MINIMUM STOCK COSTS AT GIVEN TIMES FOR DELIVERY WITH SIMULATION AND OPTIMIZATION

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Abstract

High complex optimization problems regarding production planning could often not be achieved with standard planning methods, because they are not able to solve practical problem sizes. This makes the usage of mathematical optimization methods and dynamically validation features of simulation necessary. As a result of high complexity and lots of interdependencies between the different targets, optimization has many degrees of freedom. Competitive objectives are minimal cycle times, maximal workload of resources, minimal stock sizes, minimal set-up costs (sequence dependent) and high order fulfilment. Resulting runtimes of computation are not bearable in industries, because near- and medium-term planning assignments are recurring rapidly. The case study describes the solution on the basis of a practical example, which was implemented at Erne Fittings in Austria. The challenge was to solve a high parametric, complex, and dynamic optimization problem below twelve hours computation time and nevertheless guarantee high quality of output. The optimization part was solved with *ISSOP 2.0*©, an optimization tool, which uses many parallel working metaheuristics, composed of deterministic, stochastic, evolutionary, and genetic algorithms that are controlled by an intelligent learning method, which spreads calculation time ideally. The simulation model programmed in *Flexsim*© has three main assignments. One is to emulate the calculation methods and interfaces of Erne's ERP software *Brain*© and to test the cooperation with optimization. Second task is to simulate the whole information and material flow in production, stock keeping and order processing over two year time periods, to analyse optimization suggestions regarding stock sizes and customer satisfaction. Third task is to adjust optimization and to check resulting effects. Additionally the simulation is used to convince Erne of optimization quality and to check the impact of different possibilities in production planning (e.g. high or low order-fulfilment against stock size).

Keywords: Simulation and Optimization. Simulation for Optimization Validation.

Presenting Author's biography

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1 Motivation

1.1 Trends in production planning

Due to internationalization and liberalisation of the world trade, network supported communication, and information flow, competition in global markets is increasing [1]. The demand to develop innovations in constantly shorter growing cycle times is accelerating [2, 3, 4]. Companies have to keep up with the rapidly changing environment and react flexible and fast to changing markets [5]. Main task of planning is therefore in the design of short-term production plans which is on one side defined through the interdependency between material and information flow and on the other side affected through manufacture and product structure. On that background the support of intelligent systems within production planning has an increasingly important role to differ between success and disappointment. The use of simulation to forecast and analyse dynamical behaviour and optimization methods to determine good solutions is getting more and more important and is no longer only used in research [6].

1.2 Simulation and optimization in production planning

This paper describes the problem of production plan optimization on a practical example, which concerns many companies. Differentiation to competitors can not take place through price, at least not in central Europe. Therefore many companies need combinations of quality, service and price to define themselves against their competitors. In our example this means, that a manufacturer of standard products has to offer high availability at acceptable prices. The resulting task of cost optimized production- and supply-planning can not be achieved with standard planning methods. This makes the deployment of mathematical optimization and dynamical evaluation methods necessary. [7]

High complexity and much coherence between product, process, and resource structure in practical cases, cause an optimization problem with a vast number of possible solutions. This takes fundamental impact on computing time. At this level of complexity linear optimization methods can't be used, without making many simplifications to the model and reducing limitations. According to this fact linear optimization methods are unusual in practical production planning problems. Non-linear models demand heuristic optimizations, which do not guarantee the global optimum and are much more time expensive than linear methods. The combination of large solution spaces and calculation time consuming algorithms questions the adoption of such an approach. Thus such methods need help to get acceptance in economy. This can be done with any tricks that shorten optimization time (branch and cut, rule based optimization to scale down solution space etc.) and with the use of simulation to evaluate quality of the results of optimization to prove its potential. In the treated example simulation is used to emulate the ERP-system (enterprise resource planning). This offers the possibility to test the collaboration between optimization and ERP-software and to simulate with real data from earlier periods over time slots from one or two years to evaluate the output and therewith the quality and advancement of the optimization against other simpler alternatives as reorder point inventory management [8] or batch size calculation with EOQ (economic order quantity from Wilson) [9].

