14TH EUROPEAN CONCURRENT ENGINEERING CONFERENCE 2007

ECEC'2007

4th FUTURE BUSINESS TECHNOLOGY CONFERENCE

FUBUTEC'2007

EDITED BY

Danny Van Welden

APRIL 25-27, 2007

DELFT, THE NETHERLANDS

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2007

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PREFACE

The **ECEC** conference started its life as an enhancement of a conference track of ESM 1988, which looked at the factory of the future. The first dedicated unnamed workshop was held as a standalone workshop alongside the ITEC 1993 conference, which was held at Wembley in the United Kingdom. The next event was called **CEEDA** as it fell under the umbrella of the University of Southampton. As the University of Southampton stopped the bi-annual event and we wanted to go on with a yearly event, the name was changed to **CEE** in 1996 and **ECEC** from 1998 onwards to emphasize the European connection. Thanks largely to the input from people of DaimlerChrysler and related companies the conference has carried on through the years.

ECEC is also special in its own right, as it is the only EUROSIS conference, which has a best paper award named after one of the founders of the event, who died in tragic circumstances, in a car crash, while returning home from ECEC2002 in Modena, Italy. His name is **Steffen Schwarz**. And it is an honour and a privilege for us to be able to award the authors of the best ECEC conference paper with this award named after him.

On the other hand, the first **FUBUTEC** conference was held in February 2004 at INSEAD, Fontainebleau, France. As one of the best known business schools in the world, INSEAD was perfect as the launch pad for this event as INSEAD, in its studies also covers all the various topics of the **FUBUTEC** conference. As time went on, the **FUBUTEC** event topics aligned themselves more and more with the **ECEC** conference topics and that was the reason the **FUBUTEC** was paired to **ECEC** (The **E**uropean **C**oncurrent **E**ngineering **C**onference) in 2005, where it has remained ever since.

In 2007, the ECEC-FUBUTEC’2007 is hosted by Delft University of Technology It is aimed at industrial enterprises, industrial associations, universities and research institutes, and features a variety of interesting contributions to the following major topics:

1. Business Model Simulation
2. Datamining and Management Information Systems
3. Guided Vehicle Simulation

We would like to take this opportunity to thank the general and local organizers of the conference, and especially Philippe Geril from EUROSIS in Ghent for his efforts and work, and to all Session Chairs, Members of the Technical Program Committee and Reviewers for their efforts to make this Conference a success.

We hope that this event will lead to further CE activities, which will also bring people from industry, research and education closely together. As General Chairman of the 14th European Concurrent Engineering Conference and the 4th Future Business Technology Conference, the Organizing Committee of the Conference joins us in thanking all of you for supporting this event and in wishing you a pleasant and rewarding stay in Delft.

Danny Van Welden
General Chairman ECEC-FUBUTEC’2007

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BUSINESS MODEL SIMULATION

SIMULATION IN THE CATERING SERVICES INDUSTRY: THE CASE STUDY OF EQUILIBRE & SAVEURS

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KEYWORDS
Simulation, business model, catering services.

ABSTRACT

Catering services in the French market are under continuous transformation: people require to eat in limited time window, pay a reasonable amount of money and follow a healthy diet. These behaviour changes lead to the introduction in the market of a new generation of quick service restaurants that offer fresh meals of high quality, at affordable prices and in a short time. This paper proposes the Equilibre & Saveurs business model for the catering services industry that fulfills the changing requirements of the French market. The proposed business model is optimised with the application of simulation, as far as layout organisation and operational scenarios are concerned.

INTRODUCTION

French eating behaviours are evolving: people are now demanding to eat faster, better, cheaper and healthier. As a consequence, catering businesses attempt to offer new services that suit best customers desires. A new generation of companies providing high quality meals at affordable prices appeared on the catering market few years ago. In view of market studies, there is a current opportunity to develop a company based on meals on tray delivery system. Present research aims to create such business model, to evaluate and optimise it, in order to propose a fully optimised business model to investors interested in getting into catering industry.

In order to achieve our objective, we will base our research on both layout design optimization and model assessment and improvement through simulation. The core question that will lead our study has been formulated as follows: how can we evaluate and optimise the proposed business model through enterprise simulation?

A literature review of the various types of business configurations, layout design models, optimisation methods and simulation concerns is carried out and constitutes the base of this research. The methodology used to conduct the present research is based on the case study.

The proposed business model is then described by defining its mission, objectives, strategies and resources, as well as analysing the catering market. The layout of the proposed model is evaluated and optimised by seeking to minimise the total distance travelled by entities in the system.

The business model is build with ProModel Software to allow the assessment of the overall model performance through simulation. Results, based on customer satisfaction, resources utilisation and stock management criteria lead to an improvement process thanks to additional simulation runs.

LITERATURE REVIEW

Companies are all distinct, producing unique products, offering diverse services. They all have their own organization and culture, their own strategies and objectives. All these factors imply an adapted layout in order to provide products and services efficiently. Consequently, it can be said that each firm has a particular layout that fits better its objectives than the others.

Business configuration types

Abdul-Hamid *et al.* (1999) reviewed layout organisation through an extensive literature review stating that: "production volume, batch sizes, flexibility in meeting customers orders, types of machinery, levels of labour skills, production control and scheduling difficulties, machine and labour utilization, lead times and the materials handling systems required" are main layout features. They identified product, cellular and batch layout configurations. At the end of the 20th century, it clearly appeared that these three types of layout do not meet the needs of companies which are faced with high volatile environment. Consumer's behaviour is hard to forecast and production is more and more made-to-order (MTO). Academic research thus focused on the development of new layout types, mainly based on flexibility. Flexibility is defined by Lotfi (1995) as "the capability, as well as the ease (i.e. time, cost or any other resource) with which any change can be accommodated by a manufacturing system". In every definition given to flexibility, the idea of adaptability to the uncertainty is relatively strong.

