BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS
FACULTY OF TRANSPORTATION ENGINEERING

MODERN OPTIMIZATION METHODS AND PROCEDURES OF INVENTORY SYSTEMS AND PROCESSES

Ph.D. THESIS DISSERTATION

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1. INTRODUCTION TO THE RESEARCH TOPIC, METHODOLOGY, PURPOSE AND ACTUALITY OF THE RESEARCH

1.1 Overview of the problem

The constantly growing competitive market is one of the major motivating factors for developing modern logistic strategies. As a consequence of the spread of developed logistic approaches in the economy the role of the warehouse has changed dramatically in the value chain. The primary aim is to reduce radically the inventory and inventory reaction time to increase flexibility and the adaptability to the gradually more volatile markets. For these reasons on the basis of experience acquired there is a growing need for modern, applicable process control and optimization principles in the area of industry, commerce and service. The goal is to handle the above-mentioned contradictory criteria by applying them, furthermore the processes in the inventory system should operate better serving the above-mentioned progressive logistics strategies and they should become a part of value chain as efficiently as possible according to their modified role ([KM17.]). It has been proved unquestionably that the modified roles of inventory systems can be implemented well only

by applying the adequately prepared technical-technological background system

by storing various materials (goods) flowing in the supply processes for long or short term, furthermore

by applying the adequately prepared information and management background system

and by efficient management and operation information and value-flow relating to materials flow ([KM54.]). In case of the above mentioned conditions are fulfilled, the warehouses and the inventory chains resulting from warehouses are able to regulate the parameters expressed in quantity and time value in the value chain trough inventory stockholding. The main role of the inventory control process in accordance with modern logistic philosophies is to contribute as effective as possible to the economical operation of value chain. The efficiency of the control

process can be measured mainly with the economic performance of the supply, production and distribution systems. The inventory activity in the company logistic system is mainly present in process system including necessary logistic operations, which “produces expense” in most cases therefore its effect is generally negative on the economic performance of the inventory process (exception can be the e.g. the so called wage stock). The main objective is to reduce the negative effect on supply, production and distribution systems led by physical and economic force in the inventory regulation system. The above-described basic framework of objectives can be actualized in various subcategories. Defining precisely the system of target is problematical in many cases, because subcategories of the targets have different opposing intentions ([KM16.], [KM49.]). A further difficulty is to define precisely the described target system (e.g. in text) in parameters, and to write a destination function by using these parameters, which reflects adequately the behaviour of the systems (often with stochastic characteristics) in the light of how parameters change. The next problem is to speculate the form of destination function is very difficult or even impossible; therefore the optimal search can be complicated. The task is more problematical, since the processes of many thousands goods must be optimized regarding to inventory system, which can result optimal search with different targets ([KM11.], [KM69.]). The experience clearly show that the inventory control processes becomes unmanageable in practice without the solution of above mentioned problems, and the task can be solved by depending on exclusively experience and routine.

The above described control problems have appeared only locally in the company’s logistics system so far, but due to expand of globalization trends the problems become more which ”global” in. According to experience the main reason for this is that the earlier local systems (e.g. production companies with relatively simple structure) have grown to large global systems, or become the part of a large global system. As a result of the process, not only to achieve the optimal search within local island system, but the objective changed to the optimal search of global value-added network. This is mainly due to that company system operating close to optimal state locally, but do not operate at all in optimal state according to whole value-added system, which was confirmed by researches indisputably. Therefore there is a need to expand the destination function to be able to examine and optimize the global

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Papers not counted as publications

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[BK9.] Bóna K. (2002), Darabárus raktárak készletezési jellemzőinek meghatározása szimulációs eljárás segítségével. p. 10-12., LOGISZTIKAI HÍRADÓ, 2002. 4. sz.

[BK10.] Bóna K., Kiss N. (2004), A készlet-szimulációval támogatott számítógépes tárolótér tervezés alapvető kérdései (I. rész p. 14-17.), (II. rész p. 8-13.), A+CS, 2004. május-június, július-augusztus.

[BK11.] Bóna K. (2004), Adaptív dinamikus készletszabályzó rendszerek tervezése. p. 29-43., BME OMIKK LOGISZTIKA, 2004. május-június.

[BK12.] Bóna K., Fodor J. (2006), Az ital-nagykereskedelemben alkalmazott információs rendszerek készletgazdálkodási modelljének kialakítási problémái. p. 13-32., BME OMIKK LOGISZTIKA, 2006. március-április.

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Electronically notes

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[BK15.] Bóna K. (2005), Készletezési folyamatok és rendszerek, készletezés-elmélet. Elektronikus egyetemi jegyzet, Budapest. Kereshető: http://www.kku.bme.hu/frame_h.html:

supply network processes. ([KM69.], [KM71.]). According to experience present state of handling inventory problems is that the inventory optimization in the value added systems has not been solved yet even within local systems.

