ASSOCIAÇÃO DE POLITÉCNICOS DO NORTE **(APNOR)**

INSTITUTO POLITÉCNICO DE BRAGANÇA

"Production Optimization Using Discrete Simulation"

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Bragança, June 2018

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Abstract

Production and manufacturing setups involving lean solutions and customer driven “pull” logic (e.g. kanban systems) are more and more common. Usually, these systems allow companies to increase efficiency, quality levels, work force motivation and general productivity. Although these systems are not too difficult to plan and operate, in complex situations, even small adjustments can produce some unforeseen effects.

In this scenario, discrete simulation can provide the tools to model the underlying systems and test the desired changes before implementation.

In this work we modelled typical pull production systems with more or less complexity using a commercial discrete simulation software (SIMIO). Once the modelling phase was completed, different adjustments in the number of Kanban cards in the system were tested and evaluated, in order to optimize the system.

Also, the final simulation model was built generic enough to be used in classroom environment to familiarize students with pull production concepts.

Keywords: discrete simulation, production planning, pull, kanban.

Resumo

As configurações de produção e fabricação envolvendo soluções *lean* e a lógica *pull* orientada ao cliente (por exemplo, sistemas kanban) são cada vez mais comuns. Normalmente, estes sistemas permitem que as empresas aumentem a eficiência, os níveis de qualidade, a motivação da força de trabalho e a produtividade geral. Embora esses sistemas não sejam muito difíceis de planear e operar, em situações complexas, mesmo pequenos ajustes podem produzir alguns efeitos imprevistos.

Nesse cenário, a simulação discreta pode fornecer as ferramentas para modelar os sistemas subjacentes e testar as alterações desejadas antes da implementação.

Neste trabalho modelamos sistemas típicos de produção puxada com maior ou menor complexidade usando um software comercial para simulação discreta (SIMIO). Uma vez concluída a fase de modelação, foram testados e avaliados diferentes ajustes no número de cartões kanban no sistema, a fim de otimizar o sistema.

Além disso, o modelo de simulação final foi construído de forma suficientemente genérica para ser usado em ambiente de sala de aula para familiarizar os alunos com conceitos de produção puxada (*pull*).

Palavras-chave: simulação discreta, planeamento de produção, pull, kanban.

Аннотация

Организация производства и технологическая наладка с применением концепций «бережливого» и «вытягивающего» производства, ориентированных на нужды потребителя (например, система канбан) получают все более широкое распространение. Обычно, данные системы позволяют компаниям повышать эффективность, уровень качества, мотивацию сотрудников и производительность в целом. И хотя реализация данных подходов не является слишком трудоемкой, в сложных ситуациях даже малейшие корректировки могут привести к непредвиденным последствиям.

В таком случае, дискретное моделирование может предоставить инструменты для создания базовых моделей и их тестирования, до внесения изменений в реальную систему.

В данной работе было смоделировано типичное, более-менее сложное вытягивающее производство с применением коммерческого программного средства дискретного имитационного моделирования (SIMIO). После создания симуляции было протестировано и оценено использование разного количества канбан карт в системе с целью ее оптимизации.

Также, финальная симуляция была создана достаточно общей, чтобы ее можно было использовать во время аудиторных занятий для ознакомления студентов с концепцией вытягивающего производства.

Ключевые слова: дискретное симулирование, планирование производства, вытягивать, канбан.

Table of Contents

List of Figures

List of Tables

Introduction

To complete the most global view of possible outcomes must be calculated a significant amount of information and designed rather detailed simulation model. While modern computer facilities allow calculating very complex simulation models, there is no need to simplify them to analytical solution capability. Computers make it possible to solve complex mathematical tasks; the tasks can be multivariate; in the process of solving it is possible to change parameters and to analyze the results. Modeling helps to illustrate the objective in 2D and 3D, to see personally what is planned.

With the help of computer modeling, it is possible to make a qualitative and quantitative process assessment, to calculate the possible results. But modeling is first of all an instrument to find the most optimal solution. Basing on the model results it can be optimized, improved, the idea can be corrected. That is the final goal of “creative” process for the implementation a new idea.

The motivation for this work was the implementation of a production environment using the *pull* approach to production control, using the Kanban system. The simulation developed are a proof of concept on the topic and can also be used to familiarize students or factory staff with the *pull* approach and Kanban.

This work is divided into 3 parts. The first chapter is dedicated to simulation applications, Simio and Arena software and kanban cards system. At first, it is described, what means the simulation, its sphere of approach, and advantages of simulations use. Following is a description of Simio software. There are mentioned the history of the software, its description, interface describing and the advantages and benefits. Next are discussed the Simio’s competing software Arena. There also are mentioned its background, description, and differences from the Simio software. In the end, the first chapter emphasizes kanban cards system. It is described the concept itself, history of development, sphere of application. Also, are mentioned differences from similar systems and finally advantages and disadvantages of kanban system.

The second chapter covers the methodology of the research.

In the third chapter are presented models of kanban system in the Simio software. There is a simple model, which represents a single stage kanban system as a proof of concept. It is described the structure of the given simulation, how it is used. Following is a complex simulation model example, its description and idea. The chapter then refers to the experiment, which allows to understand the benefit of kanban system in context. There will be described possible scenarios, how they can be built, their results and conclusions.

1. Literature Review

The first chapter of this work addresses:

- Simulation applications. Its meaning, sphere of approach, and advantages of simulations use;
- Simio Simulation and Scheduling Software. The story of its creation, description of program's features and interface, its application, advantages and disadvantages, comparison with competitors;
- Arena Simulation Software. Description and story of creation, advantages and disadvantages, comparison with Simio;
- Kanban approach. The system description, history, field of application, advantages and disadvantages, ways of application and types.

1.1. Simulation Applications

Discrete simulation is one of the most promising modeling methodologies, which is implemented through the simulation software (Vaitechovich, & Franzeskevich, 2014). It allows analysing difficult production systems, to optimize material and financial resources management and to predict the system development dynamic. At present there is an active development of object-oriented visual tools, modern PCs become highly productive, possessing powerful system and application software. This contributes to an effective interaction of human and computer. A simulation model is a special software, which allows imitating an activity of an object (Shannon, 1975). In addition, the simulation also implies the maintaining of the process's logical framework and sequence of events (Pedgen, Sadowski, & Shannon, 1995). The simulation model should present a big number of parameters, a structure, continuity, and patterns of modeling object's behavior. A model gives detailed statistics on the performance of a simulated system (Shelemeteva, & Guseva, 2016).

Popular discrete simulation applications in management are:

- Simulation of business processes;
- Simulation of manufacturing systems;
- Warehouse logistic;
- Integrated processes management on the base of simulation software;
- Supply chain management;
- Digital production.

A simulation model, unlike traditional CASE (computer-aided software engineering) tools giving static images of business processes, is capable:

- To show the process in time development;
- To find out and to demonstrate latent tendencies;
- To give an opportunity to analyze the impact of decisions;
- To assess the influence of various accidental factors and a price risk;
- To make an extended ABC analysis (Selective Inventory Control).

The simulation concept becomes more popular as for tactical objectives of business analysis, so for the strategical planning of managerial situations.

Simulation modeling increases the opportunities for traditional CASE tools and provides:

- Business processes visualization and analysis of weaknesses;
- Ability to collect and to analyze business processes efficiency indicators (time-cost);
- ABC analysis pegged to real-time processes;
- Reengineering implementation, comparison on quantitative indicators of variants “AS-IS” and “TO-BE”;
- Business processes optimization using advanced genetic algorithms.

Simulation models are always dynamic. It allows analysing the business process behavior as a developing process at a certain trajectory over a modeling period time. This permits to predict the future states, progress trends taking into account environmental factors under conditions of uncertainty.

In industrial production simulation modeling is used widely, then in other spheres. There are many reasons for:

- Modern computing production systems and equipment are very expensive and complex, requiring the analysis through modeling;
- An animation visualizing the process flow, and an information derived from simulation model contribute to a better understanding of the ongoing processes and of the consequences of decisions.

The main opportunity for applying the simulation software is the understanding local changes influences on the scale of entire production framework. If there is a change at some working station, the influence on this working station will be quite predictable but it is rather difficult to predict how it will impact on the whole system (Law, & McComas, 1998).

Simulation modeling is used for analysis, planning, and optimization of production systems. It provides an opportunity to asses and to compare a large number of alternative production scenarios.

Discrete systems are production systems where processes and handling are performed on several parts, semi-finished products, etc. May be considered production processes related both to the production of piece-goods and flow line production. Discrete simulation is used to solve different tasks on the strategic, tactic and operational level. In strategic planning, it is to face tasks in cases of creation of new or modernization of an old production. The main goal is to evaluate the functioning of the production system and to calculate the main production indicators. According to results is taken a decision about:

- Types and quantity of equipment;
- The topology of a system;
- Material flow organization.