After reviewing the traditional types of layout, Benjaafar et al. (2002) developed novel ways to arrange factories, better adapted to our society, based on main three concepts: flexibility, modularity and ease of reconfiguration.

Therefore, they elaborate four new groups of layouts: modular layout, reconfiguration layout, agile layout and distributed (scattered) layout.

Layout design models

According to Braglia et al. (2003), the Facility Layout Problem (FLP) is concerned with the identification of the most efficient arrangement of m resources, within a shop floor, according to suitable constraints.

The Quadratic Assignment Technique (QAP) is the oldest method that has been used by designers to generate better layouts. As stated by Askin et al. (1999), the QAP has been modelled to minimise total cost (flow) between departments. This procedure is based on the assignment of n workstations to m locations and gives optimal solution for very small cases. The problem is by far too complex when more than 12 cells for some authors, 15 for others, are implied in the problem. This is explained by the explosion of the number of possible combinations. However, Liggett (1981) presents a combination of this technique and other procedures that allow the optimization of larger cases.

Graph theoretic approaches have been well studied by Montreuil (1990) who conducted various studies on the subject in the 90s. Thus he defined 3 design skeletons types: planar adjacency graph, matching adjacency graph and cut tree. The weakness of such approaches, revealed by Montreuil (1990) is that they "rely entirely upon the human designer".

Layout optimisation methods

Layout optimisation has traditionally been done through mathematical programming techniques. Nonlinear programming, mixed integer programming are examples of such techniques used by designers. In order to generate solutions of higher reliability, faster, for larger problems and less expensive, researchers looked for new techniques and thus developed random search heuristics algorithms. Two examples of such techniques given by Meng et al. (2004) are genetics algorithms (Rajasekharan et al. 1998, Kochhar and Heragu 1999) and simulated annealing (Jajodia et al. 1992). Hooke and Jeeves pattern search method is a third technique that allows layout optimisation.

Simulation

Simulation is extensively used in operations research. It aims at reproducing a system, real or not. In the case of an unreal case, simulation can be done trough the modelling of the system. Simulation can be used as a design tool, in the case of a system creation. What is happening in the system is thus observed, and performance is studied under various conditions to determine the best solution for the system. Simulation can also be employed as an analysis tool to answer "what-if" questions. In this situation, the changes effects in the system are studied, what is happening in the system is quantified. From a production perspective, simulation can be used in system development, production planning, production control and education and training.

Simulation always requires a set of determined elements: entities, locations, resources, entity arrivals, processing and routings. Banks et al. (1996) suggest a specific procedure made up of 12 steps to design a model for simulation. Before running a simulation and even before conceptualising a model, the research problem has to be defined and formulated in order to generate a set of questions that will be the purpose of the experiment. The second step asks for setting the objectives of the simulation and elaborating a plan of the project. Once this has been determined, a model is conceptualised while data are collected. Model conception necessitates data as an input. The model is then translated, verified and validated to ensure that it works and represents an accurate view of the reality. After that, experiment is designed to allow the production runs and analysis. When generated data have been analysed, decision can be taken to run additional simulations. Since no more simulation run is required, results are gathered and reported into tables before the last stage of the process: the implementation step.

METHODOLOGY

In this paper we followed the case study research methodology. Case study is a qualitative research method that can be defined as a method of learning about a complex instance, based on a comprehensive understanding of that instance obtained through extensive description and analysis of that instance taken as a whole and in its context.

This approach has been balanced with quantitative research methods by many scientific researchers. Kerlinger (1986) identifies three major weaknesses of qualitative researches: the inability to manipulate independent variables, the risk of improper interpretation and the lack of power to randomise. Lee (1989) identifies four corresponding problems with case study research – a lack of: controllability, deductibility, repeatability and generalisability. However qualitative research methods offer many advantages. Case study allows the researcher to study a system in its natural context, to learn about reality, to generate theories through observation. When the objective of the research is to study contemporary events, Yin (1984) suggests such method and recommends the use of single case study when the researched subject is investigated for the first time, as well as the use of a multiple cases study when the objective of the research is to describe, build or test a theory. Even if case study method lead to low controllability, deductibility, repeatability and generalisability, it also conducts to high discoverability and representability, that is a high degree of explorability but a potential model complexity.

Yin (1984) developed four steps for a good case study design: problem definition, unit of analysis selection, data collection methods and data analysis strategies determination. The core problems of the current research are the layout design and optimisation, as well as the model evaluation and optimisation through simulation process.

The unit of analysis corresponds to the entity being investigated during research process and for which data are gathered. In the present research, the unit of analysis is the case of the new company Equilibre & Saveurs. The fundamental purpose of the company is to provide to business people an affordable healthy meal, as fast as possible. As soon as the customer orders, employees work for him and deliver what has been required as fast as possible. Meals are delivered cold, ready to be warmed up, by delivery people.

Data needed for the research are both qualitative and quantitative. They are collected through environment investigation, observation, exploring secondary data, experimentation and interviews and then analyzed through model building under ProModel Software and simulation runs.

LAYOUT EVALUATION AND OPTIMISATION

The overall layout of the company has been designed according to a) the HACCP rules that gathers hygiene rules about the role of employees, the way to order raw materials, to take delivery of them, to store them; how to prepare the multiple elements that compose a menu, how to manage finished goods, how to deals with traceability, unsold products, wastes; how to clean and disinfect; and b) the "Marche en Avant" procedure that makes mandatory the respect of a clear distinction between areas (storage, production, finished goods storage and sending areas). In Figure 1, the layout of the proposed business model is depicted according to these legal requirements.

