 7 illustrates the main activities of a particular production company. Improvement activities and various control methods work to improve the value of auxiliary input variables. In this study [17], it is assumed that the structure of the production processes and, accordingly, the management methods are constant.

The purpose of the ERP system is to unify and effectively manage information flows in the organization [19]. The implementation of ERP requires the regeneration of most processes in the production organization. Therefore, the authors are united in this research, improving processes using Lean principles. In this study, the authors assume that materials-related activities are only improved through Lean manufacturing, while transaction-time activities can be adjusted by the ERP system.

Regarding the application of Lean, the impact of Lean principles on production parameters in the textile industry was found in the literature review to have the following improvements - 30% in productivity, 50% in inventory, 80% in quality or 65% on average [20]. The effect of ERP on transaction time has not been considered so far, therefore, in the case of ERP application, 25%, 50% and 75% improvement in transaction time is assumed.

Real data are used for simulation purposes. Since the data is collected for one year, the simulation is set for one year, which is 269 working days. The results of simulation show that the system needs few days to come in steady state. For model validation are used real historical data from middle size plant. The difference between simulation and real results is around 3%. This means that the model structure is proper, and the parameter values are correct. The model accurately corresponds to the real manufacturing. This paper proposes a suitable system dynamical model as an example of ERP-implemented manufacturing. Lean practices must be properly integrated into the ERP system. Therefore, it is necessary for companies to design an ERP based Lean system and build effective Lean practices before they can reap the benefits of an ERP system.

The implementation of even the most powerful ERP system without prior analysis of business processes and reengineering will hardly achieve the set goals - efficiency and flexibility of production process management.

9. Conclusion

This article is an overview of ERP implementation methodologies, both universal and modern designed for cloud-based SAP systems.

Examples of the use of the presented dynamic model of the process of data collection and transfer to the ERP database are shown. It aims to offer a tool for studying the processes in large and complex information systems. This model can be useful at the system design stage to determine the type and size of the database, data transmission channels.

The presented dynamic modelling approach is also successfully applied to modelling the process of detecting vulnerabilities in large and complex information systems as ERP systems. Using this model, the work of applying patches to protect discovered vulnerabilities can be simulated and the most effective directions of impact to improve information security can be determined in advance.

Information security itself requires significant investment. The next proposed model of the investment process for the improvement of cyber security allows determining the most effective solutions depending on the size and direction of the investments.

Finally, system dynamic models can be used to examine the effectiveness of an ERP system implementation.

In all presented examples, the same approach is used - System Dynamics and the same modelling tool Vensim PLE is used for modelling different aspects of the functioning of ERP systems. All these examples can be extended and enriched with new cases of the use of universal methods for the study of various management information systems.

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