The importance and solution difficulties of the above-presented rather complex problems are supported by the fact that experts of other scientific disciplines (such as economic sciences, operations researches, engineering) studied deeply the above-mentioned questions ([KM17.], [KM21.], [KM22.], [KM54.]). Due to complexity of inventory systems researches have proved that the problems can be dealt with the best if we model the inventory process in system approach, and we examine the parts of the processes with mathematical and statistical methods, we write down the mathematical methods (e.g. variables equation), we write destination function by logical connection of sub process-models and by calculating them we "adjust" the significant parameters that control the system. The literature calls this kind of handling of inventory systems and processes *inventory modelling* ([KM16.], [KM51.]). Recently hundreds inventory models have been developed to handle the various inventory problems ([KM16.]). Their description is generally available, but their efficiency is not proved in many cases (except of the relatively simple models). Besides the mathematical and statistical modelling of inventory system, it is a great challenge to implement the developed mathematical process models into practice. Experience sadly shows there are serious delays in this area; as to model mathematically the operation of stochastic processes requires a rather complex mathematical apparatus. Given the standard of the our time information technology it is out of question that to start the optimal search task should be backed up by information technology, on the other hand it was recognized soon, that due to the complexity of the mathematical apparatus the model regarded ideally can not be solved in requested short time in many cases.

What is the solution? How is possible to build a bridge to connect the literature often full of complicated mathematics and the practice? How would be possible to apply more efficiently the research results in the field of inventory models in the company practice? How to define an ideal modelling method that can be used to reflect relevant processes and relations with satisfactory accuracy? Which optimal search procedures could be applied efficiently to find the marginal values of the destination

functions of the processes? How could we speed up the optimal calculation?

Summary: which procedures can be successful in the future in the field of optimization of inventory system and process operation?

The variety of inventory systems and processes mean a difficult job for experts. However, many believe it can exist an approach of the inventory system, where the goal is to develop an inventory system and optimization model system by using the achievements in an integrated way and practice orientated from the field of technical, economic and other applied disciplines. ([KM51.], [KM54.], [KM69.]).

1.2 The methodology and the main objectives of the research

I have been dealing with the examination of the above-mentioned problems on the basis of theory and practice for over four years. The first main target of my research is greater understanding of scientific results relating to operating of inventory systems and processes, and the examination of their application in practice. In accordance with above introduced problems I conducted continuous researches simultaneously in the field of the practical application of modelling theory, system simulation and optimal search procedures.

I defined the main objectives accordingly to above mentioned:

1.) greater understanding of scientific results relating to operating of inventory systems and processes, and the examination of their application in practice,
2.) search for modern modelling, simulation and optimizing methods, which are effective regarding to the operation of inventory systems and processes in practice,
3.) examination of information systems serving the inventory systems and processes,
4.) creating an adaptive, dynamic conceptual system plan of inventory system, in particular consideration on explored simulation and optimizing methods, including
    a.) developing an effectively applicable modelling technique,
    b.) developing a target orientated simulation system, moreover
    c.) developing a target orientated optimization background system in cooperating with the simulator.

5. PUBLICATIONS OF THE AUTHOR RELATING TO THE DISSERTATION

Chapters of the book

[BK1.] Bóna K., Duma L., Kovács P., Molnár B., Székely Zs., Tokodi J. (2004), Logisztikai folyamatok és vállalati életképesség. 2. fejezet: p. 14-26., 6. fejezet: p. 94-105., ADECOM Rt., Magyarország.

Pre-viewed periodical articles published in Hungary

[BK2.] Bóna K. (2005), Optimization of Inventory Control Systems with Genetic Algorithms. p. 89-102., Periodica Polytechnika Transportation Engineering, BME.

Lectures in foreign language issued in international-conference publication

[BK3.] Bóna K., Molnár B. (2004), Simulation and Optimization of Logistic Systems with Genetic Algorithms. p. 251-257., Proceedings of the Eurolog 2004, Budapest, ELA, June 10-12.

[BK4.] Bóna K. (2004), Simulation Supported Optimization of Inventory Control Processes by Application of Genetic Algorithms. p. 131-136., Proceedings of the 16th European Simulation Symposium, Budapest, SCS Press, October 17-20.

Article in edited book

[BK5.] Bóna K. (2003), A raktári készletek csökkentésének lehetőségei, a készletgazdálkodási folyamatok optimalizálhatóságának vizsgálata. p. 21-29., LOGISZTIKAI ÉVKÖNYV.