The simulation model is the basis for investment decisions, the choice of system modernization variant, the assessing options for the system developing and the opportunity to implement "Just-In-Time" and "Just-In-Sequence" approach. Furthermore, simulation is an instrument to run a "What If" scenario without the interference in a real process.

Tactical planning means addressing the challenges of:

- Assessment of the current state and effectiveness of functioning of the current production system;
- Analysis of weaknesses in production;
- Choice of rational organizational and technological structure.

Operational planning and scheduling are designed to build a production schedule for short periods of time – from a few hours to a few days (Estremadoyro, Farrington, Schroer, & Swain, 1997). Simulation model helps to:

- Carry out the current planning;
- Schedule a machine load;
- Make an indicative planning figure and shift-day plan-schedule;
- Schedule the materials delivery and to equip the workshop;
- Optimize the roadmap.

The base for each of the tasks can be the same simulation model, specified and built taking into account the particularities of the task.

Except for the general opportunities of simulation modeling, there are a lot of potential benefits, not only to measure the functioning system but also to improve the efficiency due to:

- Increase in productivity (number of product, manufactured per unit of time);
- Reduction of the residence time of units in the system;
- Reduction in time and work performance lost;

- Ensure the timely delivery of accessories and equipment;
- Reduction in capital requirements and operating costs.

Simulation helps to solve several production problems and to assess managerial decisions, which can be divided into three general categories:

- Estimation of resource requirements and their rational use:
    - Quantity, type, and location of machines;
    - Requirements for loading and unloading devices, and other auxiliary equipment;
    - Storage location and number of stores;
    - Assessment of the changes in the volume of production or in the assortment of goods;
    - Assessment of the impact of new equipment installation;
    - Estimation of investments and operating costs, decline in new production investments;
    - A number of shifts, elaboration of the regulations, etc.
- Performance evaluation:
    - Productivity analysis;
    - Analysis of time while on the system and non-productive time;
    - Review of resources shortage.
- Technological operations, different strategies and scenarios assessment:
    - Technological design and production planning;
    - Material flow synchronization;
    - Inventory management strategy;
    - Transportation management strategy;
    - Study of the reliability;
    - Quality control policy.

The simulation model implementation includes 3 abstract operations. The processing operation is related to product's properties changes and to transportation. The assembly operation is a production process action, resulting in a change of main in-process part by joining another detail. Management operation is a supply of semi-processed goods to a machine, depending on the length and the queue. In production systems are implemented the priority queue method and other actions to control the progress of the proceedings. The important parameter of a production line is a process duration, which can be:

- Determined – in this case, the implementation's regularities of individual operations in the production process are determined strictly;
- Random – it is given as a timing function with random deviation.

There are also processes with constant and variable duration.

The first step making production system simulation is to define its elements, their duration distribution and other parameters. The elements can be machines, working places, elements of processing, transportation or storage. May be considered the devices incidental to machine load with workpieces, to processing, diagnostics, transportation and other, which perform the productive operations, processing operation and are marked by time delays and operational costs. In describing the production system, the following characteristics should be set:

- A quantity of machines;
- Individual characteristics (the operation number, the machine number);
- Timing function of the processing.

The main material flow characteristic is the flow intensity. In the simulation model are set:

- Batch workpieces arrival time;
- Quantitative data: size, weight, temperature, etc.;
- Qualitative data: color, flaw, expire date, etc.

The interoperation of material flows and equipment elements is described in the simulation model based on several operational rules, defining:

- Path technologies;
- Rules for order processing sequence;
- Handling procedure of the same products: fixed means each operation is processed on the specified machine; free means the operation can be processed on every available machine;
- Way to set the item for the processing: sequential, parallel, sequential-parallel, etc.

The whole production system includes all production activities, such as buffer store, material flow, and structure.

Several performance indicators are used, obtained from examining the production system simulation:

- Performance;
- A quantity of goods produced, processed and the volume of the end product;
- Operational profit margin, work in process costs, material costs, including resources costs, flaws, losses, and outage;
- Duration of manufacturing cycle;
- Order processing time, current costs for work implementation;
- In-process queue time, product's duration time in a queue;
- Transportation time, timeliness of delivery, waiting time;
- Work in process volume and queue size;
- Time losses related to machines outage: the time when the machine waits for new items, blocked or in service;
- Machine workload;
- A quantity of defective products.

In the general case, the production system is considered in simulation as a stochastic system. The possible abnormality of the production process can occur due to 3 stochastic factors, which are usually considered in a simulation model. The irregularity of timing – problems resulting in loss of working hours, unforeseen immobilization of equipment. The peculiarities of production processes can be related to:

- Downtime, a line at occupied machines;
- Lack or delays in the arrival of items;
- Transportation failures, late intermediate goods, and raw material delivery;
- Under-performance. If the real performance indicator doesn't match to performance standard, it can lead to production failure or to defective products.

Generally, the operational time is a random value given by cumulative distribution function.

Defective products involve time losses and material losses in production. In the simulation model algorithm usually sets the flaw expectation. It is a random value to produce an acceptable or defective product. In the general case, the probability of rejection depends on semi-finished product's and machine's parameters.

Equipment dependability is an important source of accidents. It is linked to machines' crashes and unplanned downtime. Processes, which are connected to equipment revamping are also usually simulated. In general terms in simulation model are set time-to-failure law and recovery time, and are modeled breakdowns and equipment recoveries.

The main source of random values in production systems' simulation models are:

- Products, orders and raw materials arrival time;
- Processing, assembly and control time;
- Time to system failure;
- Machine run time;
- Machine repair time;
- Loading and unloading time;
- Fitting time, necessary to equipment changeover
- Probability of reconstruction;
- Passing rate.

A unique element of a production system is a warehouse, which is not considered as a service system and in general case is characterized by:

- Holding capacity, number of units of issue, amount of reserve stock;
- Inner status: running inventory at stock;
- Stores management strategy, which is described by:
    - Critical stock level;
    - Size of a batch of supplies;
    - The time between supplies, etc.;

Management on a production scale means an effective inventory policy, which implements the synchronization of supply flow to the warehouse with the flow for sending while minimizing costs for storage, transportation, warehouse rent, etc. Tasks under inventory policy include the determination of (Vieira, Dias, Pereira, Oliveira, Carvalho, & Martins, 2015):

- Amount of storage;
- Volume of storage;
- Size of supplying batch;
- Allowed storage time.

The main rules and control values of a storage simulation model are:

- Supply policy: regular, dynamic, etc.;
- Supply batch size: fixed, depends on currents storage status, depends on vehicle capacity;
- Time between supplies;
- Critical stock level;
- Sizes of a warehouse;
- Allowed storage time.

Modern warehouse construction and equipage with necessary equipment and technic requires substantial investments. That is why it is important to design it before the beginning of construction. The designing requires to take into account a lot of parameters in collaboration with clients and building organizations. Success work of warehouse depends on how well it is organized. This is usually done by the companies that deal with logistic audit, consulting and engineering. The simulation model is useful in reconstruction or building of a new storage both in logistic center infrastructure and technological designing. Simulation helps to optimize investor's expenditure. The warehouse infrastructure projecting includes:

- Building the warehouse with maximum possible capacity and performance, basing on the analysis of topological map of the area;
- Choice the location and parking places sizes;
- Defining exchange area, packages selection, and storage area;
- Defining the necessary number of gates in the warehouse;
- Defining necessary resources, functional zones sizes, etc.

The simulation model with help of 2D and 3D animation allows to see and to analyze the future work of warehouse before its construction and if necessary to make adjustments to the project. It helps to be sure in the optimality of the chosen storage technology and declared resources. Moreover, it is possible to simulate different strategies, to choose the best one of them and so to reduce the project budget and operating costs.

The main goals of a warehouse technological designing are:

- Improving the warehouses' utilization;
- Reducing the service time;
- Investments in the warehouse building and equipment reducing.

Tasks, which can be solved using the simulation modeling are:

- Defining the number of men-machines resources, providing handling with external and internal material flows;
- Defining exchange area, packages selection, and storage area;
- Testing effectiveness of different variants of layout solutions for storing goods and order batching;
- Choice of most effective cargo flow processing technology:
    - Search for efficient algorithms to manage cargo flow;
    - Development of cargo flow technology;
    - Development of algorithms for multiproduct storages (organization of pallet, box or piece selection);
- Planning of procedures and timetable for completing operations of incomes and expenditures at the warehouse;
- Effective scheduling of works;
- Defining the level of stocks taking into account supplies and possible demand;
- Counting operating costs and their optimization.

Simulation helps to:

- Consider seasonality and peaks;
- Simulate flow in time, possible project characteristics on the big period of time;
- Evaluate the influence of stochastic and uncertainty factors;
- Play difficult technologies and algorithms in cargo flows processing and organization of storing;
- Choose the optimal decision.

