ACTUAL AND FUTURE OPTIONS OF SIMULATION AND OPTIMIZATION IN MANUFACTURING, ORGANIZATION AND LOGISTICS

Thomas Wiedemann
Highschool for Business and Technology Dresden
Friedrich-List-Platz 1
Dresden, 01069 GERMANY
wiedem@informatik.htw-dresden.de

Wilfried Krug
DUAL**IS** GmbH IT Solution
Tiergartenstrasse 32
01219 Dresden, Germany
wkrug@dualis.net

Abstract

The paper is divided in a basic introduction and a discussion of new and future methods of optimization and simulation. The introduction discusses actual architectures of complex information systems, which include optimization systems or modules. The opti-mization system is presented as an example for a practical solution of optimization tasks. The second part discusses mainly Web-based applications.

INTRODUCTION

Computer-based optimization has become increasingly important in the last few years. This demand is caused by a more difficult economical situation, where efficiency of all processes is more and more necessary.
Optimization tools can improve the effect of other analysis tools like simulation systems or decision support systems some times. Although the whole task of analysis and optimization is more complex than before, the connection of both tool classes reduces the needed amount of time and personal staff dramatically. Instead of having a high-qualified simulation expert, a optimization tool can automatically evaluate simulation results and will try new scenarios. The results of optimization tools, like the number of the best strategy for the next week of operation, could be presented to traditional working staff without any additional teaching or difficult explanations. The fast development of computer power allows more practical and more complex tasks.

BASIC METHODS OF OPTIMIZATION

There is a very large bandwidth of available methods and tools. Optimization methods can be divided into two large groups (see figure 1). On the one hand is the large group of continuous parameter optimisation methods, while on the other are the discrete optimisation methods (Krug ARENA/ISSOP Handbook 1997).
Within the broad spectrum of continuous methods, the first to be considered (and this is a point worthy of criticism) are the deterministic methods. These are also called discrete mathematical parameter optimisation methods, which can be applied to static, non-discrete, non-stochastic optimisation problems.

In the literature, these deterministic methods are often called hill-climbing strategies, because they method of searching for the optimum (maximum) is similar to a blind mountain climber, who tries to climb from a valley to the highest peak. For minimisation problems, the direction is reversed accordingly.
These methods currently dominate in the solution of technical optimisation problems. In the second column of Figure 1 the random methods are shown, which are becoming increasingly important in computer-based optimisation. They are used when the deterministic algorithms of column 1 are unsuccessful or unusable. These methods vary the values of the variables according to random, rather than deterministic rules.
Many deterministic optimisation methods, in particular those that require the gradient of the target function, can have convergence difficulties at points where the parameters have discontinuous derivatives. A narrow valley leads to the same problem when the finite step sizes are larger than the width of the valley. In this case, all attempts to obtain improvements in coordinate directions or by using local test steps to determine a new direction will fail.
Evolutionary algorithms are oriented towards results from observations of the natural evolution of living organisms. Using natural evolution as a basis for optimisation is justified, since it has been repeatedly shown that plants and animals have adapted themselves optimally to their environments. By contrast to deteministic or pure random methods evolutionary algorithms considers a set of solutions called a population. Each solution is correspondingly called an individual. In genetic algorithms, solutions are also called chromosomes. By analogy with biology, each component of a chromosome is called a gene. According to the nature, the values of this chromosomes are change like in a mutation and new population are generated by a recombination of chromosomes. The advantage of evolutionary algorithms consists in the combination of randomness and a stepwise selection of better population, were bad population can live also some specific time interval.
According to the endless number of optimization tasks, **there is no best algorithm**. For practical applications there should be a number of different applicable strategies !

Proceedings 15th European Simulation Symposium
Alexander Verbraeck, Vlatka Hlupic (Eds.)

ISBN 3-936150-28-1 (book) / 3-936150-29-X (CD)