Hungarian Lectures issued in conference-publication

[BK6.] Bóna K., Molnár L. (2004), Új kutatási irányok a vállalati készletezési folyamatok optimalizálásában. p. 202-212., ”30 év Győrben” Jubileumi Tudományos Konferencia, Győr, 2004. november.

right direction, or it would be more efficient to integrate these applications and the latent knowledge into a large application? It is important to answer this question as soon as possible in the future, as the needs in practice becomes bigger. One thing is certain undoubtedly: the future is for the standard integrated company management systems, because by effective connection of outside applications (namely the data reading for optimum search, and writing back the datas from the optimization) only these systems can implemented reliable, and these systems can guarantee efficient solutions for the future developments.

In my view, conceptual system plan of inventory control model system that I developed is similar to above described application, as it can be interpreted as a target specific and can be developed into an application that can be connected to a standard company management system by external integration. The theory basics are clarified in general referring to the examined industry, on the other hand there is a need for more professional approaches regarding to the software implementation, like the experimental instrument I developed currently in VBA. The inventory systems and processes are various according to the industry and problems, there it is important to notice that the order scheduling logic and experimental instrument that I developed are specified for the features of retail warehouses and within this the beverage industry. Therefore there is a possibility for development to test this instrument and to find further experimental algorithm, logics, and instruments to apply them in the area of other trade activities and the area of production. Furthermore, I consider extremely important that the other research results achieved in optimal search are worth testing in practice and to implement as a model. As an example there are several possibilities: multi criteria pareto methods, fuzzy logic, application of multipopulational genetic algorithm to find the control parameters, neural system to use classifying algorithm or to help local search, and the combined application of these methods. Another direction for developments, that the control conception becomes more important to solve the problems of the value chain, as the process model and optimization system can be developed for the whole value chain, which can mean further researches.

The referred publications can be found in the list of publication in the end of the disseratation according to the reference number.

From a methodological point of view I considered extremely essential to acquire the available *wide palettes of literature* comprehensively (I reviewed more than 170 relating source literature). The above presented two main research priorities were integrated in the examination of applicability of the acquired knowledge, I chose a field that have had a great deal of difficulties for a long time, where my developed theories, methods and procedures and their efficiency could have been examined. Hence, my further researches were concentrated on commerce relating to beverage industry within this the problems occurring in wholesale trade of beverage. I applied the following methods to collect the *premier data* of my study:

- conducting goal-orientated interviews with company executives of the examined area;
- examination with multiply-choice type questionnaires;
- collection of predefined transaction data form applied company information system;
- (where it was available) collection of processes description in applied process control .

During recording the *secondary data* I applied process-observation, and in some cases I carried out measurements.

The primer and secondary input data recording was followed by *detailed process and data analyses examination*, I tried to draw the most important conclusions from them. My further examinations and developments are based on this experience, and these numerical results were used like input data in the developed methods and procedures in many cases, and these results were used for comparison in several cases.

1.3 Actuality of the research topic

My research in the field of the integrated enterprise resource planning system (ERP) and the warehouse management system (WMS) that supports the optimization the physical processes of the warehouses demonstrates the fact visibly that there is a rising demand for further developing of supportive background systems to operate, manage and optimize the company inventory systems and processes . The actuality of further developments can be summarized in the following points:

1.) The *volatility of markets increasing* served by various value-added chains because of the variability of the demand of customers (end-users) referring to quantity and time grows within the chain, therefore the instability presents in a greater level in the demand and supply processes that generating the inventory of the companies.
2.) It has been proved due to reasons presented in the 1.) point the only way to be prepared and deal with unpredictable supply processes efficiently without increasing radically the inventory reaction time is the application of *a well-structured optimization inventory system*.
3.) As a result of these above mentioned reasons the *processes* of the inventory system *must be controlled* according to predefined purposes, furthermore the general requirement that according to the probable instability the control system including the applied control logics must be

adaptive, namely
it should adopt to the probable volatility of the demand and supply processes generating the inventory systems and procedures
dynamic, namely
the parameters that operate the inventory system should be up-dated according to well-defined time intervals in controlling approach , and if it is required than to it should be modified for the given purpose.

4.) Currently the *applied systems in practice* do *not generally use* the achievements of the mathematics in the field of modelling, simulation and optimal search *processes.*
5.) The research experience indicates that the currently *operating information system solutions in practice* supporting the above mentioned processes …
   a.) are optimizing systems only theoretically in many cases,
   b.) do not include effective, process specific decision models based on modern principles,
   c.) can not be automated at all, or just in small portion,
   d.) the range of many important parameters that influence the efficiency of inventory systems and processes is based on the intuitions of the warehouse operators ,
   e.) are rather control than regulatory systems,
   f.) they are not dynamic sufficiently, therefore they are not adaptive.

technology devices. There is a clear conclusion from the examination that *the optimal calculation supported by simulation* by applying the possibilities provided by the experimental instrument *can be used efficiently* to solve the examined inventory and order scheduling problem. (dissertation *7.8 subchapter*)