Often simulation method is used also by designing and re-engineering logistic networks. Logistic implies system approach to integrated and dynamic management of material, financial, informational flows in the organization. Development of simulation modeling, and its use for logistic network management today has become a necessity and reality alike. Simulation makes it possible to see the process development to the plan and project realization, as well as visualizes varied and complex processes and enhances the full-scale understanding of logistical processes, what makes the simulation very important in the logistical audit. Further, the simulation demonstrates material flows and their complex interaction with financial, transportation and informational flows. The model makes able to automate the process of survey alternative options to choose and to provide optimal solutions based on advanced heuristic genetic optimization algorithms, which are used in logistical networks reengineering. The simulation allows not only to describe and to measure performance indicators by all key and operational features of supply chain but also provides instruments to choose optimal material sources, infrastructure of production and logistical capacities, characteristics of processes and flows for the whole chain, taking into account future demand, costs, capacities and other internal and external factors. The simulation allows assessing the consequences of several operations before they are implemented in a system. Else it helps to conduct a comprehensive review of possible developments, which helps to make optimal managerial decisions. Modeling allows not to interrupt the system work when it is necessary to compare different decisions and also reduces the duration of the decision-making process. Proper use of such models provides accurate risk and profit assessment in different possible future operating activities. Guided by complete and reliable information relating to a wide range of possible future operational activities, managers can make informed supply chain management decisions.

Benefits of using the simulation for logistics systems are:

- Comprehensive understanding of processes and characteristics of logistic chains with help of charts and animation;
- Opportunity to take into account the stochastic nature and dynamic of several external and internal factors. A user is able to simulate random events in specific areas and identify their impact on the logistic network, using probability distribution;
- Opportunity to reproduce system dynamic, to reflect dynamic of logistic processes nature and abundance of time and cause-and-effect relationships (e.g. consumers demand is usually stochastic and dynamic, running inventory is a dynamic parameter);
- Multistage design procedure allows to consider the complexity of decision making, a large number of decisive rules and optimization parameters;
- Availability of several acceptable decisions;
- Risk minimization because of possible plan changing, due to initial analysis and possible scenario simulation;

Main tasks to design the logistics network are:

- Maximum integration of logistic functions all over the whole logistic network;
- Capacity planning;
- Material flows synchronization;
- Materials and capacities coordination;
- Increase in productivity;
- Prevent losses from outages;
- Weaknesses analysis;
- Production, storage and transportation costs reduction;
- Consumption demand assessment and planning;
- Improve purchase order compliance;
- Choice of rational variant of business organization;
- Supply chain optimization.

Supply chain optimization allows to implement:

- Effective meeting demand;
- “Just-In-Time” strategy realization;
- Costs minimization along the entire logistics network;
- Investment planning and development.

Hallmark of logistics networks is that many types of resources are mobile objects (means of transporting). Such simulation model describes processes of movement and goods accumulation. There are parameters, which define the model condition and which are changing in time according to operational rules.

To create logistical network simulation, it is needed to fill it with some data. Production process and its time intervals:

- Production process: process implementation duration, prioritization of processes and time frames, amount of equipment in each process;
- Scheduling: data on shifts, weekends and holidays, prophylactic works;
- Equipment: its amount, mean time to failure, to repair, data on alternative resources, prophylactic works and its utility value;
- List of materials and material flows characteristics.

Inventory policy: guaranteed inventory level of stock and materials, fill rate.

Information on delivery:

- Delivery lead time;
- Drop Size;
- Supplier’s capabilities;
- Delivery forecasting time-frame;
- Delivery time.

Demand:

- Payment deadline;
- Priorities;
- Delivery initial and final time;
- Demand pattern and dynamic.

Policy and strategies:

- Alternative solutions and scenarios;
- Inventory policy;
- Marketing policy.

Simulation of the supply chain on strategical, tactical and operational levels is a traditional field of using simulation instruments. Complex strategic simulation of relationships between production, transport, and distributive chains allows companies to create optimal and resistant to market fluctuations strategic model of transport chain, to determine chain development strategy. Furthermore, the following tasks can be solved:

- Choice of best policy and parameters of supply chain administration;
- Identifying weaknesses in existing distribution chain and solving solutions development;

- Most rational network objects utilization, taking into account business restrictions; supply chain safety buffer defining in case of jump in demand or problems in supplies;
- Carrying-out of “What-If” and risks analysis;
- Fixed and variable distributive network costs reduction with help of “What-If” analysis and comparison of the result before and after;
- Service and customer experience improvement;
- Budget and timing data planning;

The simulation system of strategic optimization is used for new resources other strategic decisions analysis, such as new factory building construction, estimating of breakeven prices for resources purchase and supply chain for new product engineering. The goal of such system is net profit or return on investments improving. Tactical optimization simulation model establishes an integrated plan of stock supply, production and distribution for the whole distribution system for the following 12 months. Its goal is to reduce logistics meeting demand costs or to increase net income.

Simulations can be an important tool for managerial decision-making and have a number of benefits, which are:

- Consistency in solving complex managerial situations on supply chain designing, including a large number of requirements (supply patterns and channels, inventory strategy, planned production capacities, distribution network structure and parameters under uncertainty of external environment and demand);
- Mainstreaming uncertainty. Uncertain factors are future demand, competitors’ prices, delivery time, consumers flow intensity, and interest rate change;
- Alternative solutions comparison according to simulation received and deferent policies impact analysis;
- Multiple results monitoring. Complex simulations can be used for different factors dynamic tracking, particularly for profit, sales volume, costs and client layer;
- Simulation model using doesn’t have any risks of its own accord. Moreover, without simulation different strategies would have to be tested in the real world, what can bear the risks on the contrary. For example, simulation allows to change the good price and to watch the impact on sales volume.
- Costs saving. Simulation models are relatively cheap. It is possible to check different situations and so to save money for small price of simulation and for small period of time.

To summarize, it can be repeated, that simulation modeling is going to be used for wide range of management tasks both in big and medium-sized business. In purchasing management, it could be a model, which provides a simulation of automated order for goods placement and which considers different parameters such as prices, logistic endurance, goods quality, costs minimization, etc. The model helps to analyze specific ordering policy and to understand if there could be some problems. In distribution sphere simulation modeling can be used both on the stage of distribution network building and on the operational stage, which includes defining an optimal place for distribution centers, transport flow planning, warehouses, logistic costs analysis, etc. In transportation field simulation helps to choose types of vehicles and routes, transport operators, and logistics partners. In stock management simulation is used to rate the service quality, to define safety and operational stocks. In warehousing, it is appropriate to apply simulation for defining parameters of stocking system, for evaluating and choice access point and warehouse complex variants, for evaluating different technological solutions, etc.

The most effective use of simulation models is on pre-implementation stage and to design new or to modernize the current system. On these stages is the highest risk to make wrong decisions, the price of which is rather high.

1.2. Simio

Simio Simulation and Scheduling Software was developed in 2006, by the Simio LLC, which was founded in 2005. Founder and CEO of the company is Dr. C. Dennis Pegden. He has over 30 years of experience in the field of simulation and scheduling. Before he founded Systems Modeling Corporation, he had taken part in the development of such computer simulation software as SLAM, SIMAN, and Arena. The system Arena is focused on business processes. That are any systematic activities in a very broad sense. The Arena software has certain strengths but like any other products it becomes outdated. Thus, it should be replaced with another software (Borshchev, 2015). The Simio software worth particular attention at least because it was developed by the same people, who took part in the development of the Arena software. While keeping the advantages of the Arena software, the Simio software brought new opportunities with a view to compliance with the new requirements. The company tagline is “Forward Thinking” (Yakimov, Kirpichnikov, & Rodina, 2016).

The perfect combination of modeling and planning makes Simio one of the most advanced products on the market of simulation programs. The Simio system is a software with object-oriented processes and objects, defined in a graphic form without requiring programming. The program allows “rapidly build accurate 3D models and objectively analyze alternatives to reduce risk and improve performance”. It makes possible not only to improve the efficiency of the business from the perspective of object design but also to maximize the results of business processes by optimizing the use of resources and by the ability of risk assessment, related to business solutions. Simio can be used to model a wide range of systems, including manufacturing, healthcare, supply chain, transportation, defense, and mining.

“Simio is a simulation modeling framework based on intelligent objects”. Objects can be borrowed from other projects, stored in libraries and used in other projects and built by modelers themselves. This is how is realized the opportunity to simulate without requiring programming. The objects can be machines, vehicles, workers and different other elements. The Simio models look like the real systems. It is possible to show the model in 2D and 3D, to change its view and to download models from the 3D Warehouse. The apparent advantage of the system is the full support of both discrete and continuous systems.