2 Problem description

2.1 Initial situation and goal

The company Erne Fittings GmbH (Erne) placed in Schlins, Austria produces advanced buttwelding fittings on three different locations in Austria and Germany [11]. Erne produces a wide range of elbows, tees and reducers from a large range of materials, both standardized and after customer request. Distinguishing feature between Erne and its competitors for standardized products (DIN, ANSI) is the service in order fulfilment. High availability inside a broad product range, short delivery times, and compliance of agreed delivery dates are promised [10].
Erne is manufacturer, as well as commercial enterprise. The second category is called supplier. In this category the finished goods are sold from stock. Altogether Erne differs seven ordering processes that vary in quantity and delivery time. The different ordering processes need separate treatment logistically and therefore also in optimization. [7]

The ordering processes can be divided into three groups. Customer orders with delivery time between six and ten weeks, orders from stock (supplier) and basic agreements. The first and the second group are split into large (up to half batch sizes), middle (pack size), and small (till single units) quantities. The second group has specific guidelines. Large and middle order quantities need to achieve availabilities between 90% and 95%. Small quantities should always be disposable. The third group, which defines basic agreements, provides a fourth year preview on demand and needs a 100% order fulfilment rate.

Hence the assignment was to valuate the diverse business processes inside the order fulfilment concerning their consequences for stocking and to find an adequate strategy for manufacture planning and purchasing primary material (tubes). Thereon a software planning tool was implemented and established.

Implementation contains the following steps:

1. Analysis and evaluation of order fulfilment and its consequences for stocking

2. Deployment of a planning methodology for production planning and purchasing.
3. Implementation of an optimization module with *ISSOP* [12] and integration in the operative enterprise resource planning system (*Brain*) of Erne.
4. Verification of the planning methodology with emulation of the ERP system in *Flexsim* [13] and simulation to prove quality of optimization results.

2.2 Causal relationships in production and purchase planning

Assignment was to assure logistical promises concerning delivery dates and volumes, under consideration of conditions and restrictions. Main target was a cost optimized solution, which is able to achieve these specifications.

In detail:

- Differentiated treatment of processes regarding production and stock keeping.
- Preserve high flexibility under dynamic demand.
- Illustration of varying positioning concerning price-list articles.
- Adjustable ranges of stock capacity within the different inventories.
- Planning of production volumes and times considering set-up costs, storage costs and penalty costs (delay in delivery).
- Purchase planning with consideration of minimum units of trading, discounts and storage costs.

Altogether the accounted price list comprises more than two thousand articles. The relationships are pictorial explained in Figure 1. Production subsumes the demand of goods into set-up groups. Each order belongs to a different ordering process and has thus an associated production priority and date. The set-up groups have unbalanced order quantity and are scheduled dynamically. Primary materials have heavy alternating lead times (steel market) and are disposed on basis of sales forecasts. The relationship between primary materials and finished products is one to many. Finished products and primary materials are kept in different stocks, which have different stock capacities in tons.