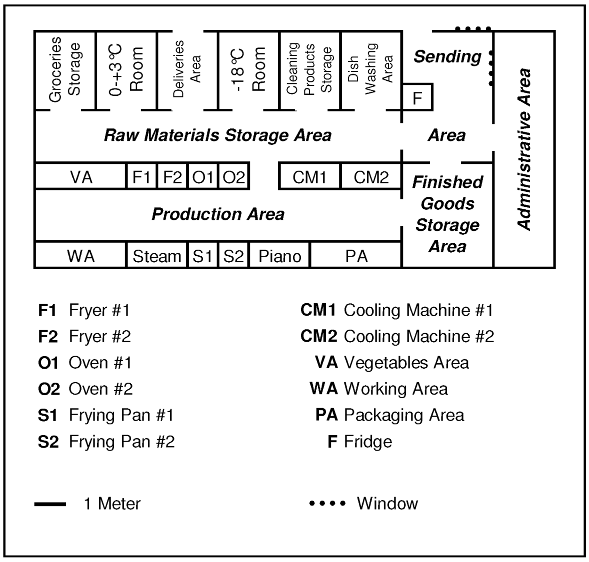

Figure 1: Layout of the proposed business model

In order to evaluate the pertinence of the proposed layout, distances in meters between each pair of cells of the proposed model are determined and gathered in a table. Then, routings are defined according to the analysis of detailed menus procedures including production steps, departure and arrival location of each inter-cells movement. This step next supports the creation of a table gathering the number of movements occurring between each pair of cells for the five menus production (per batch of 20 servings). These two tables allow the computation of the total distance travelled for such production. The formula used for such calculation follows:

$$\sum_{i=1}^{20}\sum_{j=1}^{20} x_{ij} d_{ij}$$

where: x_{ij} = number of material movement per production sequence moving from department i to department j and
d_{ij} = distance in meters between departments i and j

In figure 2 the simulation model that is used in the ProModel is shown.

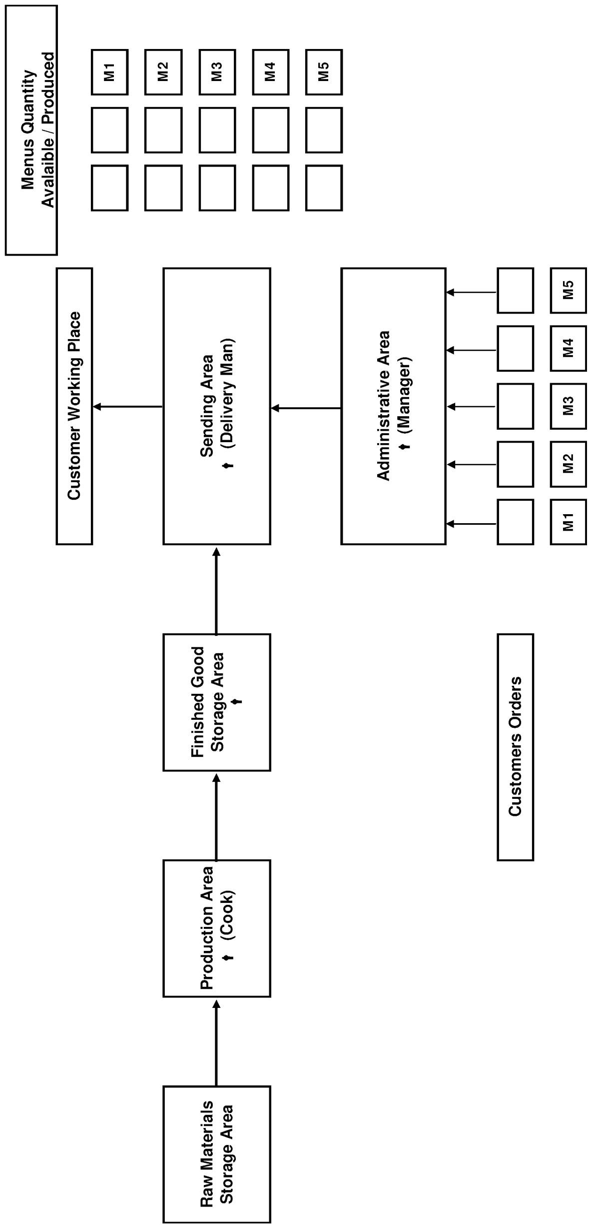

Figure 2 : ProModel Model

Layout optimisation aims at minimising the result of this formula, that is to minimise the total travelled distance that represents a cost in term of time and money. Reducing total distance travelled also brings a better comfort for employees that have to make fewer moves and thus increase their performance. According to data gathered and this formula, total travelled distanced for proposed model accounts for 1591 meters. New layouts are generated and evaluated to optimise the proposed business model. The results are shown in Table 1.

	Total Distance Travelled	Difference with Previous Map (Meters)	Difference with Previous Map (Percentage)	Difference with Initial Map (Meters)	Difference with Initial Map (Percentage)
Initial Layout	1591	-	-	-	-
Layout #1	1294,5	-296,5	-18,64%	-296,5	-18,64%
Layout #2	1209	-85,5	-6,60%	-382	-24,01%
Layout #3	1172	-37	-3,06%	-419	-26,34%
Layout #4	**1149**	**-23**	**-1,96%**	**-442**	**-27,78%**
Layout #5	1153	4	0,35%	-438	-27,53%
Layout #6	1197	48	4,16%	-390	-24,51%

Table 1: Selecting the optimum layout

Layout #4 is proving to be the best one for the particular case we are studying, by minimising total distance travelled and reducing it by almost 28% in comparison to the initial layout. The technique used in this experiment is based on layout improvement since the work was done on an existing initial layout.

MODEL ASSESSMENT AND OPTIMIZATION

Locations, entities, resources, processes, arrivals, shifts are determined in order to allow the building of the proposed model with ProModel software. Four scenarios are created in order to a) evaluate pricing policy elaborated in the concept proposed, b) evaluate the overall designed model and c) see how the system behave when performing under its maximum capacity. Model assessment is carried out through observation of three chosen indicators generated by the simulation: customer satisfaction, resource utilisation and stock management.