Simio contains 6 classes of intelligent objects:

1) Fixed objects, that can be used for submission of the whole modeled system or its parts, which are not moving at launch (Source, Server, Sink).
2) Links define the motion path for Entities and Transporters. They also transfer Entities between two Nodes (Connector, Path, TimePath, Conveyor).
3) Nodes are points of intersection between communication links and ways in and out of fixed objects (BasicNode, TransferNode).
4) Agents are used for object's behavior simulation, which can be dynamically created and destroyed. They are able to move, recognize, pursue and capture other objects.
5) Entities are used for simulation of the behavior of objects, which can follow the working flow in the system (ModelEntity).
6) Transporters are used to transfer Entities through communication links.

A user can switch between 2D and 3D views. 3D allows to change the view aspect, to enable the camera rotation continuously around the model, to choose the ground color, to set time of day and much more. 3D mode also allows to make changes in the model and to see immediate results.

Like most other simulation systems, Simio allows to see the results of the work of the model. The system can provide the results in the form of the pivot table (PivotGrid) or the report. The pivot table allows to group, sort or filter indicators and to export them in .csv format. The report makes possible to show results in the form of a traditional report, which is convenient to use for the following printing, or reporting.

Separately worth noting, that Simio developers provide a collection of free training videos for learning the program, which it is easy to get directly through the program. Furthermore, there are plenty of materials on the internet.

In summary, it can safely be said, that Simio is up-to-date, constantly improving system, which has several undeniable strengths, making it one of the most promising products on the simulation software market.

1.3. Arena

Software "Arena" is created by Rockwell Software (before Systems Modeling Corporation), is a software for discrete simulation, which allows creating dynamic system simulation, which can be used to implement big amount of real systems. The first version of the Arena software was created in 1993. It has easy-to-use object-oriented interface and can be adapted to all kinds of subject areas. In general, the system is rather easy.

Arena software is a pack, which includes the Arena simulator, the Input Analyzer (for input analysis), and the Process Analyzer (PAN) (for output analysis). The advantages of Arena could be:

- Its relatively small price;
- The software is easy-to-learn;

- The software can be used for large projects.

The base of Arena software is simulation language SIMAN and the system Cinema Animation. SIMAN was first created in 1982 (Shsherbakov, 2012). It is a “high-level language”. It means users can develop their code by using built-in templates for entities, processes, and queues. It is always being improved by adding new features. To show the result of the simulation is used animation system Cinema Animation, which is known on the market since 1984. The simulation creating process is following:

1. A user builds the model in Arena simulator;
2. The system is generating the appropriating SIMAN code;
3. The Cinema Animation starts.

Arena interface includes all kinds of tools to work with data, including spreadsheets, databases, ODBC, OLE, DXF supporting. Arena includes Application Solution Templates. Each template represents set of special modules, which make Arena task-oriented simulation environment. By creating or changing these templates, it is possible to adapt Arena to address the challenges facing users (Yakimov, Kirpichnikov, Mokshin, Kostukhina, & Shigaeva, 2014).

Arena software includes the following basic elements:

- Create and dispose;
- Process;
- Queue.

Models can be much complex. They can include hundreds of elements of different types. Elements, working with entities (e.g. Server) can have different states, like “waiting” or “working”. Each state can have its own image and so simulation model can be animated. Arena software has set of image examples.

It is not always possible to create a simulation without preliminary business processes analysis. That’s why functional and simulation models don’t replace but complement each other. In doing so they can be closely linked. Simulation model gives more information for system analysis. The analysis results, in turn, can lead to changes in the simulation model. Most appropriate is to build the first functional model and then at its basis to build the simulation model. To support this the functional simulation toolkit BPwin is able to convert IDEF3 (Integrated DEFinition for Process Description Capture Method) diagrams to Arena simulation model. As simulation model has much more parameters than IDEF3 diagram, BPwin can set these parameters.

Arena is used often in universities because it is relatively easier to teach Arena. But on the other hand, due to alternative software, including SIMIO, has better animation and visualization capabilities, Arena is less used in business projects. First of all, Simio is more intuitive, because it is built around the concept of intelligent objects. Simio is based on the drag-and-drop placement of objects, instead of logical modules. In their turn, objects represent physical components in the real system, what helps more to imagine the future system. Secondly, the cause can be that Arena is mainly two-dimensional software (2D), with limited post-processed three dimensional (3D) viewing capabilities. Real-time, interactive 3D visualization provides a more visible advantage in verification and validation. Perhaps, it engages stakeholders emotionally, makes them trust more (Theodore, 2011).

1.4. Kanban

In the modern world, there is special attention paid to time and costs reduction. Firms try to minimize inventory. The stock in today's business becomes one of the basic management utilities, that provide success of a company. Due to the broad implementation of flexible manufacturing systems there appeared more opportunities to optimize a flow of goods and to create flexible workshops, where the supply of required components and semifinished items are being implemented by robots, controlled remotely. They are also aimed at minimizing an inventory.

Kanban is a system of planning and management of inventory and material flows between separate operations with an aim to produce and supply parts and semifinished goods with zero defects at the time what consumers need (Kniberg, & Skarin, 2009). The point of the system lies in the fact, that the primary inventory in its amount suits the needs of the initial stage of a production process and is not accumulated. The system was created and first time realized by the Japanese firm "Toyota". In the year 1959, this firm started experimenting with the kanban system (Monden, 1998; Welgama, Mills, & Osmond, 1995). Since 1962 was started the global use of the system. The theoretical basis of kanban system finds its start in the ideas of F. Taylor (1856-1915), who was one of the founders of scientific management; of H. Ford (1863-1947), who started the mass production of the automobile industry. The word kanban comes from two Japanese words: "KAN" – Signal and "BAN" – Card or Board, hence kanban is considered to be actually a signal card. The system uses such cards as signal cards to point out the need to add or to produce a certain number of items. The kanban system organizes the production process so, that at all stages of the production cycle required components are delivered to the place of the subsequent production operation "Just-In-Time", what means when it is necessary (Pisuchpen, 2012). And finished products are produced and shipped when there is a demand for them in a distribution network. The kanban system provides the performance of production orders not by weeks but by days or even hours. Whereby the production control is realized by the workers.

Usually, kanban is a plastic card. There are two types of cards: card of selection and card of production order. In the card of selection is identified the number of workpieces, which should be taken at the previous step of processing. Meanwhile, in the card of production order it should be specified the number of workpieces, which should be produced at the previous section of processing. These cards are used both inside of the factory and between firms-suppliers. In the kanban system there is no strict plan of production. There is the only general scheme for providing the calculation of demand for inventory and workers at each production sector. The comparison between a scheduled and actual volume of output at the end of each time cycle is not necessary, because the plan can be automatically corrected during the process of production.

The kanban system is based on:

- Strict quality control at all levels of the production process;
- High qualification of workers;
- Increased responsibility of workers;
- Close cooperation with suppliers.

The kanban system implies specific approach to the selection and evaluation of suppliers, based on working with a narrow range of them, selected by their ability to guarantee the deliver “just-in-time” and high-quality. Furthermore, the number of suppliers should be reduced and with the rest of the suppliers should be set the long-term economic relations. The head office provides to the suppliers their help, aimed primarily at the improving the quality.

The main principles for the functioning of the kanban system are the following:

- Providing all materials in the relevant quantity and quality to the moment and the place of their use;
- Replacement of inventory with the information about the possibility of their rapid acquisition;
- Replacement of the selling policy for produced goods with the policy of producing saleable goods. That means renunciation of surplus production;
- Providing the flexibility of production and rapid adaptability to the changing requirements of the market. That means the use of several cheap machines instead of one expensive but all-purpose. That means also, that workers are allied professionals;
- Debureaucratization: avoiding of paperwork in favor of oral instructions. Refusal of unnecessary administrative workers;
- Reduce the number of suppliers;
- Implementation of all orders in the best possible way and as soon as possible.

If to use the permissive interpretation of kanban concept, considering that it refers to any system, based on cards, then most of the companies can say, they use kanban system. For example, in manufacturing industry, there is for a long time a standard operating procedure to supply the order during the production process with a card, known as workflow chart. Such cards have nothing to do with kanban system, because they are used in the system based on “push” principle, while kanban uses “pull” principle. The difference between these two principles is described in Table 1 on the next page.

Table 1. Differences between push and pull systems.

Push	Pull
Production	
Maximum capacity utilization, continuous production	Production is oriented on changing demand
Production management	
Centralized operational production management	Decentralized operational production management
Production planning	
Planning start from preparation sector	Planning starts from assembly stage
Performance requirements	
Single-functioned workers	Allied professionals
Suppliers	
Significant number of suppliers, irregular supply, mainly large consignments	Small number of suppliers
Inventory	
Excessive material resources, availability of finished goods	Virtual absence of inventory and finished goods

Source: Author's own elaboration.