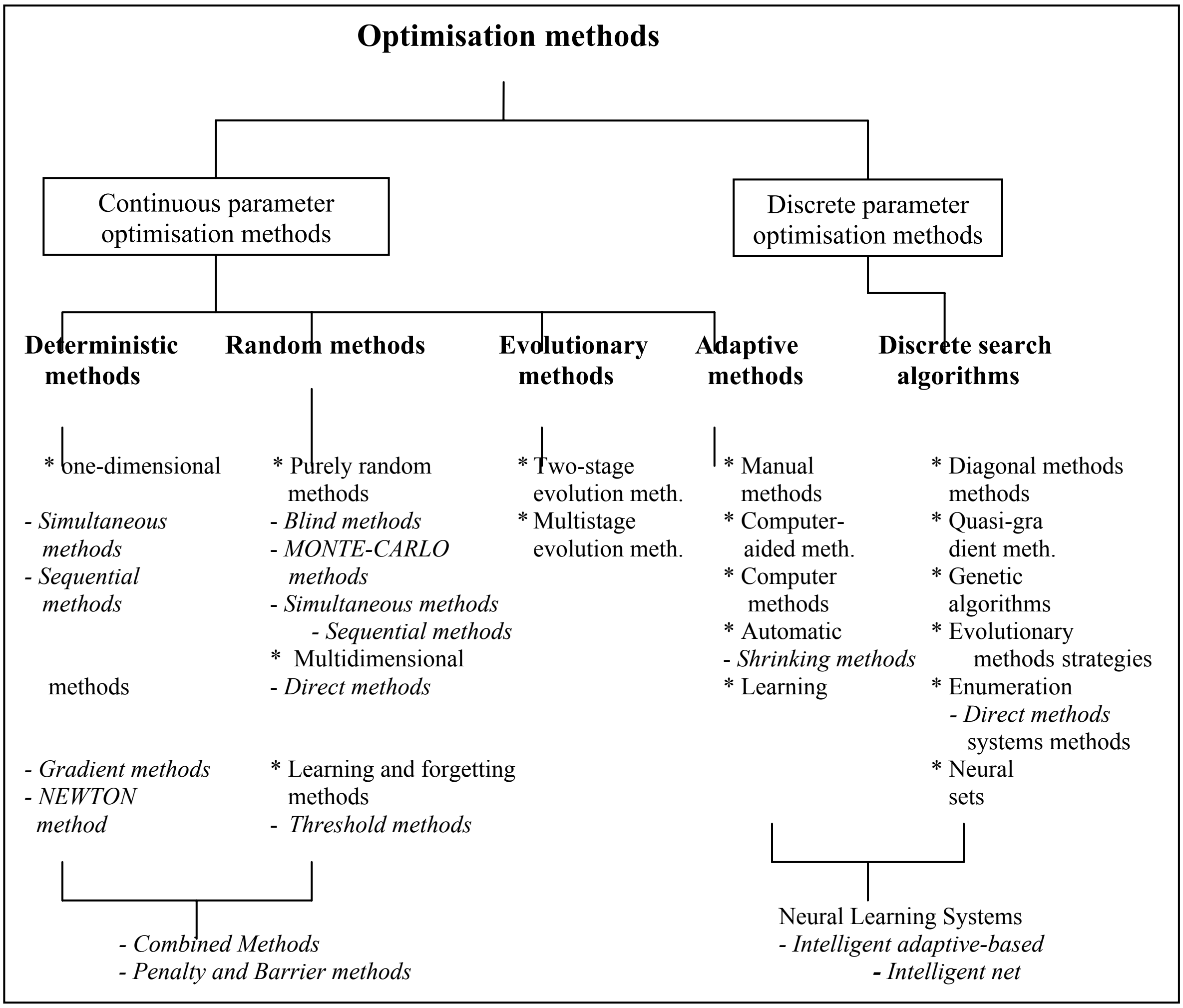

Figure 1: Classification of optimisation methods

Finding an optimal solution for a problem by building a model and running a simulation has always been the goal. Until now, however, it was usual to define the model a priori with certain parameters, and then to simulate, in order to see "what comes out", i.e. a human performs optimization by hand. He or she compares and evaluates results, fixes new parameters, and re-starts the simulation. This approach is very time-consuming, and the probability of finding an optimal solution in this way is relatively low.
With complex processes, which contain a large number of possible combinations of parameters and several mutually contradictory target criteria (costs, utilization, throughput etc.), it is practically impossible to perform a manual optimization. This is also true for manufacturing sequencing.
One solution is to use software with powerful optimization strategies which is coupled with the simulator. This optimization software must be able to access the model and to modify the values of model variables, read the simulation results that are relevant to the goals, and to determine the optimum (or a compromise).

INDUSTRIAL APPLICATIONS OF OPTIMIZATION AND SIMULATION

Europe`s Producing companies and especially Small and Medium-size Enterprises (SME) have to participate in dynamic networks and virtual factories in order to exploit (within alliances which are limited in time but not in distance) market chances that are hardly accessible for a single enterprise. Within such constantly self modifying environments the processes of organization, production and logistics have to be evaluated and optimized continuously. This requires the integration of comprehensive process models, efficient simulation and optimization tools as well as systems for Workflow Management, PPC, etc. via standardized interface. Various surveys have identified problems with the decision making process which are related to using methods that do not reflect the dynamic aspects of the manufacturing environment. The Paper aims to overcome these problems by producing integrated methods and tools, based on simulation, and optimization, to support effective decision making at all levels, from strategic to operational, of the company production, planning and control and business reengineering. The main theme is to support decision making

associated with the whole life cycle of products, but also included is evaluation of the impact of these decision making support tools on the personal using them, the organizational structure, and the Logistics management aspects of the company.
The Performance by integration of intelligent tools will be implemented in a software package. Existing state-of-the-art tools for PPC, analysis, simulation and optimization will be integrated into this software. The integrated systems SAP-R3 and ARENA/ ISSOP will be validated by solving actual problems in industry under virtual enterprise conditions.

Typical software architectures

Today, a number of powerful software systems individual are available for most of the a afore-mentioned tasks, e.g. tools for

- Order processing
- Material management
- Production planning and control
- Enterprise Modeling and analysis
- Workflow management and Standards
- Statistical evaluation of processes (e.g. average processing times, frequency of changes between different media or organizational units, process-oriented cost calculation etc.)
- Dynamic analysis (simulation and optimization) and visualization of processes.

Well known examples for such systems are SAP-R/3, ARIS, BAAN-DEM, STEP, CIM-OSA, EXPRESS, CRIMP, BIASS, ARENA, AUTOMOD, CIMPLE, ISSOP etc..

However, all these systems, though providing more or less elaborated interfaces for information exchange, are not systematically integrated so that they do not form a homogeneous platform for the user. Consequently, planning and business process reengineering usually is performed as shown in figures 2 and 3 .