4. PRACTICAL APPLICABILITY OF THE SCIENTIFIC RESULTS AND DEVLEOPMENT POSSIBILITIES

Experience indicates that the company information systems currently applied in practice do not support efficiently the optimizations of inventory systems and processes. They may be rather applied to the up-to-date and up-to-the-minute implementation of process monitoring, than the implementation of various decisions models and business intelligence logics. Despite the big number of different information solutions from relatively cheap devices up to very expensive standard integrated company management systems, I have not met any well operating integrated solution that is applicable in practice during my researches. Solutions only work partly, but in my point of view complex, total handling of problems can be done by task and target orientated operative management systems, which are always developed to solve a given optimal search problem. Taking general problems of other company logistic optimum search tasks (e.g. route planning) not excluding only problems of the inventory processes indicate that it does not exist and it will not exist for a long time an information solution of optimal search that provide an effective solution for all kind of logistic problems occurring in a given company. On the other hand companies recognized company management can not exist without an effective logistic process optimization. As a result of this there are greater possibilities awaiting for devices and applications – which connect to the standard company information system by using external integration – are able to solve the problem of the missing knowledge. My experience in practice indicate that all kind of logics, or algorithm, which approved that can be applied effectively to answer these needs, there is a good chance to develop into software. There is a prosperous future for applications using processes based on innovative approaches backed up by optimal calculation methods, with particular reference to design and operation of logistic systems preceding the optimal search supported by simulation. Is this the

combined by these two problem specific local search methods and the elitisms technique. During the examination of suitability of units the developed combined algorithms use the solutions generated by *simulation system model running many times* coded in simulator to calculate the actual value of destination function and the fitness value. (dissertation *7.2 …7.7 subchapters*)

(b.) I developed an optimal search experimental instrument in VBA development environment capable of testing characteristics of combined genetic algorithms examined by experiment presented in 4.(a.) sub thesis.

According to experience I *specified* the *optimization* subsystem of inventory control system presented in 1.(b.) sub thesis for the optimum search calculation developed by experiment presented in 4.(a.) sub thesis. The other part of the experimental instrument created in VBA development environment previously presented (see in 2.(b.) sub thesis) is the *optimalizator*, where the combined genetic algorithms were implemented discussed in the 4.(a) sub thesis .The purpose of the development is testing the practical applicability of genetic algorithm based on two different format principles to solve the above mentioned problems. In the course of testing regarding to both algorithm I proved that it takes long time to find the optimal point or they cannot find in many cases without efficiency increasing procedures in many cases. My statement is in order to increase reliability and the speed of convergence the operation logic of basic algorithms is recommended to combine the *local search* with characteristics of *elitisms*, and as a result of this (in the examined cases) the accuracy and the speed improved greatly as well.

Moreover, during testing it was proved that in case of schedule ordering problem defined in the *first hierarchical level* EOQP stochastic optimal calculation task the more efficient way is the combined real vector format *FPGA*, and in case of DISP deterministic optimal calculation task defined on the *second hierarchical level* the combined bit serial format *BGA* optimal search algorithm was unquestionably more efficient. It can be stated that the running time and search accuracy of some optimal search algorithms greatly depend on the complexity of the problem (e.g. the number of SKU to order at the same time), the starting parameters (e.g. in case of bit serial format the length of the pl. chromosomes, the probability of mutation), the required simulation running time (this is the most significant factor), moreover the capacity of the applied information

The above listed *five relevant reasons* guided the research, which purpose was to develop- an *adaptive*, *dynamic* inventory control systems according to the research experience -which can be applied efficiently to regulate inventory systems and processes - in accordance with the above mentioned expectations- furthermore to examine its application for a given company by using the defined methodology.

2. LITERATURE REVIEW

In order to achieve the defined objectives I aimed to examine the application of the scientific findings of the area in practice relating to the research topic. According to the main issues of my research the following *sub categories* were in the focus of my research.

2.1 Company information system

Scientists have been interested in how the possibilities provided by information technology can be used to support strategic and operative company processes since the beginning and mid 70s. [IR3.], [IR9.], [IR16.], [IR17.], [IR28.]. The financial systems were the basic of the company information system, so the first breakthroughs were experienced in this area [IR10.], [IR26.], [IR27.], therefore inventory issues were brought to focus relatively early. Developers soon recognized that to built data operating logic reflecting the companies material and information flow is highly complex task [IR7.]. As a consequence of the complexity of company procedures and systems another crucial question is to create a risk management logic relating to data [IR4.]. Beginning with less integrated later more integrated company information systems and applications started to appear relying on the breakthrough achieved in financial systems, where ERP represents the peak [IR20.], [IR21.], [IR26.], [IR27.]. The next breakthrough was to support the decision-making situations in strategic and operative level [IR1.], [IR13.]. It was proved early, that unfortunately supporting the decision-making do not always mean process optimizing as well [IR19.]. Many companies deal with distribution of various ERP in Hungary [IR11.], [IR12.]. Selecting the adequate ERP is a complex task [IR2.], [IR25.], [IR15.]. The applied information systems face more and more challenges economic changes, globalization, new techniques and technologies etc. These questions are

thoroughly discussed in the publications [IR22.], [IR23.], [IR24.], [IR8.], [IR5.] .I mainly found ERPs [IR6.], [IR14.], [IR18.] presented in the publications during my further study, but there were several smaller ERPs, and systems developed locally that can not be called ERPs .