	Scenario 1	**Scenario 2**	**Scenario 3**	**Average**
Number of Orders Received	504	437	460	467
Number of Meals Delivered	496	434	442	457
Number of Missing Orders	8	3	18	10
Customer Satisfaction	**98,41%**	**99,31%**	**96,09%**	**97,94%**
Cooks - % in use	40,98%	39,19%	41,91%	40,69%
Cooks Utilization	**Poor**	**Poor**	**Poor**	**Poor**
Delivery Men - % in use	92,77%	82,91%	84,43%	86,70%
Delivery Men Utilization	**Excellent**	**Good**	**Good**	**Excellent**
Number of M1 in Stock	17	8	35	20
Number of M2 in Stock	28	21	37	29
Number of M3 in Stock	53	23	32	36
Number of M4 in Stock	18	51	55	41
Number of M5 in Stock	16	53	19	29
Total Number of Meals in Stock	132	156	178	155
Stock Management	**Poor**	**Poor**	**Poor**	**Poor**

Table 2: Simulation results

With a view on previous results, the proposed model needs improvement on specific points such as cooks' utilisation and stock management. Tracks for model improvement are thus provided and then tested thanks to new simulation runs. This allows the generation of a better model.

CONCLUSIONS

The proposed business model Equilibre & Saveurs refers to a company that aims to deliver fresh and healthy meals on tray to business people. This service is somehow similar to those provided by Class'Croute, L'Affiche in Paris or Commande Grourmande in Lille. However, Equilibre & Saveurs differentiates itself by offering affordable meals that are diverse and often renewed. The business model is based on multiple strategies that allow a better organisation of its production and delivery systems. Special offers help the company to attract new customers and make the current ones more loyal.

Production area layout of the proposed model is evaluated and optimised through an improvement process that leads close to a 30% reduction of the total distance covered by cooks. Layout enhancement is possible thanks to simulation assessment.

The business model is evaluated according to customer satisfaction, resource utilisation and stock management criteria. This first analysis showed that model needed improvements. As a consequence, it was enhanced accordingly to previous results thanks to new simulation runs. The proposed business model is not entirely optimised because of the time-constraint. However, such application gives a better idea of why and how use simulation. Besides, this analysis has shown the importance and the difficulty to control stock management that is key success factor in catering industry.

Further research should refer to the comparison of the simulation results with another modelling approach such as the Petri Nets (Leopoulos et al. 2005), in order to triangulate the results and confirm the optimization effort.

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LET'S BE SERIOUS – ICT IS NOT A (SIMPLE) GAME

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KEYWORDS
business processes, ICT service management, ASL, BiSL, simulation, serious games

ABSTRACT

In this paper we will discuss the requirements for introducing a (serious) game as a tool for training skills in the area of application and business information service management. We introduce a reference model for (serious) games, that serves as a touchstone to determine the effectiveness of service management games, and we will indicate the architectural requirements that must be met to satisfy these criteria. Technical and artistic issues in developing effective service management games will also be discussed, as to provide clear guidelines how to approach the production of service management games.

INTRODUCTION

There is a growing need for ICT service management which provides ICT service providers with the basic functionalities to manage complex information systems. Since the early 1990s the world of ICT infrastructure has been in a state of constant flux due to profound changes in field of Information and Communication Technology (ICT). The complex interplay between technological innovation and the rearrangements of applications, service oriented architectures, and enterprise integration has led to new service management operations. At Getronics PinkRoccade, a leading company which acts as a service provider to many large institutions in the Netherlands, we are developing an integrated role playing and simulation environment for ICT service management. The adoption of serious game technology is motivated by the observation that with regard to the complexity of the tasks involved in service management, which also includes extensive communication with clients, traditional methods of instruction and learning are not adequate. Following Huizinga's dictum that *in the game we confront a function of the living creature which cannot be determined either biologically or logically*, we regard games an an effective learning environment. From a game theory perspective, which we will discuss in section 3, a game not only provides the learner with an environment to learn the rules, but also allows us to re-create to some extent the context that promotes an actual involvement of the player with the world in which to apply these rules.
The structure of this paper is as follows. First, we will provide a brief overview of application and business information service management at Getronics PinkRoccade. Then, we will further motivate the use of serious games, and provide a reference model for (serious) games. After that, we will make a first attempt to identify the criteria for effective service management games, and we will outline architectural requirements for such games. Finally we will discuss some technical and artistic issues in game development after which we will draw our conclusions.

ICT SERVICE MANAGEMENT

ICT infrastructure facilitates the provision of services and information. The success or failure in the application management as well as functional management depends on whether the actors in the value chain are able to provide better ICT services as required by the end users. However, the provision of new and better services is a complicated process, because it requires coordinated actions between many players. In the field of outsourcing, for example, the management of expectations of the client users and the ICT provider users are not only dependent on a service level agreement but also of the changing perspectives, roles and interests. Failures could have major consequences for both parties. ASL stands for Application Services Library, and is a method for the performance of application management in the broadest sense of the term independently of any supplier, Pols and Meijer-Veldman (2006). It is an extrapolation of and a supplement to ITIL for the purposes of application management. Not only does ASL offer a cognitive approach, framework and conceptual context but also best practices for the purposes of practical implementation. It is intended to make it simpler for applications to provide optimum support for business processes throughout the entire life cycle of the latter. BiSL stands for Business Information Services Library and constitutes a method for the performance of functional management in the broadest sense of the word independent of any supplier, which is to say, anything from operational duties, such as support for users and handover tests, to strategic information management. At Getronics PinkRoccade, ASL and BiSL are instruments in determining ICT strategies in cooperation with clients. The integrated gaming and simulation environment we are developing is meant to train our employees in the use of ASL and BiSL. In developing this application we draw on our experience in business process simulation, Eliens et al. (1996), and visualisation, Schonhage et al. (2000).