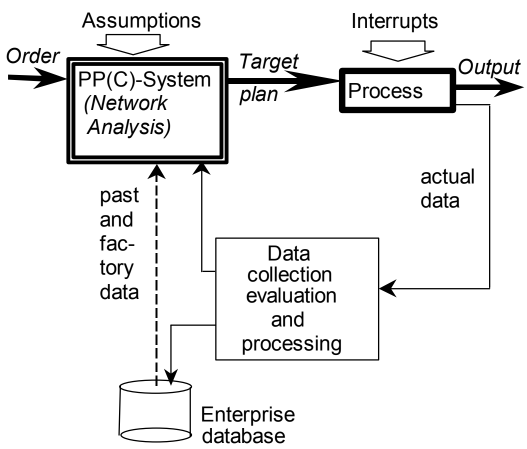

Figure 2:

Conventional production planning cycle without simulation support

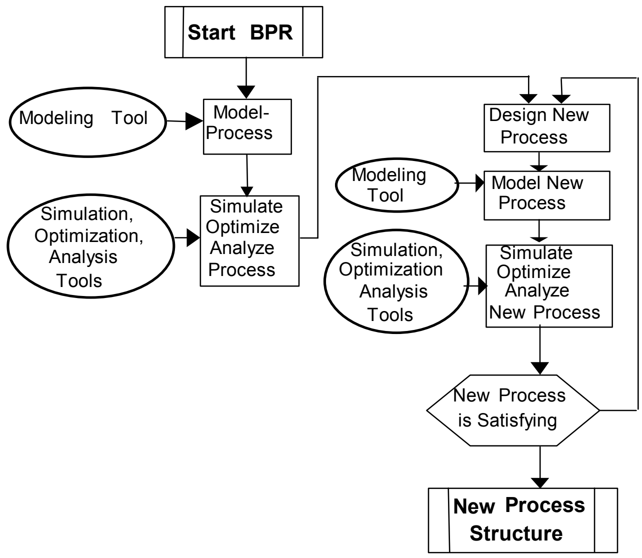

Figure 3:

Conventional BP improvement without integrated tool support

Complete product models, descriptions and related data may be exchanged using PDDI (Product Definition Data Interface), PDES (Product Data Exchange using), STEP (Standard for the Exchange of Product Model Data), EDIFACT (Electronic Data Interchange for Administration, Commerce and Transport). In particular, STEP will be relevant for standard interfaces.
Actual PPC systems mainly use network analysis as a planning mechanism. Thus, temporal data like transportation time, machine preparation time, processing time, fault time etc. are modeled b input values that enter the calculation as fixed entities, although they are, in reality, subjected to variations.
Network analysis tries to cope with that restriction by calculating the values each from an optimistic value, a pessimistic value and from the expectation (Erkollar and Mayr 1997). For reasons of simplicity, however, often only average values are considered. Thus, what actually happens in reality and the danger emerging from deviations are considered only insufficiently so that bottlenecks and delays are not always transparent to the planner.

To sum up, producing companies actually face the following problems in Manufacturing and Logistics:

- There is no common proceeding model for computerized modeling, simulation and optimization.
- There is only few flexibility in the available planning and controlling mechanisms.
- There are no integrated means for evaluation, analysis, simulation and optimization.
- There are no means for automated re-design and re-structuring of models based on optimization results.
- There are rarely means for the iterative improvement of process dynamics.
- The interfaces of the different tools are poorly coordinated and therefore do not allow for an effective integrated use.

Consequently, comprehensive process models are needed as well as a coupling of powerful tools for simulation and optimization in connection with automated mechanisms for Workflow Management, PPC, CAD, CAE etc.. A standardized interface might guarantee the integration that is necessary for efficient computer supported cooperative work within a dynamic network of SME's. Moreover, in order to achieve the goal of capturing and sharing the knowledge of the partners within a virtual enterprise reference models have to be used. Such reference models are available as results of foregoing projects.

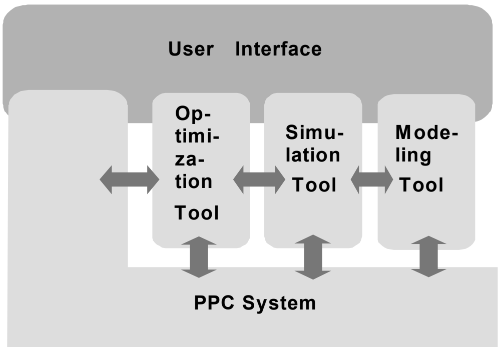

Figure 4:
Interconnection and integration

Objectives (or aims) are variable process parameters of the simulation model that result from a simulation run, e.g. mean flow time of orders, machine utilization, manufacturing costs etc.
After the objective are weighted, they are used as a substitute objective function.

THE ISSOP-OPTIMIZATION TOOL

To achieve the level of system integration that SME's need for an successful participation in virtual enterprises/networks on a global market, the optimization tools ISSOP was developed under the following goals:

(1) Integration of the reference models for distribution, procurement, order flow and production control into the context of the usage within an SME network.