2.2 Inventory models

The first classical inventory model was published by HARRIS in 1915 [KM36.], which became well known as the *„optimal economic order quantity (EOQ) model"*. Many modified versions of the model have been published up to now (e.g. [KM11.], [KM16.], [KM70.]). There was a big breakthrough in 1951 by the publication of FORD [KM29.], where he published the *ABC analysis*, the effect of Pareto's principles on inventory systems and processes. Similar to EOQ models so called *continuous review of stock models* besides that there is another big research area the so called *periodic review of stock models*, where there are also several inventory models have been published. Hungarian researchers also have achieved outstanding results in this field, amongst them BENKŐ [KM7.], CHIKÁN [KM16.], CSATH [KM20.], [KM21.], [KM22.]. The issue of the so called [s;S] models relating to classical min-max strategy is relevant to practice, and we can read about them in the publication of BASHYAM, FU [KM5.], FU, HEALY [KM30.] KLAFEHN [KM43.] .In relation to inventory model subject the classical *average-cost* inventory model ([KM8.], [KM9.]), and *JIT*[1] *philosophy* model analysing and optimizing the cost-effectiveness of logistics ([KM6.], [KM48.] represent a different direction. One of the results of the fast growing information technology was the appearance of *simulation technique*, which provides a new approach to unsolved problems of inventory model. The publications of BYRKETT [KM13.], HADDOCK, BENGU [KM34.], SHOWERS [KM60.] from the 70s and 80s are examples for that. At present, the inventory problems and the modelling intentions aiming to solve inventory problems have focused on company *supply chains* since the 90s up today. ANGERHOFER, ANGELIDES [KM2.] apply the dynamic system modelling principle to support strategic inventory decisions in the chain. The operation for the value chain is typical the so-called *bullwhip effect*, which deals with the effects of *demand prediction problems* is in the publications of CHEN,

[1] JIT = Just In Time

parameter estimation is validated by χ^2 -test. According to the results of the test and both the demand and supply processes LSM-DSA algorithms was able to seek the parameters necessary for optimal adjustment of Weibull-distribution in wide range. (dissertation *5. chapter*)

4.) I proved by experiment that genetic algorithms combined with modern procedures that increasing optimal search efficiency can be applied effectively in wholesale beverages inventory systems and processes to do complex, variables tasks often with rather uncertain target system. ([BK2], [BK3], [BK4], [BK6], [BK7], [BK17])

My statement is that calculation of the optimal values of the parameters of the order scheduling model on the first hierarchical level (EOQP) presented in the 2.(a.) sub thesis and intervening parameters on the second hierarchical level (DISP) cannot be interpreted as a trivial optimal calculation task. In case of EOQP a stochastic and in the case of DISP a determined optimal calculation task must be done. As the simulator itself presented in the 2.(a.) sub thesis can be used well for experiments and calculation of destination function , but it is not capable of optimal search, so I conduct the following development in order to search the values of intervening parameters.

(a.) I developed a genetic optimal search algorithm based on bit serial (BGA), and real vector format (FPGA) by local search combined with elitism technique to solve the problem of economic order quantity problem (EOQP), and the disposition problem (DISP).

I made the algorithms to be capable of solving both optimal calculation tasks of the two examined modelling tiers. In the course of the development of various type algorithms I defined the problem specific *code techniques*, the *fitness calculation* and *selection* method of the units, I also determined among the different *recombination operators* the applicable solutions regarding to the problems, finally I structured the base of the simple algorithms (BGA and FPGA). In order to increase the reliability of optimal search and the speed of convergence I developed *two problem specific local search algorithm*, which conduct further examinations in the points defined by the examined units, so this accelerate iteration processes and prevent the problems coming from genetic drift. The operational logic of simple genetic algorithms was

scheduling strategy during the experiment. The simulator includes the two-tiered system model of optimal quantity order (EOQP) developed for handling the inventory problem of beverage wholesale presented in 2. (a.) sub thesis and hierarchically connected disposition (DISP) problems. By use of the simulator any number of experiments can be done. It makes possible to define/determine the operating features of the system model (expected values of value of state and the other statistical parameters), the intervener parameters of the order schedule, and other effecting/influencing parameters up to in case of extreme setting. Consequently, the sensitivity of the inventory system can be examined according to different situation models. (dissertation *6. chapter*)