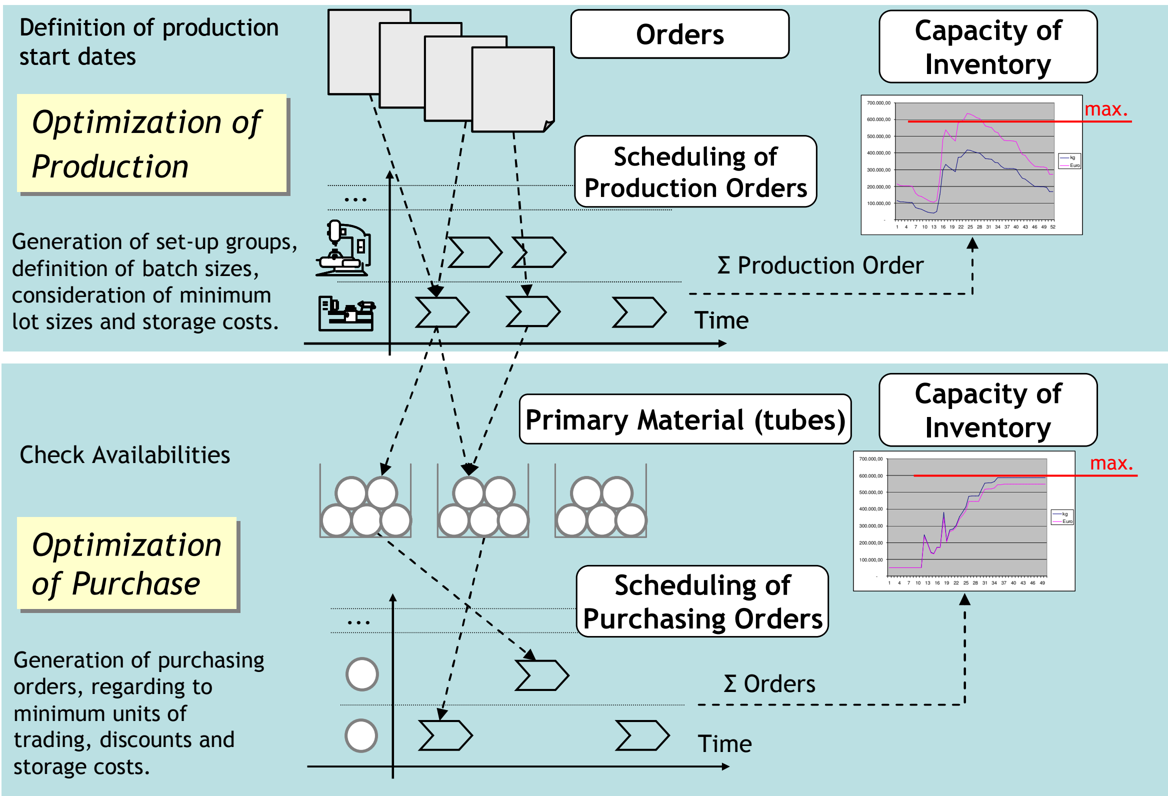

Fig. 1: Causal Relationships in Planning

3 Model

3.1 System architecture

The ERP-Software *Brain* uses defined interfaces to write the current disposition, order and purchasing data in periodical intervals. As *Brain* is not able to deliver all data, which is necessary for optimization (relations between customer orders, fixed productions orders and stock), a clearing is prefixed, to compute all essential information. The whole data-model is programmed in C++ and follows object oriented programming guidelines. In this model pre-calculation, rule based optimization to scale down the problem complexity and start with acceptable suggestions, heuristic optimization and solution polishing takes place. This means that *ISSOP* (described in Chapter 3.2.5 Optimization) is also controlled by the model. The optimization tool generates orders for production and purchasing within a period less than twelve hours and writes them back into a defined format. The left part of the system architecture could include a simulator or *Brain*. This software *Brain* they are all based on the CSV-format (comma separated values). The simulator emulates the ERP-software and uses therefore exact the same files. The optimiser doesn't differ if he communicates with *Brain* or the simulator.

An example for an interface file is "customer orders". Here is one line of data in the defined format:

000134;FA;00001861;STK;200720;200722;0;

Tab. 1 Content of fields in customer orders (one line is split in two rows)

Article number	Ordering process	Order unit	Order size
Unit	Purchase order date	Delivery date	Stock mapping

The information in the file customer orders (Table 1) is used to check if the order is already covered, how much is covered, the mapping to the stock, if stocked,