(2) Development of a Toolset which allows the coupling and exchange of data between existing subsystems for PPC, modeling, simulation and optimization (see figure 4). This interface will enable, among others, a (virtual) manufacturer to consider and exploit deviations that might occur during production in order to detect and implement an optimal solution for a given planning task. A particular step of this approach is the automatic extraction and transformation of the PPC's network into a simulation model in the format that is expected by the resp. system. The simulation results again are transferred to an optimization tool. The optimization results then are fed back into the PPC system (see figures 3 and 4).

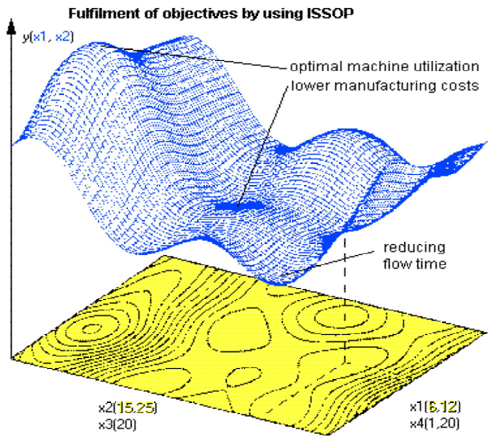

Figure 5: Optimization Results in the Production Planing

(3) Test and validation of our approach within a real live environment, i.e., by an application case study within an SME network. The improvements in speeding up production planning and control, in raising the quality of its results and in reducing costs will be measured and evaluated.

(4) Development of new mechanisms for process optimization: The change of industrial business by the globalization of markets inside and outside of Europe requires a comprehensive reorganization of enterprise structures. In this context, an important aspect is virtual enterprise reengineering based on a static process analysis as well as on a dynamic analysis that consists in validating and optimizing the (virtual) order and business processes to the highest achievable efficiency (see figure 6, 7). The results gained here will be important for industry branches like metal-working industry, processing engineering, electrical engineering/electronics, etc..

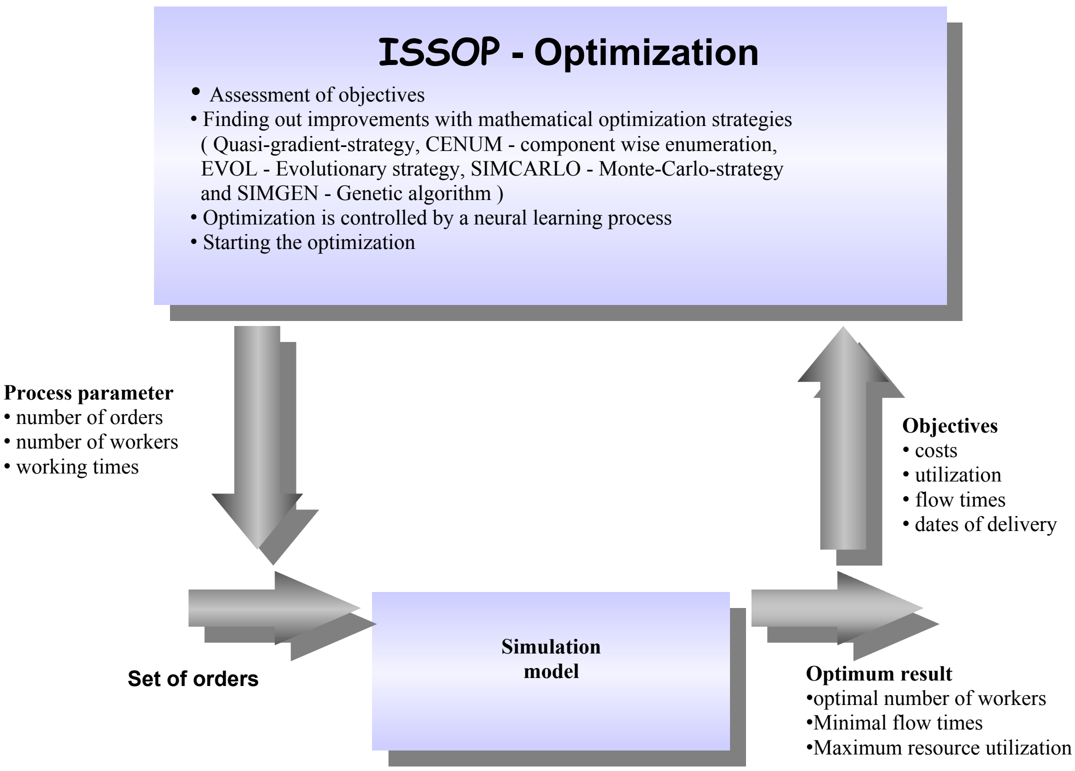

Figure 7: Simulation and Optimization in Order Processing

The Simulation and Optimization of order processes in Manufacturing, organization and Logistics in focused of variation by number of orders, number of workers, working time etc. is seen in Figure

6. In the end on the optimization in coupling with simulation will be solved the new set of orders in connection with objectives of cost, utilization, flow time and dates of delivery.