The vulnerability of the planning the demand for materials system lays in fact, that it is based on guessing of certain trends. It is necessary to predict customers demand and product manufacturing time. However, mistakes in forecasting lead to increasing of excess inventory. Until recently it was considered, that “push” system would eventually be displaced with computer system of planning. But the Japanese “pull” system, called kanban reject this prediction. Kanban provides the production of details as the need for them arises. At the same time there is no need in guessing about future trends in demand. But there is a serious restriction for use the system kanban. The system is only effective in conditions of “Just-In-Time” system, especially in reduced time of equipment readjustment and size reduction of product shipment. “Just-In-Time” system can be used without kanban system but kanban cannot be used without “Just-In-Time” (Minovski, 2007).

According to the kanban system at “Toyota” every type of product has its own container, designed for a strictly certain number of items (Schonberger, 1982). There are two types of cards, which show the number of product, its number, and another information. One of the cards is a production card, used for the sector, where the product is produced. Another card is a shipping card, which serves the sector, where the product is used. Each container goes between the production sector and the sector of product usage. During the process, one card is replaced by another.

Implementation of kanban system is used almost at all enterprises producing piece-goods and can’t be used in nonstop production. But the system provides a benefit only in following cases:

- It must be a “Just-In-Time” process. It makes little sense to implement the “pull” system, where to pull the necessary workpiece it takes considerable time. Exactly this situation appears at the companies producing batches and spending many hours on equipment reconfiguration. The main point of "Just-In-Time" system is to reduce the set-up time and the production batch's size so that it becomes possible to reduce the time of pull.

- Workpieces in kanban system should be used in production every day. A worker should always have at least one full container with them, which will be used the same day. That is why companies usually use kanban system in the production of mostly used products.

The kanban system is not used in the production of expensive or large-scale product. Maintenance and storage of such product is very expensive.

It is very simple to use the kanban system. But it is not so easy to implement kanban. The system needs the substantial reduction of changeover downtime and time of re-equipment. So, the system implementation is very expensive (Monden, 1998). But after the implementation costs are paid off and major economic impact is achieved through the rational use of materials, the productivity and quality increases (Müller, Tolujew, & Kienzle, 2012).

The main advantages of the kanban system include the following:

- Production is oriented on the market – reduction of unnecessary inventory leads to reduction of the entire production cycle, what leads to faster response on market changes; allows to change production volumes faster; allows to predict more precisely;
- Building long-term partnership with suppliers;
- Reduction of equipment downtime;
- Inventory optimization;
- Decrease in processed batches;
- Reduction in defectives and improvement in quality.

There is a simple explanation of this advantage. Since the production is in small batches, if the worker produces the object and gives it to the next worker immediately, he will be made aware at once if his object is defective. As a result, defective items are identified immediately.

- Almost total elimination of work-in-progress production;
- Better use of production and storage spaces;
- Increased productivity.

The workers are encouraged when they solve some production problems. Generally, they respond with approval to all process improvements.

However, the implementation of kanban system outside of Japan caused a lot of difficulties, from lower supplier's discipline to territorial disunity of suppliers and consumers. That is why in Japan the distance between the factory and companies' suppliers is much lower than in Europe or USA. So, some not Japan firms use kanban system only partially, often in combination with other management systems.

2. Methodology

The second chapter will emphasize the problem, which is possible and convenient to solve with the help of Simio software and kanban cards system.

The Simio software is used in production, and not just, to represent explicitly the functioning of the system. The program is also useful for healthcare, military, airports, manufacturing, supply chain, ports, mining, lean-six-sigma and other disciplines.

As was mentioned above, the point of use the kanban cards is that in the first stage of some process the volume of inventory was not excessive but was consistent with the requirements (Hao & Shen, 2008). The material is delivered to each stage, whether it be production, or delivery, according to “Just-In-Time” concept, what means, when it is really necessary.

Since the kanban system doesn’t have strict rules on the number of used cards, it should be calculated an optimal number of cards for each situation.

Turning to production, there are two types. The first is normal production – to sell what is produced. In this case, the price equals the sum of profit and losses. The second type is lean production. That means, that the profit equals the difference between the selling price and the losses. In this case, however, the selling price is defined by the market. And by reducing the losses there is an opportunity to influence the profit. According to the lean production, the selling price, defined by the market, depends on how appropriate customers expectation regarding to product or service quality and time frames are. Meanwhile, losses are results of activity which customers don’t want to pay for, which doesn’t have any value for them.

The kanban system suits the economical production as well as possible. It is aimed at reduction of losses. At first, let’s see how it could be in general, and after in context.

First will be considered the types of losses, which it is possible to reduce with the help of kanban system implementation:

- Overproduction;
- Transportation;
- Waiting time;
- Inventory;
- Defects.

The result of overproduction is an unnecessary product, which makes no profit. It has a negative effect because it:

- Increases storage costs;
- Increases cost as a result of excessive use of materials and resources;
- Delays supply schedules;
- Possible is a cause of forced discounts.

To get rid of overproduction is possible if:

- To produce only Just-In-Time;
- When there is a demand for the product;
- To producing small parties;
- Being able to adapt the production for another product.

Costs for unnecessary transportation lead to losses too. Whereby transportation means not only from one warehouse to another, or to consumer. In this case, it refers also to movements between production stages. There the sources of losses can be poor logistics organization. In this way kanban cards can help to organize the transportation more optimal, to reduce the distance, or to deliver the product just when it is necessary.

The causes of losses, as a result of waiting time can be production planning not for consumer's needs but for equipment loading. Again here, kanban system can help to signalize, when it is necessary to start the process.

If to talk about storage costs, about excessive inventory, kanban cards allow getting rid of non-demanded production in the way, that it will not be produced ahead of time. Here it is also very important to find the balance between production and distribution.

As it was already said in the first chapter, by using kanban cards system, usually it is produced a much smaller amount of production. Therefore, when the product moves to the next stage of production, it is easier to detect defective product and to react. Consequently, only small amount of production will be defective, which will reduce losses from defects.

Above it was mainly mentioned about the use of kanban cards in production. However, they can be used within different activities. For some time kanban cards are a lot used in IT sphere when implementation of the plan is less important than the speed of response to changes. Furthermore, kanban cards system can be found in the shops, cafes, and restaurants. There are used not physical cards but services to make orders from suppliers automatically when it is necessary. One of the most frequently mentioned examples referring to kanban system is recharge of shelves with the groceries in supermarkets. They are recharged not when the supplier ships new party but at the moment when the shelves become empty. So, the kanban cards system is applicable in a sufficiently large number of activity fields.

In the third chapter, there will be a particular example of kanban cards use – the pick-up point place. The problem lies in following. "Raw material" arrives at the warehouse. There are three stages of processing and the final stage is the place of pick-up the product by the consumer. On each stage, the raw material is marked with a kanban card. Before it travels to the next stage, the card is detached and sent to the start of the stage. Meanwhile, the material moves to the next stage and is marked there with new kanban card. To introduce greater clarity, let's assume that the "raw material" is furniture components:

- On the first stage of process items are captured from the warehouse;
- On the second stage they are checked for defects;
- On the third stage they are packed into boxes;
- On the last stage customer takes the box.

The idea of kanban cards, in that case, lies in the fact, that on each stage there will be:

- Optimal number of items: enough to assemble several units of furniture and at the same time they were not lying stagnant for a long time.
- Necessary number of boxes for the following stage;
- Optimal number of already packed items so that clients were not detained for a long time in pick-up point.

Simio software allows to do this as follows:

- Probable frequency of customer arrival is calculated;
- The time spent to deliver everything from the warehouse to pick-up point place is taking into account;
- The simulation with received data is established;
- Empirically with the help of the tool "Experiment" is found the required number of kanban cards (or other parameters) so that time of customers being in the system, the volume of prepared production and number of cards will be balanced and optimal.

Therefore, we considered in theory, how the realization of kanban cards system is possible, how to do this in Simio and why it is necessary at all.

3. Computational Implementation

In this chapter we will be developing two simulation models: a simple model representing a single stage kanban system just as a proof of concept and as a possible building block for more complex production setups. We then develop a more complex model (a multi stage kanban system) for demonstrating the many possibilities of using simulation to fine tune kanban systems.

3.1. Simple Model

This first model implements a single stage kanban system. There is one machine where some processing is done in one product. After the processing finishes, the product is moved into a kanban supermarket where it waits to be consumed by the costumer. The production and the amount of inventory in the supermarket is controlled with kanban cards.

The kanban signals could be invisible, but we opted to model them visually in order for the simulation to be appealing and easy to understand.

The Figure 1 demonstrates the simple model of how the kanban card system can be implemented in the Simio software.