A REFERENCE MODEL

There are many resources on serious games[1]. To indicate what it is all about, we present a quote from virtual heroes[2]:

> *Serious games and simulations are poised for a second revolution. Today's children, our workforce and scientists are increasingly playing, learning, and inventing in visually intensive "virtual" environments. In our increasingly experiential economy, immersive educational and training solutions are needed to advance the workforce of tomorrow. Game-based learning and technologies meet this challenge.*

However, regardless of the fuss being made, apart from the euphorics their is little attention to determine in a more scientific way what the actual value of the game is in the learning process, and what elements or aspects of the game contribute to the learning experience. To provide such a foundation, we propose to adopt a modified version of the classic game model introduced in Juul (2005). According to Juul (2005), the defining characteristics of a game can be expressed by making explicit the *rules* of the game, the *outcome* of the actions of the player, the *value* attached to these outcomes and the *effort* required of the player to obtain these values. In addition, the model proposed in Juul (2005) adresses why a player develops an *attachment* with the game and what might be the possible *consequences* of playing the game in relation to the real world, for example making friends in an online role playing game or become famous in a game contest. As an illustration of how to use the model to evaluate a game, consider for example that with respect to the effort required of the player, games may be very different in what skills the player needs to have to obtain the desired outcomes, dependent on the type of game, that is whether it is a role playing game, a strategy game, or a first person shooter primarily focussed on the perceptual-motoric skills of the player.
To what extent the story underlying a game is important is not only dependent on the type of game, but also on the technology used to realize the game. Whether we want our trainees in service management to be virtual heroes of the immersive kind is yet to be seen.

EFFECTIVE MANAGEMENT GAMES

As a first attempt to formulate criteria for effective service management games, we give a characterization in terms of the reference game model, introduced in the previous section, as outlined below:

- *rules* – service management protocols
- *outcome* – learning process
- *value* – intellectual satisfaction
- *effort* – study procedures
- *attachment* – corporate identity
- *consequences* – job qualification

There is no need to emphasize that this is only a first approximation, and for that matter a rough one. What we must keep in mind, however, is that the model is not only applicable on a macro-level, to characterize an entire game, but more importantly may also be applied on a micro-level, to establish the criteria for each (relevant) step in the game play. For service management games, we wish to add two more criteria to the model, namely *scenarios* and *reward*, dealing with the (serious) content of the game:

- *scenarios* - problem solving service management
- *reward* - service level agreement

Currently, there already is a great offer of business management games. For example, when googling on *game*, *business*, and *management*, we find, among many other offerings games to train leadership[3] (which provides urgent problem situations in a variety of areas, including military and health care applications), and entrepreneurship[4] (which provides a eight round cycle of sessions instruction how to start a business, get clients, etc., with extensive feedback in the form of reports and comments after each round). A general observation we may make here is that the games we have seen so far primarily focus on functionality and offer at best an efficient interface, which we do not find very appealing from a more artistic perspective.

GAME ARCHITECTURE

As observed in Van Houten and Verbraeck (2006), the defining characteristic of management games, from an architectural perspective, is the need to combine the so-called *game loop*, which propagates actions of the player

[1] www.cs.vu.nl/∼eliens/media/resource-serious.html
[2] www.virtualheroes.com
[3] www.experiencepoint.com
[4] www.marketplace-simulation.com

into the game state, with what is known as the *simulation loop*[5], which determines what events occur, and schedules future events based on a simulation model.
For the game play, we need to develop, or use, some sort of *game engine*, which following Sherrod (2006) may be regarded to consist of the following functional components:

- rendering system – 2D/3D graphics
- input system – user interaction
- sound system – ambient and re-active
- physics system – for the blockbusters
- animation system – motion of objects and characters
- artificial intelligence system – for real challenge(s)

The level of sophistication of each of these components may vary, dependent on whether we want, for example, to introduce compelling visual effects. Other requirements are set by the possible need to offer the game online, as a multi-user game, and possibly with extra facilities such as chatting and instant messaging.
Finally, we must consider that not only the game engine is important, but perhaps even more so, the *game programming*, that is the computional means to define the rules of the game, and the (visual) outcome of player actions. Van Houten and Verbraeck (2006) introduce a rule-based formalism for game programming, where our own preference would be a combination of simulation and embedded logic extending an existing game engine such as Delta3D[6], or in a more lightweigth fashion based on our *intelligent multimedia platform*, described in Eliens et al. (2002).

GAME DEVELOPMENT

In essence, according to Schuytema (2007), a game is simply a series of processes that takes a player to a result. However, observing with Kress and van Leeuwen (1996) that *games are an increasingly important element in our visual culture*, we must, in developing a game, spent sufficient attention to the visual appearance and the sensorial aspects of game. Recently, our group at the VU has been involved in'developing a climate game[7] for the *Academische Jaarprijs* competition. In the *climate game* project, we are exploring various technologies, including interactive video with flash, as well as the use of the HalfLife2 game engine, whith which we gained experience in developing a promotional game for our faculty, Eliens and Bhikharie (2006). With regard to the use of 3D we may remark that since ancient times a walk in space has served as a mnemonic device, and as such spatial memory may aid in retention and understanding, which might also provide a decisive argument for the use of 3D in a service management game!

[5]www.cs.vu.nl/∼eliens/sim
[6]www.delta3d.org
[7]www.cs.vu.nl/∼eliens/projects/project-climate.html

CONCLUSIONS

In this paper, we have introduced a game model which served as a reference to discuss the criteria for effective service management games. We have observed that the quality of a game lies both in the general flow of the game experience and in the individual moments during a playing session, which have to be defined both with respect to the (learning) goals set for the (serious) game, as well as the involvement of the player, that is fun. Against the background of these criteria we have indicated architectural requirements as well as technical and artistic issues in the development of service management games.

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ASSESSMENT OF PROCESS NETWORKS USING GRAPH AND NETWORK THEORY BASED KEY FIGURES

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KEYWORDS
engineering design process, process improvement, network theory, graph theory, concurrent engineering.

ABSTRACT

This paper presents an approach to characterize engineering design processes. It is based on a both network and graph theory to algorithmically identify and evaluate characteristics of a process to spot different kinds of weak spots that are possible starting points for process improvement projects. Information flow-oriented process models are used and converted into a Multi Domain Matrix to represent all of the network's links across different domains such as information objects or organizational units equally. Ultimately, the approach is a first step towards key figures that are able to represent the performance of a process.