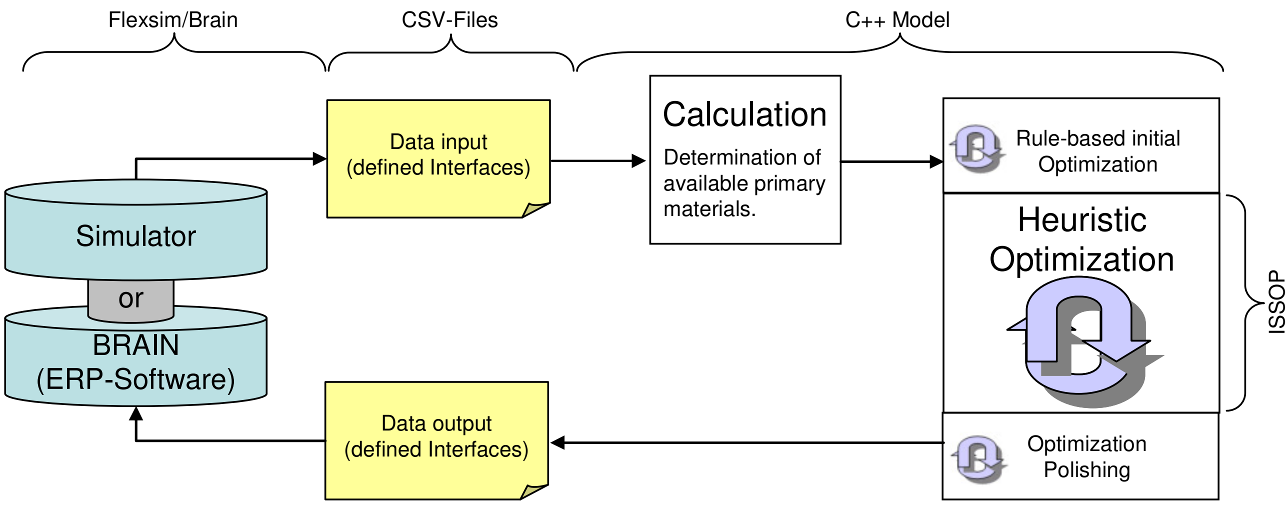

Fig. 2 System Architecture

the priority of the order and the time slot in which production has to be started. The most explicit level of detail regarding to dates in the model are calendar weeks.

was made to be able to emulate the ERP-software, to gain assurance and to prove functionality of the optimization tool. Additional simulations could have been made to demonstrate the effects on stock and availabilities under different situations (maximum stock size, distribution of different ordering processes etc.).

3.2 Implementation

The Implementation is structured into the parts of Figure 7 System Architecture.

3.2.1 Interfaces

The interface files are used for data exchange and communication between the parts of the system architecture. Due to some restrictions of the ERP-

3.2.2 Pre-calculation

The pre-calculation is necessary, because *Brain* can't provide all order data and their relations with stock and fixed production orders. Pre-calculation is made in the C++ model which comprises all parts concerning the optimization.

3.2.3 Brain

Brain is the production planning and control tool of Erne Fittings. The Optimizer accesses the required data through defined interfaces and writes them into the same ones back. *Brain* is triggered to read the outputs of optimization in periodically time intervals.

3.2.4 Simulator

The simulation model is implemented in *Flexsim* 3.0. This model holds all necessary consumptions methods of the ERP-system *Brain*. The production orders are the flow items in the model. All other parts like the amounts of stocked goods in different stocks (primary material stock, high bay racking, block storage etc.), or the relations between future production orders and their attached primary material, or reservations between customer orders and stocked goods, or between customer orders and fixed production orders are hold in a database model within *Flexsim*. This means that the consumptions take place between the different tables. The visualization of this model is very simple, because the results count and not the animations. The results of the simulation are exchanged with an Access Database through the CSV-format. The analysis is discussed in Chapter 4.3 Simulation Results. The validation of the model was made with operating data from two years past.

The simulator has three main assignments:

- It is used as an emulation of *Brain* to test the interaction with the optimization tool over the interfaces.
- It can simulate long time periods, which means it opens the capability to analyze different system loads and evaluate met decisions as for example very high order fulfillment rates or low stock sizes.
- It helps to tune optimization adjustment parameters and show resulting effects on stocks, batch sizes, order fulfillment etc.

Additionally feature of the simulation is that it could be used to convince users of optimization quality.

3.2.5 Optimization

The main part of the optimization process is done by the heuristic optimization with *ISSOP 2.0*. The other rule based parts are explained in Chapter 4.2 Quality of optimization. The intelligent optimizer *ISSOP* uses model analysing features to reduce the complexity of the optimization problem and to gain high customer acceptance [14]. The architecture of *ISSOP 2.0* with all its functionalities is depicted in Figure 3. Many parallel working metaheuristics, composed of deterministic, stochastic, evolutionary and genetic algorithms, are controlled by an intelligent learning mode [15, 16, 17]. Thereby a user must not choose the appropriate heuristic himself and with increasing calculation time the learning mode manages the used calculation time of each method intelligent [14]. Calculation time of less effective methods is reduced to a minimum. Another advantage is the robustness of the used algorithms. They are all well tested and evaluated, where a redevelopment normally costs a significant amount of time.