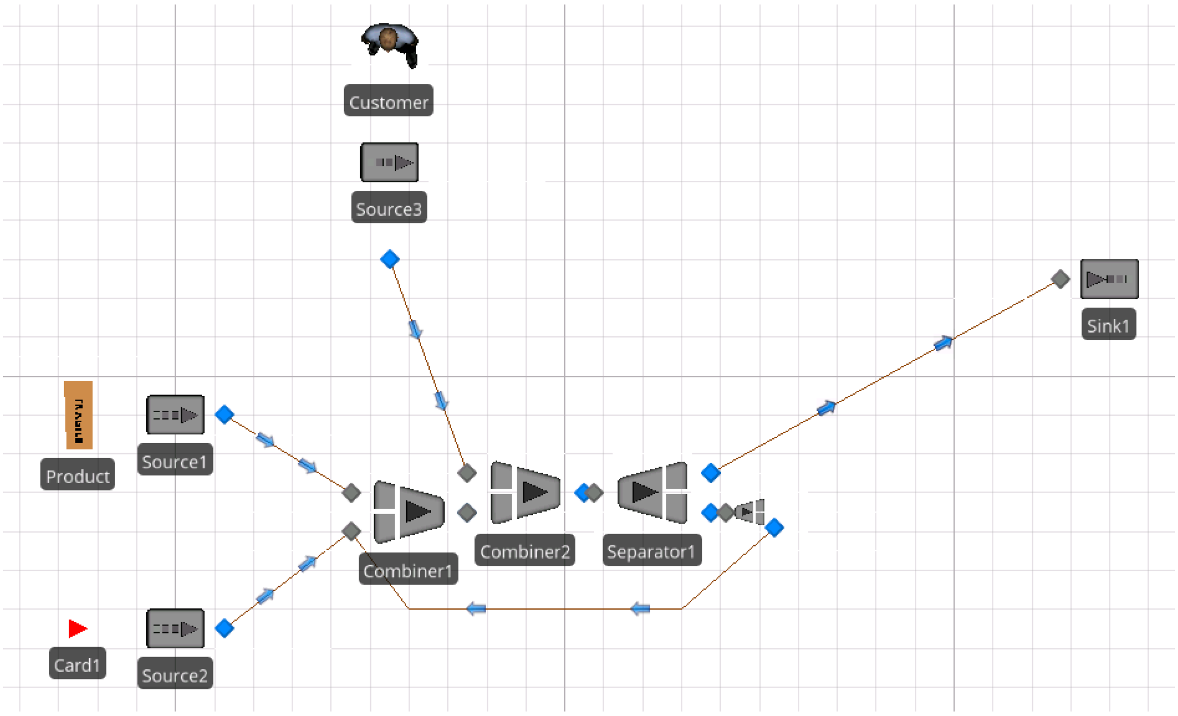


Figure 1. Simple model example.

Source: Author's own elaboration.

To create this product in Simio we need following objects:

- 3 sources;
- 3 entities: customer, product, card1;
- 2 combiners;
- 2 separators;
- Sink.

Sources create entities customer, product, and card1. The kanban system in the Simio software can be realized using a block of combiners and separators, which are illustrated on the Figure 2.

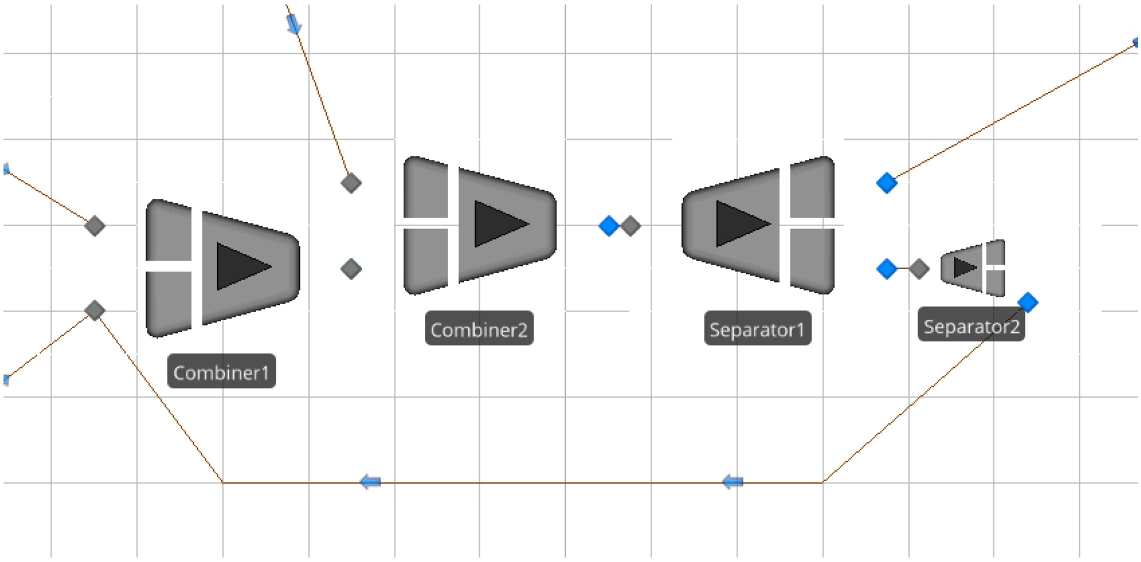


Figure 2. Kanban block.

Source: Author's own elaboration.

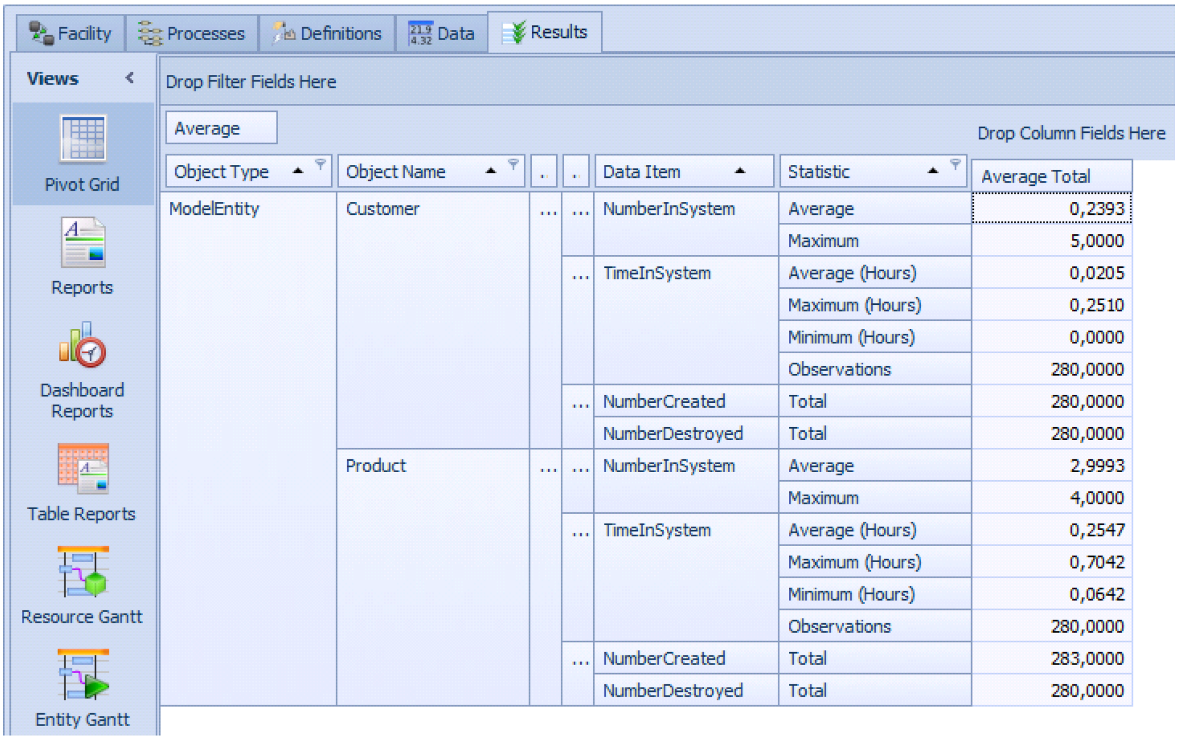
The entities Product and Card1 are combined in a batch with the help of object Combiner, what represents the processing of product and the attachment of a kanban card. Moreover, combiner can be configured to the simulation of some process for a set period of time. When the product is taken, object Separator detaches the card from the product.

In more concrete terms, the Source2 creates in the beginning of the simulation and only ones a number of cards. Each time one of the cards arrives to the combiner 1, the Source1 creates one product. With some frequency the source 3 creates a customer, what represents the arrival of the client. When the card is attached to the product, it waits for the customer. When the customer is attached to the batch of product and card, the card is detached and is sent back to the first combiner, meanwhile the entities Customer and Product leave the simulation. And the cycle continues with new product and new customer.