INTRODUCTION

It is common in industry to redesign internal procedures and organization periodically, sometimes as part of continuous improvement strategies, sometimes as part of process business reengineering projects (Havey 2005).
Goals in process reengineering vary accordingly to each individual company's strategy. Depending on the situation, a variety of aspects can be aimed at (lead time, media continuity, optimum sequence of tasks,…). To do so, typically, existing processes are modeled using a multitude of process modeling techniques, e.g. SADT, IDEF-3, EPC, DSM or others (Marca et al. 1989, IEEE 1998, Scheer 2000, Browning 2001) to search for possible weak spots. These process models are supported by multitude of tools, e.g. Staffware, SAP Netweaver, ARIS Toolset, and others.
Yet, these models often only allow for single aspects to be modeled, and they are only helpful if certain aspects are sought for. Especially in the case of larger process maps, a lot of experience is necessary not only to model but to interpret the knowledge inherent to these charts.
In turn, a methodical approach is needed to systematically assess processes to help spotting weak points and find room for improvement.
This research therefore focuses to develop an approach that enables management and engineers to methodically analyze process charts. It is especially needed to large, complex process charts that involve a greater number of tasks that are intensely interrelated. While, of course, it is also applicable to smaller process models, its purpose is to methodically facilitate the detection of possible weak spots in a process. It therefore enables engineers and managers, who are working on process improvement projects, to spot critical entities (e.g. tasks, organizational units or artifacts) or critical relations (e.g. information transfers or the attribution of staff to a team) in a process.
The approach presented in this paper was inspired by (Barabási 2003). The paper is meant to provide an overview over existing features of networks and graphs that can characterize processes and the underlying network-like structures. It focuses in particular on engineering design processes, as this research is carried out on the context of product development processes and their improvement. The following pages line out a number of characteristic features of these processes and how they can be grasped using key figures describing the character of a process.

ENGINEERING DESIGN PROCESSES

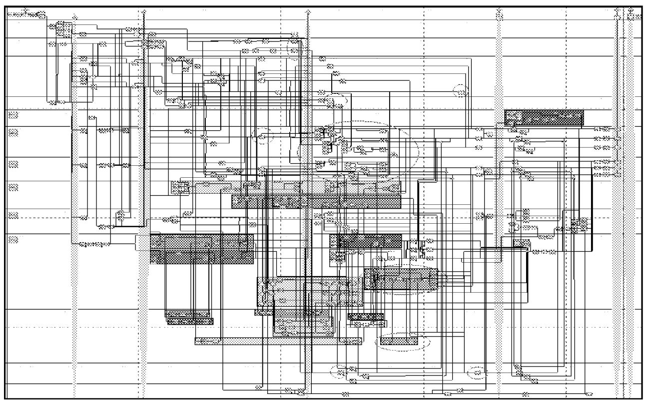

Figure 1: Examplary Design Process Model (EPC)

Figure 1 shows an exemplary design process in automotive body design. Its scope is the interaction between embodiment design and the simulation departments, comprising 192 different business objects that are processed concurrently by 199 process steps. It further involves seven milestones, ten organizational units and all IT systems. Already, these numbers show that spotting the weak point in this collaboration is rather difficult.
In general, engineering design processes differ from business processes mainly through the uncertainty of their outcome. Therefore, they have a much less deterministic

character. This leads to the fact that – in reality – detailed planning is not possible to the extend that is desirable. This problem has resulted in numerous uncertainty models, e.g. the signposting approach (Wynn et al. 2006).
Uncertainty leads to a number of typical features, also understood as the characteristic features of concurrent engineering processes, which can be considered state of the art nowadays (Carlson Skalak 2002): iterations, the exchange of immature information, the early definition of the product that is detailed only much later, and the interdisciplinary collaboration between departments.
All of these features imply that concurrent engineering processes are linked on multiple levels: networks do not just arise through the exchange of artifacts, but also e.g. on the organizational level (e.g. team structures), among resources (e.g. IT systems), and among information objects (e.g. data dependencies). Furthermore, these networks coexist and are not independent of each other. In fact, they form, again, a network whose nodes are networks themselves.

PROCESSES MODELS AS COMPLEX MULTI-DOMAIN NETWORKS

Complexity management is practised in many facets. One of them is the use of Design Structure Matrices (DSMs) that interrelate nodes (i.e. rows/columns) of one single domain among each other (Steward 1981). Thus, they are square matrices. The matrices were originally developed to model processes and to optimize them for banding (i.e. parallelization of largely independent sets of tasks), tearing (i.e. identifying and possibly removing feedback loops) and partitioning (i.e. finding the best sequence of tasks). A number of further methods for analysis exist. The matrices are nowadays used for a large number of purposes, involving component, team, activity, and parameter architectures (Browning 2001).
They are supplemented by Domain Mapping Matrices (DMMs) interrelating two domains at a time (Danilovic and Brwoning 2004). Through e.g. clustering (McCormick et al. 1972), these matrices allow for the analysis of the structure.

	business object	process step	IT-system	organizational unit
business object		DMM		
process step	DMM		DMM	DMM
IT-system		DMM	DSM	
organizational unit		DMM		DSM

Figure 2: MDM notation (example)

Together, they form Multiple Domain Matrices (MDMs) that can be understood as a system's description involving several perspectives onto the system simultaneously (Eichinger et al. 2006, Maurer 2007). In "Information Driven Management" (Danilovic 1999) both kinds of matrices are used to manage uncertainty through systematic understanding of interdependencies and needs for information exchange. Hence, they capture the dynamics of product development, enable the transformation of information between different domains of product development, create traceability of information and dependencies in different domains, create transparency between domains, synchronize actions carried out in different domains, verify the captured information in one domain against another domain, integrate an individual system into a cohesive project or program, and improve decision making (Danilovic 1999).
Process models such as the EPC model shown in figure 1 only display part of the dependencies, feigning a more linear character than they actually bear. At the same time, they are also little accessible for algorithmic interaction. They can, however, be transferred into an MDM notation without loss of information about the basic objects and their relations. This is possible for a large number of modeling techniques, e.g. IDEF-3, EPC, SADT and others (Fahrwinkel 1995). Figure 2 shows a possible setup to interrelate the elements incorporated in the EPC model shown. The MDM notification is not only more suitable for the application of algorithms; it also shows all dependencies simultaneously, thus better visualizing the networked character of the design process.