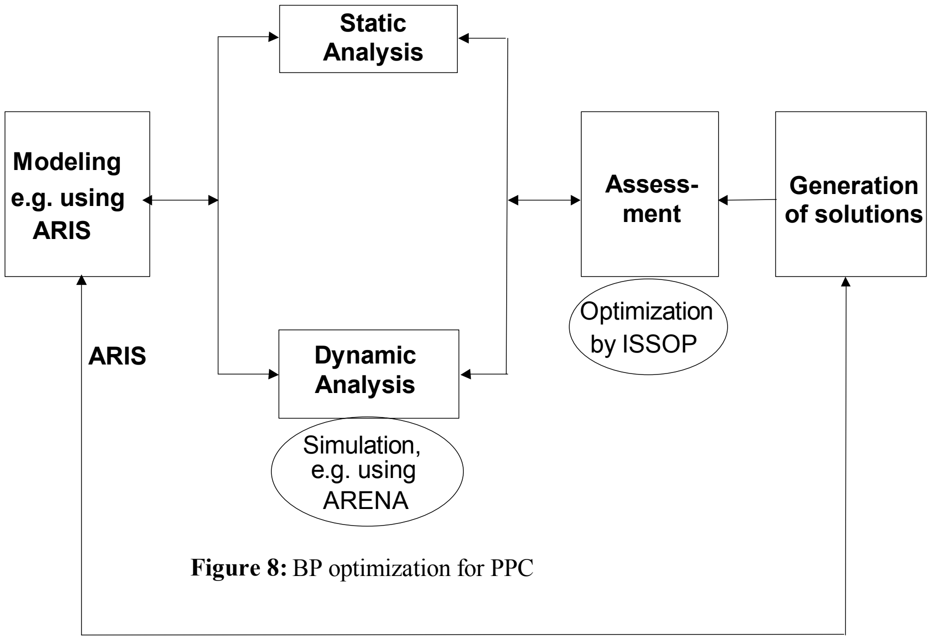

Figure 8: BP optimization for PPC

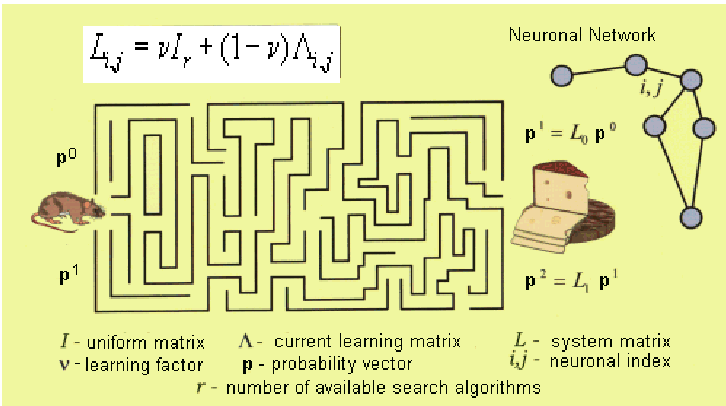

Figure 9: Neuronal Learning process

The ISSOP learning process is based on a labyrinth problem similar to the biological systems that can be found in nature. Therefore the neuronal network will be solved on a mathematical basis solving the system matrix L illustrated on the picture below. From optimization problem to optimization problem in SME's better optimization results will be obtained by means of different optimization strategies. These strategies are implemented in ISSOP (see fig.7).

In addition to the business process models as such, the following aspects have to be considered:

- Process goals and objectives as well as evaluation criteria,
- Strategies for directed search and optimization in connection with a neuronal learning algorithm, seen in Figure 9,
- Representation of possible changes and variations within a process model (e.g. change of sequence, paralleling, change of resources assignment etc.),
- Reference models and module libraries to be used for generating new process structures,
- Representation of restrictions and logical dependencies (e.g. concerning the exchangeability of functions).

It is not intended or expected to reach a complete automation of business process development. The process designer rather will be provided with a means to select the most appropriate process out of a number of promising and tested alternatives.

FUTURE OPTIONS BY WEB BASED SYSTEMS FOR OPTIMIZATION

Nearly all different requirements of simulation users can be transformed into basic terms of **profit** and **time**.

The profit is calculated as the difference between development costs of a simulation study and the expected revenues from the study. Development costs are influenced by the cost of the simulation environment and the modeling philosophy and comfort. Unfortunately the starting investments are on a high level between 5000$ and 50.000$ for typical simulation environments or external consultants. The revenue of a simulation study is unknown in the beginning. The risk of loosing money rises with increasing investment costs. Web based information technologies allow new business models of using simulation services. Instead of a high starting investment in software, simulation services can be rent for a interval of time.

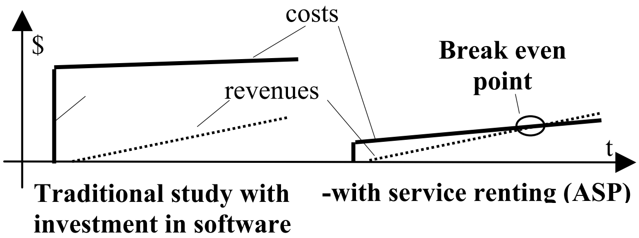

Figure 10: Costs of traditional and ASP-simulation

In traditional studies it takes a long time to reach the break even point. If the software is rented as a service, the starting investment is very small and equals the efforts for setting up the data interfaces and short teaching lessons.

The second term "Time" is important in real decision scenarios. Often a decision must be made under special circumstances like disturbance or external, unpredictable factors. The **"time to decision**", this means the time for finding a solution, is limited to some minutes or hours. This requires a very powerful simulation environment in terms of performance and optimization capabilities. More than one license and computer could be necessary. After the decision process is done, this environment runs idle until the next decision occurs. By using modern web technologies such free simulation capabilities can be used by other decision makers. The costs for simulation studies can be reduced significantly, if the peaks of required simulation power are averaged by a common pool of simulation resources, which are shared between different customers.