The whole point of the process is that the production appears in the system in a certain limited optimal quantity and only when the card signals about that, what means only when it is required. That is how the Just-In-Time system is implemented and the number of product in system is controlled. And that is kanban cards system.

The Simio provides the possibility for analyzing the performance of the system. The option “Results” provides access to the pivot grid, where required parameters can be visually evaluated, what is illustrated on the Figure 3. For example, these can be the average client’s time in system or the number of product in system. The information can be sorted and filtered. Further there is an option to export the results in Excel. The software has a tool, called “Experiment”. This tool allows to calculate different scenarios in the system with different parameters. As a result, after the analysis of the required information it can be possible to optimize the system so, that the result will be optimal.

For this simulation, all transportation times are 0, the processing time in taken from a Triangular distribution with parameters 3, 4, and 5 minutes. The costumer arrives according to an Exponential law with an average time of 5 minutes.



Object Type	Object Name	.	.	Data Item	Statistic	Average Total
ModelEntity	Customer	...	...	NumberInSystem	Average	0,2393
					Maximum	5,0000
			...	TimeInSystem	Average (Hours)	0,0205
					Maximum (Hours)	0,2510
					Minimum (Hours)	0,0000
					Observations	280,0000
			...	NumberCreated	Total	280,0000
				NumberDestroyed	Total	280,0000
	Product	...	...	NumberInSystem	Average	2,9993
					Maximum	4,0000
			...	TimeInSystem	Average (Hours)	0,2547
					Maximum (Hours)	0,7042
					Minimum (Hours)	0,0642
					Observations	280,0000
			...	NumberCreated	Total	283,0000
				NumberDestroyed	Total	280,0000

Figure 3. Results tab in Simio.

Source: Author's own elaboration

3.2. Complex Simulation Model

We now model a more complex, multi-stage kanban system with intermediate storage between stages. It is assumed that stages are physically near, so there is no need for implementing transportation kanban.

The simple model from the previous section is used as a building block in this model. Using the block, it is possible to create a more complex system. These blocks will mean some stages along the system. On the figure 4 is illustrated the system, consisting of 3 blocks.

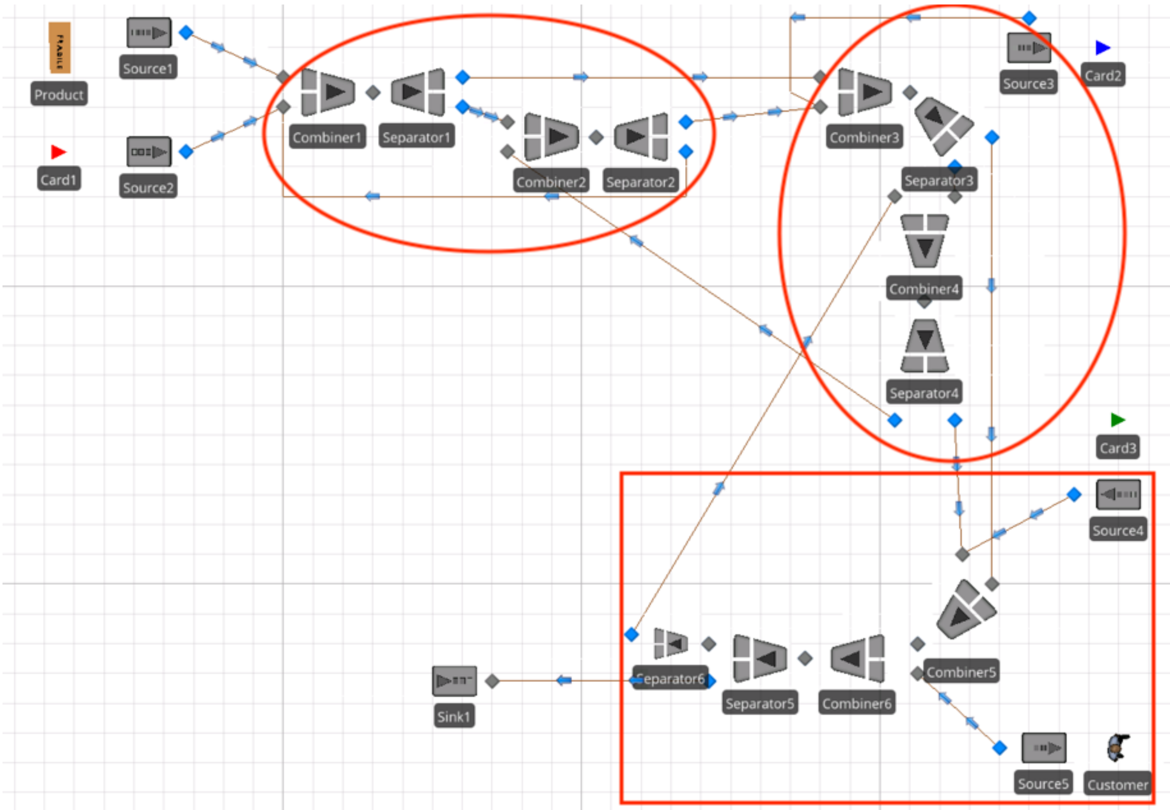


Figure 4. Complex simulation model.

Source: Author's own elaboration

On each stage the product is marked with a card. In the beginning of the simulation sources create 3 cards for each stage. Further, on the first stage product is attached to one card, processed and the card stays at the next combiner, meanwhile the product travels to next stage where it is marked with the new card. As on each stage there are only 3 cards, there are only 3 entities product on the last stage. There they wait for customers. When the client takes one unit of production, the card is detached from the product and travels on the previous stage. There it signals to send the card, which was there to the previous stage, where it signals to send the new entity of product. Thus, the system continues working, realizing the kanban cards system. Every time customer takes the product, it pulls another product from the previous stage, what pulls one more product from the previous stage and so on. That is the pull principle in kanban system.

The system can be modified in different ways. Blocks can be complemented by servers, which will possibly model some more complex processes. There can be very different objects and entities. The distance between the objects can be longer and more realistic to make the simulation more realistic and illustrative. Or it can be used “TimePaths” to set the time of travel manually. The number of all kinds of possible changes in the simulation is rather big. The number of ways implementing the simulation is rather big as well. It can be used to build realistic systems. Or to create some schematic simulations just to find out the possible results. It can be used to study in schools, universities, firms, and so on. Students can visualize the required process, can explore the logic and concept of the simulation process, of kanban cards, the Simio functions and after change and improve the simulation.

3.3. Experiments: An Example

3.3.1. Settings

As was mentioned earlier, Simio software has a tool "Experiment", which allows to create different scenarios of the simulation. It is required in cases when some parameters are changeable and the system should be optimized.

The simulation, mentioned above on the Figure 4, initially has the following parameters:

- On each stage there are 3 kanban cards;
- Each combiner needs 3 to 5 minutes to do processing and attach the card to the product;
- Customer is created with exponential distribution of 5 minutes;
- Entity product is created only when the entity card arrives to the first combiner;
- All the other objects have processing time 0 minutes;
- Time to move along the whole system is 0 minutes too;
- The warm-up period of the experiment is 2 hours;
- The simulation lasts 24 hours.

The changeable parameter in the experiment will be the number of cards on each stage. It will allow to balance the number of production so, that:

- Clients will not wait too much time to take the product;
- Production is not presented in the system too long;
- There will be no excess of production in the system.

We will study in total 12 scenarios, which are presented in Table 2.

Table 2. Experiment scenarios.

	Number of cards in the 1st stage	Number of cards in the 2nd stage	Number of cards in the 3rd stage
Scenario 1	3	3	3
Scenario 2	4	3	3
Scenario 3	4	4	3
Scenario 4	4	4	4
Scenario 5	3	3	4
Scenario 6	3	4	3
Scenario 7	5	3	3
Scenario 8	5	4	3
Scenario 9	5	4	4
Scenario 10	5	5	4
Scenario 11	5	5	5
Scenario 12	5	5	3

Source: Author's own elaboration

Additionally, there can be configured the display of required responses (in practice it would be some key performance indicator), without checking them in the report. For this purpose, we added the following responses:

- Customer's average time in the system;
- Average number of product in the system.

To find out the average data on the simulation, there will be 50 replications for each scenario. As a result, by any criteria there is information about average, minimum and maximum value.

The figure 5 represents, how the experiment looks like in the Simio.