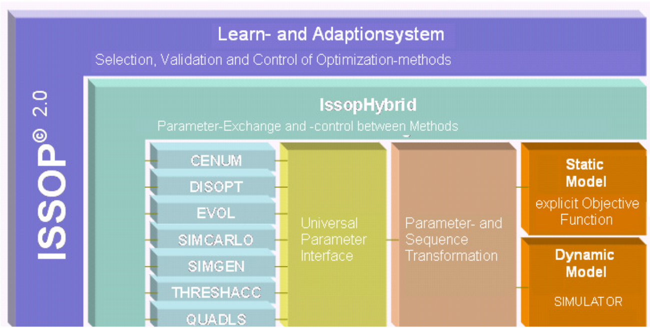

Fig. 3 Software architecture of *ISSOP* 2.0 [14]

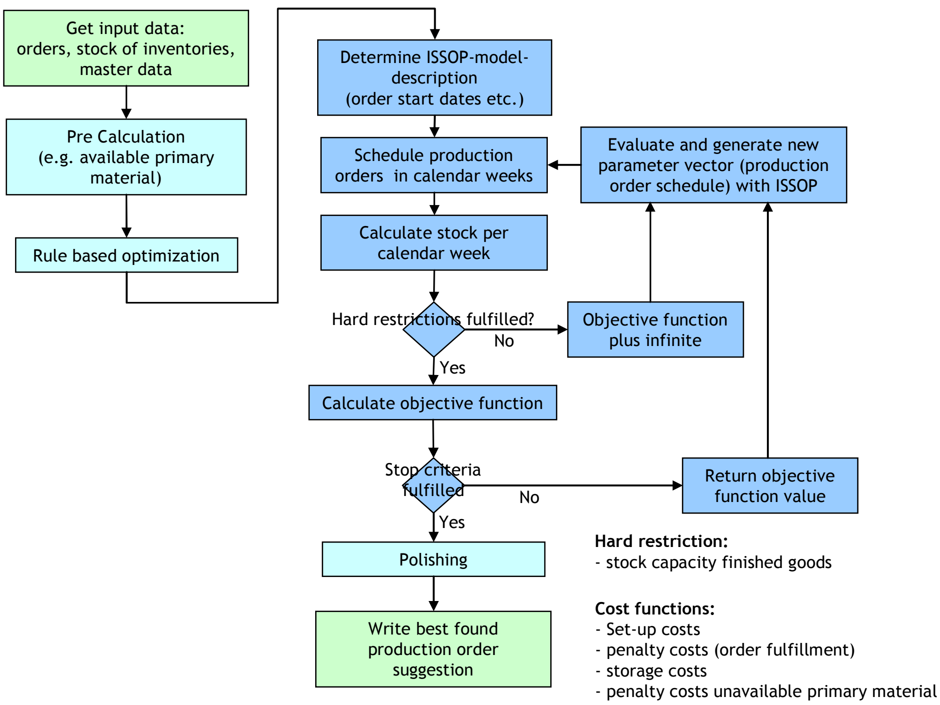

Fig. 4 Basic Flow of Optimization Process

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Figure 9 describes the basic flow of the optimization process. The whole model is in the C++ model as shown in Figure 7. First the C++ model takes current stock and order data (customer orders and planned fixed production orders) and dispatches them into sequences. The next step is the rule based optimization as described in Chapter 4.2 Quality of Optimization. The output is committed to the *ISSOP*-model, which is controlled by the C++ model. Figure 4 shows the flow of the heuristic optimization more detailed. Production orders are planned into calendar weeks. Then the C++ model calculates stock and availability indices with the production order suggestions from *ISSOP*. If the limit of stock capacity for one or more inventories is passed, the model restarts and searches for a new parameter vector, which means that the production orders are moved over the time line. If the restrictions of the model are kept, the next step is to calculate the objective function. While the criteria to stop optimization (runtime) are not fulfilled, the model passes the value of the objective function back to *ISSOP* and a new parameter vector is generated. The process starts again with the scheduling of production orders into calendar weeks.