"Portability" and **"interoperability**" are often called the most important benefits of web based simulation. This is particularly correct for the current state of different computer environments. Depending on the existing hardware there are only two options - the simulation study is impossible due to incompatible technologies or the systems allow data exchange and control. For the customer, portability plays the role of a "killer" question. If this question is answered positively, costs and time for decision making again become the most important benefits of web based simulation for the customer.

Simulation areas with high efficiency of web based systems

The costs of developing complex simulation models are always very high. Although model generators and highly sophisticated modeling techniques could be used, the efforts for basic system research, data acquisition, model verification and validation actually are still connected with human resources. As it was mentioned before, the web supports operations with information distributing characteristics very well. Tasks with a high degree of creative work, resulting in synthesis of new web objects are still executed with external programs like HTML-editors or layout programs. This means - the internal structure and available functions of the current web are not ready for a real creative developing process ! This implies the following conclusions:

- The web can not simplify the modeling process in the near future. Simulation models should be developed by using traditional simulation tools.
- The web can support the reuse of existing simulation models very well by its distributed nature and the content management function like search machines and common data access protocols.

If we combine these conclusions, web based simulation systems will be of high efficiency, if the models remain nearly unchanged and only the simulation control variables and the input data are changed. Models of this kind are based on real systems with a fixed structure and dynamic working conditions, like

- flexible manufacturing cells with N machines from a set of M machine types, where the load is defined by external ERM systems,
- computer network systems with static network layout and dynamic routing strategies and random loads,
- fixed railway networks with changing time tables,
- nearly all serving processes with fixed stations and changing customer requirements.

In traditional simulation analysis such systems are modeled as "black box" models and the load is defined by parameters or in various data files. Even GPSS was used 30 years ago for defining such models. The power of this approach is determined by the quality and flexibility of the implemented interfaces for data exchange.

REQUIREMENTS FOR SUCCESSFUL SIMULATION IN THE WEB

Concerning the actual deficits of tools for development of web based user interfaces, the efforts for model design and test should be minimized at the current time. The idea of Plug & play from computer hardware architectures will work also in web based simulation. One possible solution is a three level model repository and handling system:

- The first level provides very common, fixed models. Only external data files will change the behaviour of the models. The models are defined in the language of the used simulation system.
- The second level provides a library of predefined components. The client can define specific parameters of the components.
- This method is similar to well known component based systems like Arena or TAYLOR. Only the user interface and the number of forms and parameters are simplified.
- The third level allows a free definition of source code for the used simulation systems. The service of the ASP-system is limited to the execution and result analysis of the simulation.

Automatic data exchange

In current web based simulation environments data exchange is often reduced to manual operations, like copying text into the source code of the model or extracting results from long trace lists. Compared to professional methods of data handling in data bases or data warehouses, this level of data exchange is not acceptable for professional customers. A efficient usage of web based simulation system requires a full integration in the common data flow of the enterprise. This integration can be made by time scheduled export and import routines in ERP-systems and the simulation environment. The FTP protocol can be used for the physical transport of the data files (see figure 11). Other protocols like HLA or CORBA are also possible, but require more development efforts.

Result analysis with database functions

If the client is provided with a ERP, Data Mining or decision support system, result analysis of simulation runs is possible by importing the simulation trace files and using the integrated functions of these systems. Clients without powerful analysis tools depend on the functions provided by the web based simulation system. As demonstrated by the VisualSLX system (Wiedemann 2000) (Wiedemann 1998), this task can be solved by using databases for storing the results and calculating all aggregated values. The actual power of client-server databases also supports multi-model and multi-run comparisons. Visualization of graphical diagrams is supported by small Java applets.

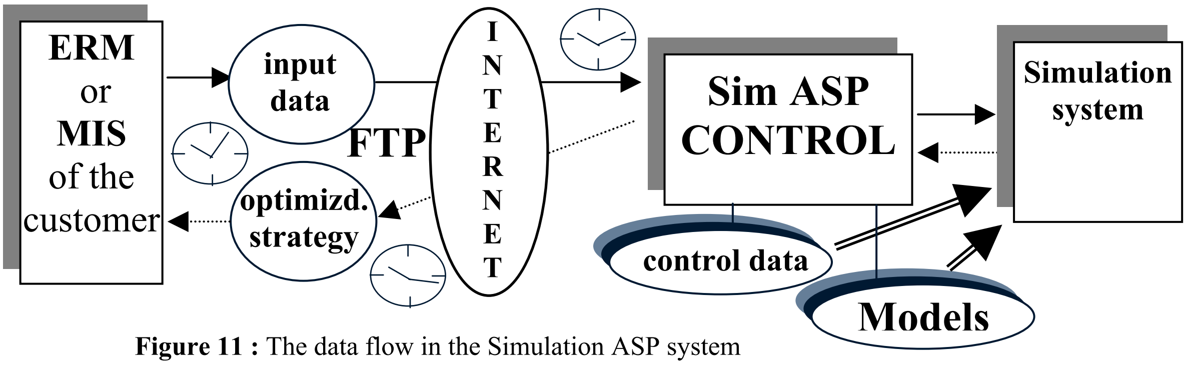

Figure 11 : The data flow in the Simulation ASP system

Fast and permanent access to simulation control functions

The first web based systems were often realized with CGI programs. The main disadvantages of this approach are low performance and a non-permanent connection to the simulation system. In result of the used batch mode, it was very difficult to control or interrupt a running simulation from outside. Information about the progress of the simulation was also hard to catch by CGI interfaces.
A web based simulation environment should provide a permanent connection between the client and the simulation kernel. State information and control functions must be available during the whole time of a simulation run.