3.) I developed a derived independent parameter searching process to estimate Weibull-distribution shape and scale parameters in order to establish modelling possibility by Weibull statistics of supply processes. ([BK12], [BK17])

I made *observations, measurements and analyses* in order to acquire the inventory practice of wholesale beverage examined experientially while creating inventory order scheduling models with purpose of examination of statistical stability of the supplies. I draw the following consequences from the results that creating the simulation model and the algorithm can be solved by mathematical modelling of demand and supply processes based on statistics. During the adjustment examination at 5% significance level an obvious domination of Weibull-distribution could have been detected. So it was confirmed that the assumption is false that during the modelling of demand and supply processes frequently used impending normal distribution, because there was a strong left side asymmetry in the examined industry. I examined the *possibility of comprehensive application Weibull statistics* my statement was that there is a chance provided the efficient (scale and shape) parameters estimation. I evaluated the given parameters estimation procedures, and the result was that they are rather complex, they mainly apply recursive numerical procedures to define the scale and shape parameters starting from derivate functions, therefore I developed a so-called *LSM-DSA procedure* a smaller based on smallest square method (LSM), independent from derivation, based on simplex algorithm (DSA), which is able to speed up the parameter estimation and to simplify it. I developed a surface in the VBA development environment to test the procedure, where the

DREZNER, RYAN, SIMCHI-LEVI [KM14.], [KM15.] and SIMCHI-LEVI, SIMCHI-LEVI, WATSON [KM63.] . There are several other interesting questions arise relating to the subject such as *organisational integration* [KM53.], a *virtual companies* [KM55.], the importance of *share information share* [KM64.], and the realized valamint a *best practice models* [KM66.]. As a result of applying simulation techniques several *simulation model and software* were developed while planning the strategy and tactics of the value chain. IBM simulator is one of such software [KM4.], [KM46.]. The model system was tested by multinationals including NOKIA ([KM38.]), and NIKE virtual company system ([KM3.]). *MRP*[2] *systems* are one of the innovative approaches of optimization of inventory systems and processes ([KM1.], [KM70.], [KM75.]), and the applications relating to the so-called *"soft" computing (e.g. fuzzy) methods* ([KM26.], [KM47.]), which always apply modelling systems and algorithms backed up by computer.

2.3 Statistical methods and procedures

During my examination it was necessary to study three main areas of the literature. The *descriptive statistics's* methods ([ST10.], [ST15.], [ST17.]), the *time series analysis* to estimate the future demands ([ST4.], [ST5.], [ST9.], [ST16.], [ST18.]), and the theory of *statistical estimation and hypothesis testing* relating to demand and supplies processes and to estimate their parameters ([ST15.]). In the course of my researches, my experiments were done by the so called khi-square test (on large samples taken from various company information system) and I according to my experience the basic empirical distribution types frequently occurring in inventory processes can be modelled well in another disciplines (e.g. quality control [ST16.], and chemical technology [ST3.]) also using applied *Weibull distribution* (WEIBULL [ST19.]). However, estimation of two Weibull distribution (scale and shape) parameters is not trivial task. The one of the most frequently used existing methods and processes is the *graphical and tabular methods* and from the *analytical methods the smallest squares* methods, the *maximum likelihood* method and the method of *momentums*, moreover the various combination of these. AL-FAWAZAN [ST1.], GUPTA, R. D., KUNDU [ST7.], GURVICH, DIBENEDETTO, PEGORETTI [ST8.], KOVÁCS [ST13.], [ST14.] and WU

[2] MRP = Material Requirements Planning

[ST21.] among others studied the question the application of the methods. According to general opinion of the researchers the most precise estimation can be achieved by the method of momentums, whereas the fastest (and also the easiest to achieve) is the smallest square method. Several further researches and articles deal with the question of estimation and accuracy of parameters and to increase the efficiency of the applied methods.

2.4 Modelling techniques, simulation and optimal search methods

It was proved in previous researches that by using modelling, simulation and modern optimization techniques long term success can be achieved in company decision making ([MO4.], [MO21.], [MO25.], [MO36.]), this refers to the area of logistics systems as well. It studies the results regarding to modelling of complex company systems, and the possibilities and constraints of their application in practice JÁNDY [MO21.], POGÁNY [MO36.]. The importance of simulation in modelling was recognized early, due to simulation several experiments could have been done on well-structured system model in case of very complicated systems, so the two terms cannot be separated at present. According to the definition of BRATLEY, FOX, and SCHRAGE *"Simulation means driving a model of a system with suitable inputs and observing the corresponding outputs."* ([MO7.]). INGALLS [MO20.] in his article referring to SHANNON gives another approach, the phase of model designing and building also gets a role. In addition to this, AXELROD writes this way around the end of the 90s *"advancing the state of the art of simulation in the social sciences requires appreciating the unique value of simulation as a third way of doing science, in contrast to both induction and deduction"* ([MO1.]). In the article of KELTON [MO23.] there are procedure descriptions of process simulation design experiments and proficient analyses of the results according to statistical analytical methodology. One of his most extensive systematizing summaries is the book of CHUNG [MO8.], which places great emphasis on the questions of verification and validation of models besides discussing detailed steps of simulation thoroughly. We can read about *the future of simulation application* in the article of BANKS and CHAIR [MO3.], which include four main directions

of order scheduling process inventory problems occurring in beverage wholesale.