3.2.6 Equipment

The following equipment is used:

- *ISSOP 2.0*: heuristically optimization
- *Flexsim 3.0*: simulation/emulation of ERP-software *Brain*
- MS Visual Studio 6.0: programming C++ model
- MS Access Database: result queries
- MS Excel: diagrams and tables

4 Results

4.1 Runtime

A total of approximately 50,000 disposal orders and about 30,000 purchasing orders need scheduling concerning batch sizes, dates and sequences. The biggest affect on runtime has the amount of involved orders. Due to the fact that orders couldn't be grouped, because of their different ordering processes, the mapping between disposal orders and resulting production orders needs to be done individual. As a result the steps the optimization has to make and to evaluate are caused by the number of considered orders and thereby also the runtime. Given restriction of runtime from Erne was that one run of optimization must fall below twelve hours. This restriction made some rule based methods necessary, which scale down the problem complexity and speed-up the whole optimization process. More thereto in Chapter 5 Challenges.

4.2 Quality of optimization

The requirement to finish the optimization process within twelve hours shouldn't reduce solution quality. Hence some methods to reduce model complexity were added. Following methods are used to downsize the optimization problem or speed-up the whole process:

- Blurring
- Containment
- Rule based optimization
- Polishing

Blurring means that customer orders with a delivery date after lead time aren't treated individual. A parameter can define how they are summarized. For example all orders with a delivery date in later than twenty weeks are weekly accumulated and put as one order instead of more individual orders in that week. This reduces the amount of orders to optimize and although has no impact on solution quality, because only the first orders are really fixed in the production planning system. Later ones are only important to allocate primary materials or trigger purchases. The effect of the method is that future orders are blurred to single ones and individual orders do not remain visible.

Containment means a concentration on orders which are relevant for the optimization problem. Customer orders or prognoses of customer orders which have a delivery date in a time period after the whole replenishment lead time plus primary material lead time need no attention.

Rule based optimization takes place before the heuristic optimization process. Target of rule based optimization is to deliver feasible production orders to the heuristic optimization. The idea is to start from an already good point and improve solution quality constantly through heuristic optimization. An example for a rule based optimization function is to backward schedule production orders, that they are adequate to customer orders and then determine the first possible (connected to primary material) respectively latest necessary (customer order availability) production start date, according to the current availability of the concerned primary material. All production orders of the same article can't be produced before this date. Therefore they are scheduled to the same date or later. Another step of the rule based optimization is to check set-up relations between different products. The algorithm starts with near time productions orders and searches for other orders with the same set-up group. Then it checks the possibility to produce the orders back to back at the start date of the first one. This means the comparison between set-up costs, which accumulate now only once and the increasing amount of storage costs, because of earlier produced orders. On the one hand the savings of set-up costs need to be larger than the increasing storage costs and on the other hand the second order needs earlier primary material, which availability must also be checked. If both conditions are fulfilled the second order is moved to the date of the first. These rules and some others need many cycles over the production order list, but the time they save to the whole optimization process is much bigger than the time they need themselves (see Figure 6).

The last function is called polishing and follows the heuristic optimization. If the number of evaluated iterations or the whole runtime of the heuristic optimization is rather short chosen the production order suggestions are sometimes not optimal. This function can be compared with a smoothing. First the heuristic optimization smoothes the bigger and smaller peaks and later the polisher smoothes the small heaps. It is only a local optimization. The polishing method runs through the production order list and checks if their start dates are as late as possible. If there are more articles with the same set-up group within one schedule week the check breaks down, but if not and the order could be produced later to get ready on time for his associated customer order, the production order is moved to the latest necessary date. This saves inventory costs and allows reducing the runtime over the heuristic optimization, because suboptimal solutions are polished.

4.3 Simulation Results

To simplify the analysis of simulation results, they are collected in a database (MS Access). Using SQL (simple query language) all reasonable combinations of data could be made and exported to Excel. The whole process of generating result documents is automated. This means that after a finished simulation run all result documents could easily be created. Figure 5 displays a diagram to analyse one article. The X-Axis presents the time line in weeks and the Y-Axis the amount in units. The diagram shows progressions of stocks size, customer demands, start and ending of production orders, and unsatisfied respectively delayed customer orders. The diagram on bottom right is the associated diagram of primary material. A production order on the top diagram is a stock reduction in this diagram. Relations between a delayed production order and a shortage of primary material are directly seen.