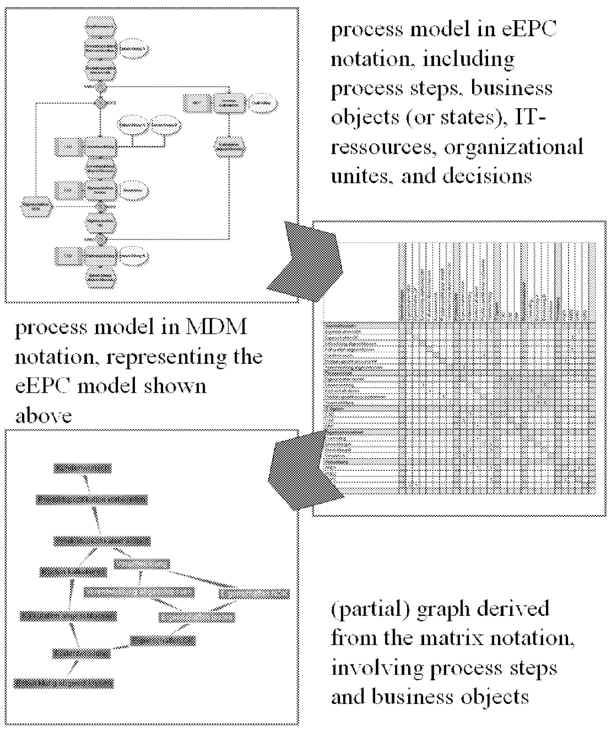

Figure 3: Transformation of process models

As graph or matrix representations are not suitable to represent decision points, these have to be excluded from this research. However, as in this paper the structural characteristics of the process are of interest, this is no shortcoming. As can be seen later, for an overall assessment of the process network, decision points are of little importance and can be ignored. Otherwise, it would also be possible to resolve each decision into a new matrix, as proposed by (Belhe and Kusiak 1995).
From the MDM matrix, graph representations can be extracted to visualize partial networks. Touchgraph-like visualizations have proven most useful as an intuitive user

interface for the interaction with complex structures (Maurer et al. 2004, Gross and Yellen 2005, p95). Figure 3 shows how an EPC model is transferred into an MDM, from which a graph involving the flow of artifacts and the process steps is deduced.

NETWORK AND GRAPH THEORY

As it is the goal of this paper to describe local and global characteristics of processes numerically, network and graph theory are used to classify the dependency structures between single elements of the network represented by the DSMs and DMMs. These elements or entities of the process, also referred to as 'nodes', belong to different domains, e.g. process steps, artifacts and so on. Their dependencies are called 'edges' and can be directional or not.

Network and graph theory are closely related, making it difficult to separate the two. Whereas network theory focuses on the global features of any network, graph theory acknowledges structural features that originate from the interaction of single nodes and edges of a network structure. Graph theory is often dated back to Euler's works (e.g. the *Seven Bridges of Königsberg*, see Biggs et al. 1986), and network theory can be traced back to the research of (Erdös and Rényi 1959), (Watts and Strogatz 1998), (Barabási at al. 1999), (Strogatz 2001) and (Albert at al. 2002).

In research on network and graph theory, the structure or architecture of a problem is of interest, i.e. how the dependencies between the problem's entities or elements can be described, modeled and analyzed using formal methods. Being developed to describe network-like structures, these theories therefore are of particular interest to process analysis, as they provide insight into the structure or architecture of the process. They offer a systematical and analytical means of understanding properties of the process, e.g. what feedback loops there are and which documents they have the most important impact on. Thus, they offer a means of better and more systematically obtaining information on possible weak spots.

GRAPH AND NETWORK-THEORY BASED PROPERTIES OF COMPLEX NETWORKS

As shown in
Table **1**, process networks can be assessed globally and locally using graph and network theory.

Table 1: Global and local process features

local features	**global features**
• connectivity	• multipartite graphs
• cliques	• planar graphs
• trees and hierarchies	• degree distributions
• cycles	• clustering coefficients
• matchings	• degree correlations
	• graph spectra

Graph and network theory provide formulas and theorems for all features (or properties). However, some applications cannot be computed nowadays. Thus, they remain of theoretical character for now. In the following, those characteristics most interesting to process evaluation are listed to provide a more overview.

Local Characteristics

Locally, one characteristic to be evaluated is the graph's *connectivity* (Gross and Yellen 2005, p217). For a process network, this refers to how intensely different entities of the process (e.g. tasks or documents) are dependent on each other. Connectivity of a directed graph regards if and how well two different nodes can (mutually) be reached. Hence, subsets of the process can be identified that are connected in a way that every task can be reached from any other. This way, closed subsets can be identified which are suitable for modularization of the process or which form local iterations. Furthermore, those nodes (e.g. tasks, documents,…) or edges can be identified that – if not present – make the overall process fall apart into distinct subsets. See figure 4 for an example.