In course of my further examination I focused on *brewing industry* suppliers, I set up the most preferable inventory scheduling strategy using the results of my analysis, moreover I established *a two-tier hierarchical process model and optimum calculation logic* which is capable of modelling this way rationalization process.

The *first hierarchical tier* of the model is the so-called EOQP modelling tier. The objective of this is to formalise a mathematical-logical algorithm based on SKU experience stock speed of one given supplier at the same time, and based on the relation rate of expenses of stockholding and shortage of stock, which can be used to examine the value of state, which determine the efficiency of order scheduling strategy, by using simulation technique. The *second hierarchical tier* of the model is the so-called DISP modelling tier, which necessity can be verified that suppliers in order to order transaction bonificate set up a pre specified criteria, which is recommended to follow for the supplier at the final disposition of the order. For this purpose I established a system in this tier, which enables to show the efficiency of the final disposition plan adjusting to the logistic criteria given by the supplier. The connection between the two tiers is done that the calculated size of order in the first tier is taken/interpreted as an input of the second tier, and by correction of the quantities can be reached the final disposition plan. (dissertation *4. chapter*)

(b.) I developed an experimental simulation tool in VBA development environment capable of analyzing and defining the features of the schedule order strategy experimentally examined rational inventory process (presented in 2.(a.) sub thesis).

I *specified* the process *modelling* and *simulation* subsystem of the inventory system presented in the 1. (b.) sub thesis according to the experimentally examined inventory process presented in 2.(a.) sub thesis. The created simulator is a part of a complex experimental tool/instrument (it will be presented later, in the 4. thesis). The task/role of the simulator in the experimental instrument- modelling the operation of the adaptive systems- producing the necessary data to operate the optimization during the optimal calculation, and to ensure the capability of testing the operation efficiency of the modelled inventory system rationalized order

moreover I evolved the logics of data change also. Following to this I defined the necessary functionality of subsystems (data convert, process modelling, simulation and optimization), then I described in detail the internal structure, with particular reference to those *business intelligence methodology solutions integrated* into control system, which were placed process modelling, simulation and optimization subsystem which is regarded as a new approach in inventory control. (dissertation *3.2 subchapter*)

2.) I proved experimentally that the extended methodology presented in the 1. thesis can be applied efficiently in modelling , defining the operational features and analysing of the inventory systems and processes in beverage wholesale. ([BK2.], [BK3.], [BK4.], [BK6.], [BK8.], [BK9.], [BK12.], [BK17.])

I examined the inventory problems occurring in beverage wholesale *in order to test the practical feasibility of the theoretical conception* defined in adaptive, dynamic inventory system (see 1.(b.) sub thesis), based on optimal calculation supported by simulation. In the course of my researches I examined basic inventory processes of *ten independent wholesalers*, the logics of order scheduling practice and their applied information systems by observational process analytical technique by examining the functions of the applied information systems, and by detailed statistical analysis of the data obtained this way. My statement is that the variaty of order scheduling practice is rather wide in controlling the inventory processes (even within one supplier can be different). These logics are only customary principles based on practical experience, which can really used to schedule orders, but they are not capable of optimization of the processes directly, because they are not strategies in a classical way, therefore the basic process optimization principles are not completed. I lay down according to my examination based on efficiency test of inventory processes that the applied applications demonstrably do not provide optimal solution. Bearing in mind the above statements *I conducted an experiment* to reduce the number of applied methods, to establish a correct order scheduling strategy and in order to process optimization to rationalise the logics based on practice by using the modelling methodology described/notified in the 1. thesis.