Design | Response Results | Pivot Grid | Reports | Input Analysis

Scenario		Replications		Controls			Responses	
Name	Status	Required	Completed	MaximumArrivals1	MaximumArrivals2	MaximumArrivals3	CustTimeInSyst (Minutes)	PrdNumbInSystAvr
Scenario1	Idle	50	0 of 50	3	3	3		
Scenario2	Idle	50	0 of 50	4	3	3		
Scenario3	Idle	50	0 of 50	4	4	3		
Scenario4	Idle	50	0 of 50	4	4	4		
Scenario5	Idle	50	0 of 50	3	3	4		
Scenario6	Idle	50	0 of 50	3	4	3		
Scenario7	Idle	50	0 of 50	5	3	3		
Scenario8	Idle	10	0 of 10	5	4	3		
Scenario9	Idle	10	0 of 10	5	4	4		
Scenario10	Idle	10	0 of 10	5	5	4		
Scenario11	Idle	10	0 of 10	5	5	5		
Scenario12	Idle	10	0 of 10	5	5	3		

Figure 5. Experiment settings.

Source: Author's own elaboration

3.3.2. Results

In Table 3 are presented all the results of the experiment. We are interested in columns called CustTimeInSyst (minutes) and PrdNumbInSyst. The first column in the responses shows the average customer's time in the system. The second column shows the average number of production being in the system at the same time.

Table 3. Experiment results.

Scenario	Customer's time in the system (min)	Number of product in the system (min)
Scenario1	14.567	3.19904
Scenario2	6.65474	4.20275
Scenario3	6.6164	4.19957
Scenario4	7.8103	4.20063
Scenario5	13.9878	3.19867
Scenario6	14.0175	3.19878
Scenario7	5.84884	5.19727
Scenario8	4.25466	5.19759
Scenario9	4.94753	5.20049
Scenario10	3.95856	5.19783
Scenario11	4.64667	5.20036
Scenario12	4.46795	5.19877

Source: Author's own elaboration

We start from the analysis of the average customer's time in the system. The minimization of that parameter will allow to reduce the customer's waiting time. That will have, of course, the positive impact.

According to the first scenario, we have 3 kanban cards on each stage. In that case average time in the system of customer is approximately 14.6 minutes. Under the second scenario we increased by one the number of cards in the first stage. The average time decreased around a factor of 2 and becomes equal to about 6.7 minutes. Under the third scenario one more card was added on the second stage. This led to decrease by 0.03 minutes of the average customer's time in the system, in comparison with the 2nd scenario. In the 4th scenario another one card was added to the last stage, so there are 4 cards on each stage. In that case the time increased in comparison to the previous scenario by 1.2 minutes.

Thus, we see, that with regard to the customer's average time in the system the third scenario is the most optimal among the presented, because the time is the minimal. And if to add the card on the third stage – time will increase.

On Figure 6 we see, what will happen, if to add kanban cards first on the last stage, rather than on the first stages.

Scenario			Replications		Controls			Responses	
	Name	Status	Required	Completed	MaximumArrivals1	MaximumArrivals2	MaximumArrivals3	CustTimeInSyst (Minutes)	PrdNumbInSystAvr
☑	Scenario1	Compl...	50	50 of 50	3	3	3	14,567	3,19904
☑	Scenario5	Compl...	50	50 of 50	3	3	4	13,9878	3,19867
☑	Scenario6	Compl...	50	50 of 50	3	4	3	14,0175	3,19878

Figure 6. Results 1.

Source: Author's own elaboration

Scenarios 5 and 6 show, that even the time is declining, it is not as effective as adding cards on the first stages, which leads to time decrease in 2 times, what equals almost 7 minutes.

Further can be verified the effectiveness of adding larger number of kanban cards. On Figure 7 we see the results.

Scenario			Replications		Controls			Responses	
	Name	Status	Required	Completed	MaximumArrivals1	MaximumArrivals2	MaximumArrivals3	CustTimeInSyst (Minutes)	PrdNumbInSystAvr
☑	Scenario3	Compl...	50	50 of 50	4	4	3	6,6164	4,19957
☑	Scenario7	Compl...	50	50 of 50	5	3	3	5,84884	5,19727
☑	Scenario8	Compl...	50	50 of 50	5	4	3	4,25466	5,19759
☑	Scenario9	Compl...	50	50 of 50	5	4	4	4,94753	5,20049
☑	Scenario10	Compl...	50	50 of 50	5	5	4	3,95856	5,19783
☑	Scenario11	Compl...	50	50 of 50	5	5	5	4,64667	5,20036
☑	Scenario12	Compl...	50	50 of 50	5	5	3	4,46795	5,19877

Figure 7. Results 2.

Source: Author's own elaboration

Form all the counted variants, the 10th scenario with 5, 4, and 3 kanban cards on the 1st, 2nd, and 3rd stage correspondingly is the most optimal. In comparison with the 3rd scenario the time decreases in about 1.67 times.

On Figure 8 the results for each scenario are illustrated in form of a chart. It demonstrates visually the minimum, maximum and average time, customers spent in the system according to each scenario. The black rectangular box shows the region containing observations between a lower and upper percentile point which are 25% and 75%. The black bar shows the range of all values. The tan box is the confidence interval on the mean, and the blue boxes are confidence intervals on the lower and upper percentile points. The dark tan area is where the confidence intervals overlap. The point in the centre is the mean.

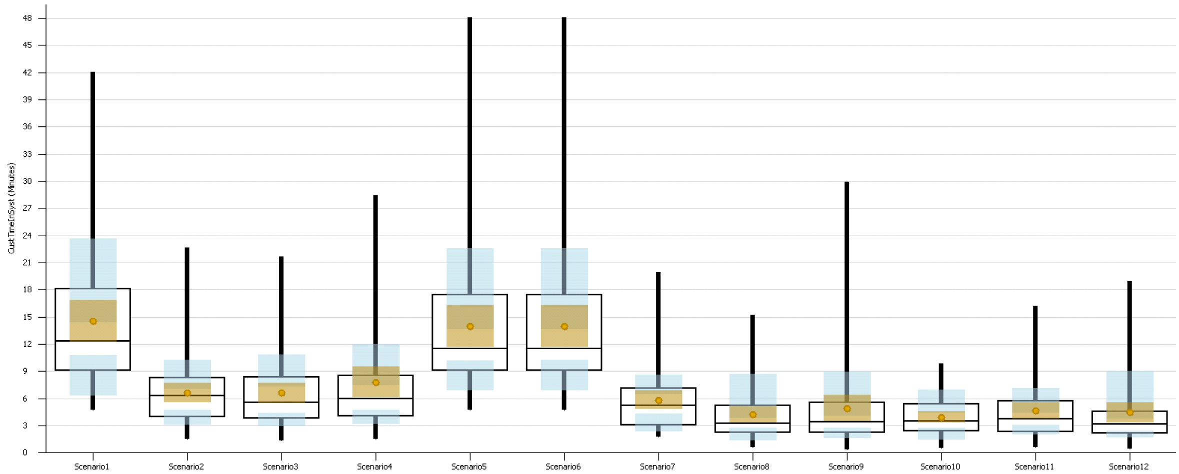


Figure 8. Response results. Chart.

Source: Author's own elaboration

Concerning the average number of product in the system, it is limited by the maximum number of kanban cards on any of the stages. As for the minimum value, it is the first scenario with 3 kanban cards on each stage. The average number of production in the system equals about 3 unites. According to the scenario 3 the number equals 4 cards. And under the 10th scenario these are 5 cards.

From all of the above following conclusions may be drawn:

- The 1st scenario is the most optimal regarding the average number of production in the system;
- Scenario 3 is the most optimal, if to limit the number of cards in the system with 4 cards;
- The 10th scenario is the most optimal regarding the customer's time in the system;
- Scenario 3 allows to reduce customer's time in the system in about 2 times in comparison to the 1st scenario, meanwhile the number of product in the system increases by 1.3 times;
- Scenario 10 allows to reduce customer's time in the system in about 1.67 times in comparison to the 3rd scenario, meanwhile the number of product in the system increases by 1.3 times, comparing with the 3rd scenario.

The conclusions are not surprising, as adding more inventory leads to a better customer service, so a balance must be achieved.

Therefore, were simulated the possible scenarios depending on given parameters. The choice of scenario, certainly, depends on existing requirements, possibilities and priorities.

Conclusion

In this work we implemented a computer simulation of a pull system using Kanban cards. The simulation can be viewed as a proof of concept for implementation of this type of production setups.

The last chapter of the work is a practical part, which allows to see in a context the benefits of kanban system and Simio software. There are simulation models, which are described and explained. In the work an experiment was carried out. In the end are given the experiment's results and analysis of the result.

Due to carried out experiment and analysis we see, how kanban cards help to optimise the production. The advantages of their use are the minimization of customer's residence time in the system and the reduction of number of product in the system. The Simio software helps to get an information about possible scenarios. Basing on that information company can optimize the system according to its requirements, resources, and possibilities.

Limitations and Future Work

Using computer simulation we could implement more complex production environments, like the use of multiple purpose workstations with Kanban controlled inventory. It was not possible to implement such setups in the time span of this dissertation.

We also would like to apply this concepts by modelling a real production environment, so we could see exactly how the simulation models would perform with real data and production setups and constraints.

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