A Simulation ASP-SYSTEM

Concerning the discussed requirements, an Application Service Providing (ASP) System for simulation was developed. Basic elements of this system are:

- a database for all model and simulation data,
- an object oriented modeling philosophy based on model entities and attributes,
- an universal code generator for converting the model description into a simulation program.

Details of the modeling philosophy and the code generator are presented in (Wiedemann 2000). The most important feature is the interface of the simulation environment to the web. In result of existing powerful software components for internet applications this interface is realized as combi-nation of the VisualSLX database system and a web-server-component (see fig. 12). Here we have no CGI-interface or similar technology. Data-base related requests from the web are received by the Winsock-component in the VisualSLX/WEB-appli-cation and are answered immediately. Advantages of this web-server integration are:

- a very high performance in result of direct data-exchange and always open database tables,
- a long-time connection between the client and the server with continuous data flow during simulation or result processing .
- Actually the SLX simulation system is used as a simulation kernel. For all code templates are stored in the database, the same code generator is used for HTML files and simulation programs.

The system can work in three modes:

- as a traditional, local stand-alone system,
- as a multi-user database in a local network,
- and as a real client server system in Intranet or Internet environments.

The first two modes are realized by traditional database forms. Application specific forms can be developed in some minutes by using latest technologies of assistant supported database design (e.g. in Microsoft Access).

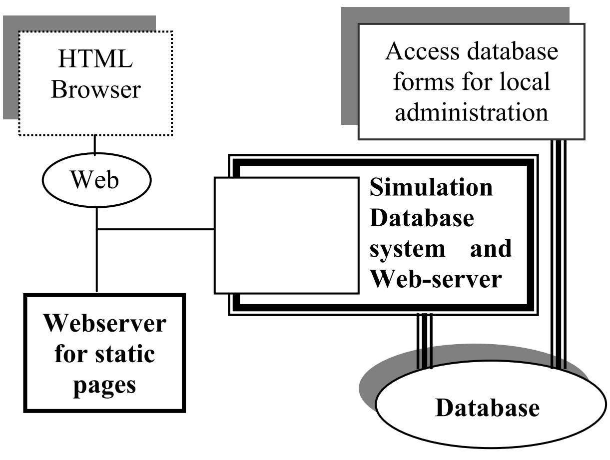

Figure 12 : The architecture of the system

The system supports all three levels of Plug & Play models according to the discussed requirements. The supported simulation systems are SLX and SIMPLEX III. Other systems can be integrated without large efforts. Currently a integration of the Enterprise Dynamics is under construction.

WEB SPECIFIC PROBLEMS

In result of specific characteristics of the actual Internet technologies we meet some typical problems.

Web performance and bandwidth

Outside of the intranet the bandwidth is very often low and rapidly changing. In order to solve this problem we see a solution in parallel editing of more than one entry. For example all objects and their parameters could be offered in form fields at the same time. Checking operations are done with only one connection to the web server and all problems are reported at the same time to the user. A second option is the usage of more than one browser window and a interleave interaction mode of the user. The best solution would be a Java-based user-interface which performs all major operations at the client side. For time reasons this solution is planned for a later version.

Multi-user lock problems

In the multi-user local database mode a database record is locked, when a user edits the content. During this time other users are able to see the record but they can not edit them. The Web is a system without defined sessions. Thus a user can switch off the computer or close the browser during an edit operation and the database receive no information about the loss of the connection. Similar to modern client server system this problem can be solved by a timeout of the lock mode. In the current database this lock operation and the check for time-out is done by VisualSLX.

Run-Time interaction

Due to the delay of information transfer from the server to the Web, the state of the simulation system and the visualization at the web based client user interface may differ for some seconds. Thus the feedback for user interactions like Break or Stopping the simulation will take two times the interchange time (from the client to the server and back), which could be sum up to 10 seconds. The main solution is revealed in the further technical improvement of the Web or a usage inside a Intranet with guaranteed quality of service. A simulation at the client side is not very useful due to the bad performance of Java.

License and security constraints

Web-based simulation also creates new requirements for software licensing and project management. Traditional software licenses of simulation packages only allow a single place usage. A web-based system must have the same license model like a network license. The payment of the simulation customers can be done per project or time. Another very critical fact is also data security. If a company uses a web-based simulation system possibly sensible data will be stored in an external database. In order to provide a safe simulation study some secret data could be decrypted with a public key of the company. A special encrypt DLL will be included in the import routines of the simulation model. The private key for decryption is directly transferred between the customer and the decryption module. If the source code of the decryption DLL is validated by an external institution, the security level of the private input data for simulation will be very high.

A further improvement of security is possible by **a content scrambling** at the side of the customer. Sensitive data like customer names or product brands are replaced by random values. The conversion table is stored only at the customers computer. For the simulator there is no difference about working on a order from BMW or on data of F3234. After the simulation is finished, the results are decoded by using the stored conversion table at the customer side. Even if the network connection or the simulator is hacked by external intruders, there is no risk of loosing information , because all important data does not leave the customer system.