(a.) I developed a two-tier hierarchical process model and optimum calculation logic capable of rationalization and testing the efficiency

- better and tighter integration with other industrial software (CAD[3], ERP, WMS) ,
- tighter integration with control technique applications,
- tighter cooperation in creating virtual reality ,and
- development of simulation program languages and applications, making them more user friendly by Windows user interface development

Besides the above mentioned I revised several publications dealing with special problems of modelling and simulation, such as [MO26.], [MO28.], [MO32.], [MO35.], [MO36.] and [MO41.]. The range of *optimal search* and *optimization methods* are quite wide and they are developing rapidly at present, as the practice recognizes the importance of optimization of the processes. The so-called differential and variation calculations was created by distinct prominent scientists NEWTON, EULER, LAGRANGE and BERNOULLI in the XVIII century. Sudden development of various methods and processes began with the appearance of operation research science. The above-interpreted tasks go back to so called *multifaceted decision problems* in many cases, RAPCSÁK [MO38.] deals with them with the point of mathematics. The *nonlinear optimization* is a fast-growing area of optimization theory because of its theoretical significance and its practical application ([MO37.]). Another particularly important field regarding to inventory theory is *stochastic programming*, which deals with uncertainty in decision-making ([MO11.], [MO17.]). Among the applicable so-called direct search strategies the *simplex method* is also a unique approach of optimal search ([MO12.], [MO27.], [MO45.]). An approach (HOLLAND, 1975), which has been known for a long time, but referring to technology it can be considered innovatory, the main topic of my research is applying *genetic algorithm* in optimal search. According to GOLDBERG *"Genetic algorithms are search algorithms based on the mechanics of natural selection and natural genetics. They combine survival of the fittest among string structures with a structured yet randomized information exchange to form a search algorithm with some of the innovative flair of human search. In every generation, a new set of artificial creatures is created using bits and pieces of the fittest of the old; an occasional new part is tried for good measure. While randomized, genetic algorithms are no*

[3] CAD = Computer Aided Design

simple random walk. They efficiently exploit historical information to speculate on new search points with expected improved performance." ([MO15.]). Several extensive systematizing, summarising book has been published nowadays (such as [MO19.], [MO24.], [MO30.], [MO46.]) which have different approaches towards the theory of genetic algorithm discussing the questions of practical implementation. The number of users of genetic algorithm is increasing, so there are more updating solutions of the backing theory is developed, modified, avoiding the disadvantageous features of genetic algorithms were published (e.g. [MO2.], [MO44.]). The significant part of applications relating to control technique (e.g. [MO22.], [MO41.]), but there are special fields such as game theory ([MO6.]). The importance of connection of simulation techniques with optimization methods occurs mainly in case of problems, where the definition and writing of destination function cannot be done or it can be done with difficulties in exact form (closed shape). *Simulation-optimization* deals with this topic, which is considered a newer research area of the subject presented in this subchapter ([MO35.]).

3. THE MAIN SCIENTIFIC RESULTS OF THE DISSERTATION

I summarize the scientific results developed in my PhD dissertation in the following theses:

1.) My statement is that the lack of practical applications of available documented models that were developed to optimize the inventory and order scheduling processes based on mathematics is due to methodological problems referring to interpretation of company inventory processes as modern control system ([BK1.], [BK5.], [BK11.], [BK15.], [BK17.])

I conducted intensive researches to gain greater understanding on scientific results regarding to inventory systems, in order to study their practical application at companies. I found out despite the big number of available documented inventory models their practical application lags behind. My researches in the area of industry, commerce and service supported that the interpretation of inventory processes as control system (therefore inventory control managed this way also) only exist in theory in company application in many cases unfortunately. The modern company and process-orientated reliable decision models operating

integrated with the inventory control system are frequently missing, which enable the optimization of inventory systems according to predefined criteria. In accordance with the above-described deficiencies:

(a.) I expanded the methodology of inventory control as a system, establishing the optimization and process-orientated modelling aided by decision models of modern operation of real inventory systems.

My statement is that *first* main constraining factor of creating an effective applicable decision model is *lack of process-oriented modelling methodology*, by this model the inventory and order scheduling problems capable of modelling can be formed. Formalisms created by this way are mathematical-logical models, where any number experiment can be done on them in order to examine the behaviour of the real inventory system and their main operational parameters and the value of the state. The *second* revealed fundamental problem is *the lack of optimal search systems* can be operated by formalisms creating decision models, where the actual set-up values of the predefined control parameters of the decision models can be defined efficiently often in case of system with uncertain relations. As a result of above mentioned I expanded the main components of modern decision models applicable in inventory control with *process model* and *optimal search algorithm*. Using this methodology enable us to develop modern target specific inventory system, which can increase the adaptation of company inventory system, hereby the efficiency can improve. (dissertation *3.1 subchapter*)

(b.) I established an adaptive, dynamic conceptual system plan of model based on principles described in 1.(a.) sub thesis, where inventory control generally interpreted.

Firstly, I defined the general conditions, where the adaptive, dynamic control of the inventory processes is feasible using the principles defined in 1. (a.) sub thesis and the gained experience in practice, then I developed a conceptual structure of model with generally interpreted controlling system. I defined the main parts of the control system, and their functional connections, in addition to it the operation principles of the control process. *Secondly*, I specified the data group, which is necessary to operate the control system, and which occur during the operation, whose handling is done by internal information subsystem. I defined the interface, where attaching of control system into standard integrated company management information system can be achieved,