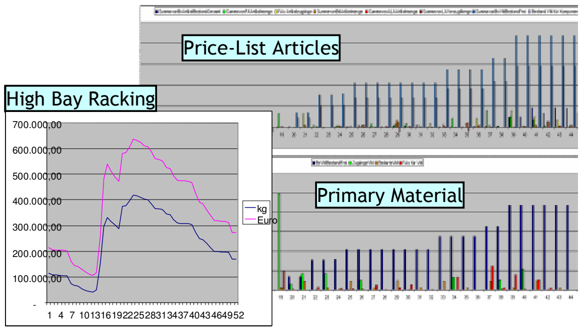

Fig. 5 Stock and Order Progression

The diagram on the left in Figure 5 displays progression of stock in both money and tons. The diagram also shows the average load and the capacity restriction. Many other results and operating figures like inventory turnover, amount of satisfied customer orders or average stock sizes are presented tabular. This tool offers the possibility to analyse simulation results very fast and to identify bottlenecks.

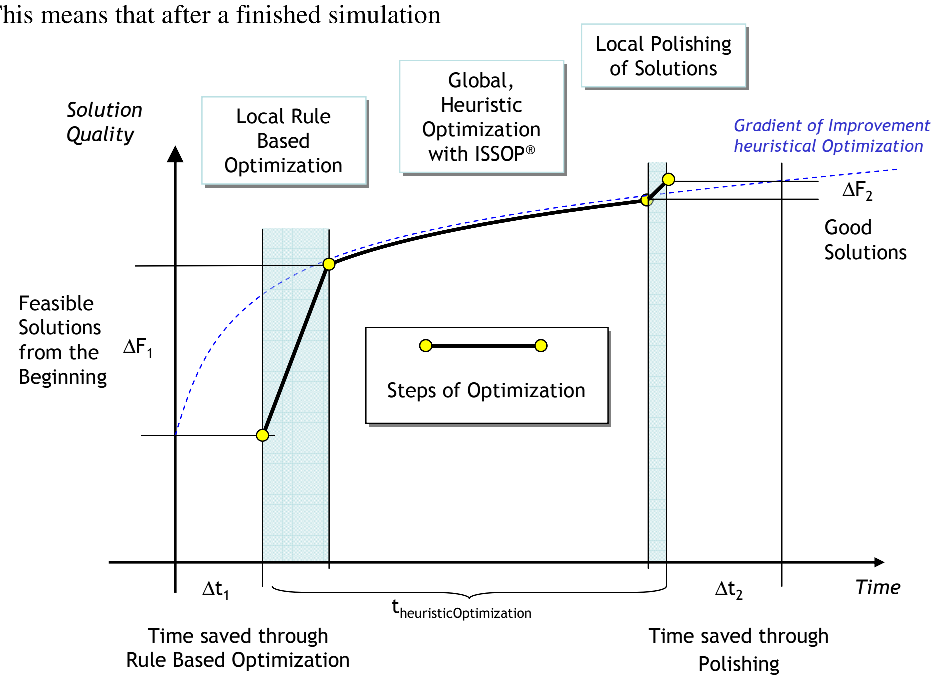

Fig. 6 Optimization Quality and Runtime

5 Challenges

The greatest challenge was to reduce necessary optimization time below twelve hours and nevertheless guarantee high quality of optimization output. Chapter 4.1 Runtime and 4.2 Quality of optimization describes the essential steps to meet the requirements.

Another key point was to convince in practice and to prove the optimization abilities are plausible and practical useable. This wouldn't be possible without simulation and the comparison with alternative production planning and stock keeping methods as reorder point policy or EOQ.

6 Conclusion

This project demonstrates the succeeded combination of simulation and optimization inside an industrial environment. Erne is using the described optimization tool since April 2007 with about 140 articles (one price list) and will add more price lists gradually. One of the biggest advantages is to analyze high complex and dynamic systems and to simulate the behavior of all system components under different situations and specifications. Additionally a high complex and practical optimization problem is solved and evaluated. Faster becoming computers and new approaches in programming open many possibilities to solve large scale problems in reasonable amounts of time and make it feasible to use this potential in industrial processes.

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