All security issues should be seen as very important decision factors for or against a ASP-system. If a potential customer only feels some possible security risk of giving his data in external hands, this could be a "killer fact" against the ASP-idea, where all technical and financial benefits will be without any relevance.

Web Service for Optimization & Simulation

Based on new web technologies like SOAP, direct connections between applications are now possible. Compared to traditional web interfaces with human oriented HTML-forms there are no GUI-elements. The applications communicate directly by transfering short XML-messages with the SOAP-protocol on different communication channels like TCP/IP socket connections, HTTP, FTP or Email (not recommended, but possible).

In the case of Enterprise Dynamics models, the network interface is realized by an special optimization ED-Atom. The atom includes an TCP/IP-socket and communicates with the remote optimization server. For the end user this atom acts like a traditional, directly included optimization module. The difference comes only in the pricing scheme – there is no need of an expansive investment for the optimizer, but only the effective time used for optimization is billed with 5 to 100 Euros per hour. Related to optimization effects of more than 1000 Euros per successful experiments this seems very interesting for smaller firms.

The above descriped WEB SERVICE was registered at uddi.ibm.com for world-wide-usage (see fig. 13 and 14).

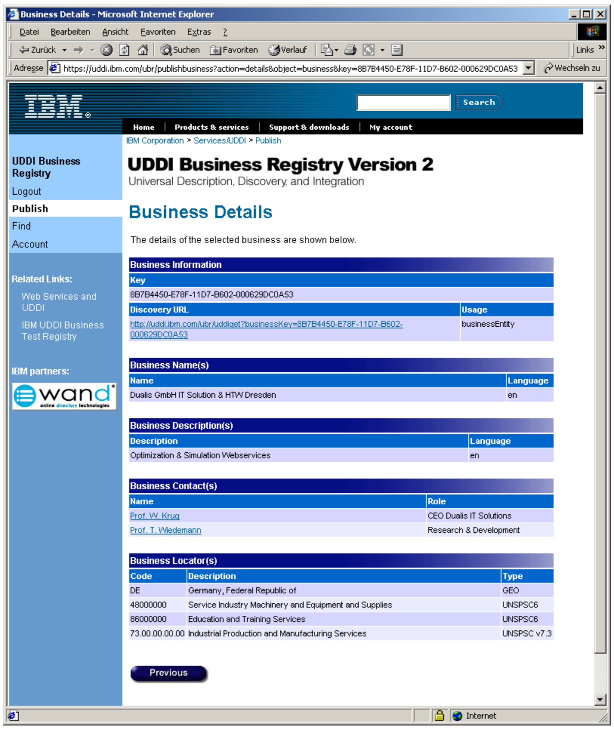

Figure 13: The official registration data of the optimization web service at **uddi.ibm.com**

Figure 14: The XML-based optimizer task description

CONCLUSIONS

The success of optimization technologies depends on the combination of optimization tools with other Information Technologies for PPC, and Workflow Management Systems. Simulation- and Optimization Tools and Standard Interfaces will be changed continuously. This is the best strategy for getting a maximal synergy and a wider usage of optimization and simulation tools.

The perspectives of web based simulation will improve, if the current web technologies are used for a maximum of user friendliness instead of copying existing simulation systems to the web. Actually this approach will limit the capabilities of modeling large and complex systems. But the ease of use and the fast return of investments will turn this user driven approach into a very interesting way for improving and increasing the usage of simulation in commercial decision making.

REFERENCES

Erkollar, A., Mayr, H. C.: Simulation Aided Network Analysis in Production Planing and Control, In (Teo, Y.M. et al. Eds): Proc. WCSS'97, World Congress on Systems Simulation, Singapore, 1997, pp. 88-92.

Fishwick, P.A. 1996. Web-Based Simulation: Some Personal Observations. *In Proceedings of the 1996 Winter Simulation Conference*, 772-779.

Henriksen, J.O., 1995. An Introduction to SLX. *In Proceedings of the 1995 Winter Simulation Conference*, ed. C. Alexopoulos. 502-509. Institute of Electrical and Electronics Engineers, Piscataway, NewJersey.

Healy, K.J. and R.A. Kilgore, 1997. Silk: A Java based process simulation language. In *Proceedings of the 1997 Winter Simulation Conference*, 475-482.

Krug W., Modeling-, Simulation – and Optimization – based Intelligence Business Process Engineering, in Proceedings: Facibiliting Development of Information and Communications Technologies for Competitive Manufacturing IiM 97, Dresden, 1997, Edited by D. Fichtner and R. Mackay, Page 329-333.

Krug 1997 : Intelligent Simulation- and Optimization system for Manufacturing, Organization and Logistic ARENA/ISSOP Handbook, 1997, Edited by SCS International San Diego U.S. 200 Pages and 100 Figures.

Kuljis, Ray J. Paul, 2000: A Review of web based simulation: whiter we wander?, *Proceedings of the 2000 Winter Simulation Conference*, Orlando Florida, page 1872-1881

Wiedemann. T., 1998. Sim-Mining and SimSQL - A database oriented approach for component-based and distributed simulation, *Summer Simulation Conference 1998*, Reno Nevada,

Wiedemann. T., 2000. VisualSLX – an open user shell for high-performance modeling and simulation, *Proceedings of the 2000 Winter Simulation Conference*, Orlando Florida, 1865-1871