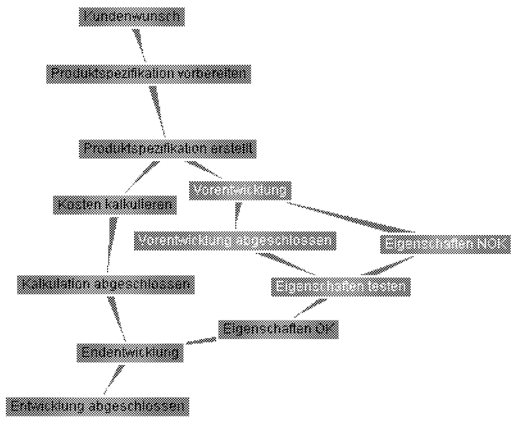

Figure 4: Strongly connected parts of a process graph

Another local feature are *cliques* (Gross and Yellen 2005, p14). A clique is basically a sub-graph of the overall process structure that is a complete graph in itself, i.e. every node is adjacent to every other node. In a process network, a clique could e.g. be formed by the tasks of the members of a workgroup that collaborate in a way that their tasks are all interdependent on each other. Cliques therefore form inseparable subsets. If in figure 4 every of the orange tasks were connected to every other orange task directly, the strongly connected parts (orange) would form a clique.

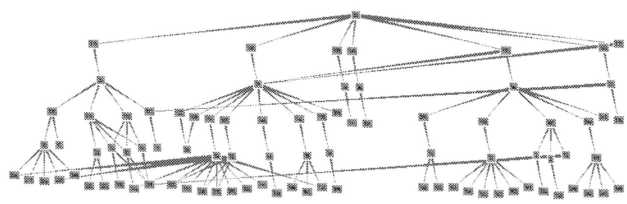

Figure 5: Hierarchy of information dependencies

Furthermore, *trees* and *hierarchies* can be algorithmically identified (Gross and Yellen 2005, p115). Trees are subsets of a graph that do not contain cycles. A hierarchy forms a special kind of tree in which all nodes depend on one root node. For processes, both are of interest in terms of change propagation or information transfer, i.e. to detect which nodes are most critical having the largest impact on other notes. Figure 5 shows an example of how one document (root node) impacts 88 other documents over a maximum of five levels for the process in figure 1.

Also, *cycles* (Gross and Yellen 2005, p39 / Lindemann et al. 2005) can be evaluated. As most process graphs are directed graphs, these cycles can also be seen as feedback-loops. The evaluation of cycles offers statistical access to the number and length of cycles as well as the occurrence of the involved nodes and edges. Figure 6 shows the occurrence of feedback loops between the tasks of the process shown in figure 1. Obviously, it represents a Poisson-distribution.

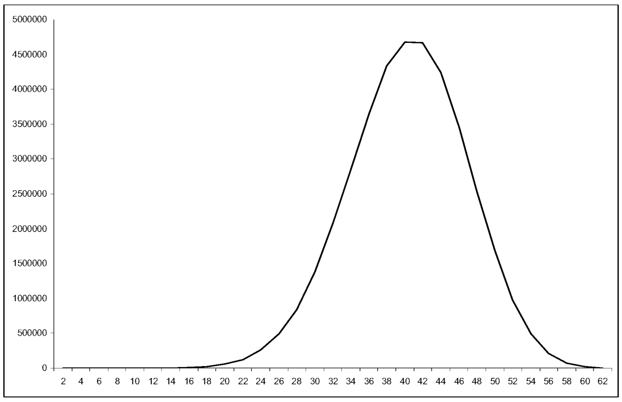

Figure 6: Occurrence (y-axis) of cycles of length x (x-axis)

Ultimately, *matchings* (Gross and Yellen 2005) can be of interest for the local evaluation of process graphs. In operations research, matchings are used to compute solutions of attributing e.g. personnel to a number of tasks. In a process, e.g. the best possible attribution of resources to the personnel involved can be regarded. However, the authors have not detailed this approach for process networks yet.

Global Characteristics

Global characteristics describe the behavior of the overall network, i.e. the graph representing the process. Of course, the characteristics described in the previous section remain applicable. However, the characteristics regarded here focus the overall structure and not just a subset.

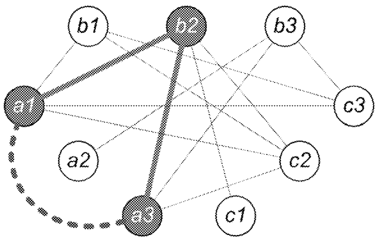

Figure 7: Indirect relation (a1 and a3) in bipartite graph

Multipartite graphs (Eichinger et al. 2006) separate the graph into sets containing nodes that are independent of each other. Of interest for processes is the computation of indirect linkages (Kreimeyer et al. 2006) that show how entities of the process (e.g. IT resources *a1* and *a3* in figure 7), which are not directly related to each other, are actually dependent on each other (e.g. because they are connected via the same process step *b2* in figure 7).

Planarity is a characteristic present when no edge has to cross another edge while the graph is laid out in a two-dimensional plane (Gross and Yellen 2005, p285). In a process, especially the lowest number of minimal crossings is of interest if no fully planar graph can be achieved. That way, sequences of tasks to be parallelized can be identified and optimized by identifying the edges that cross each other.

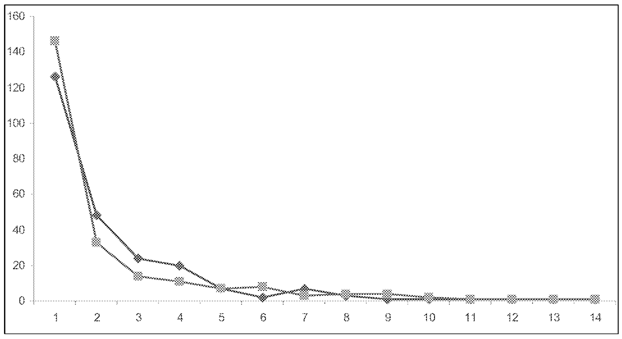

Figure 8: Number of nodes (y-axis) and number of incident / outgoing edges (x-axis)

Incident and outgoing edges of a node are counted to generate the *degree distribution* (Albert et al. 2002) of a graph. Two fundamental distributions occur: exponential and power laws. In case of a power distribution as shown in figure 8 (for the model in figure 1), the loss of a hub (i.e. a node connected to a very large number of other nodes) can cause the network to fail as few hubs typically regulate the overall network (e.g. an engineer falling ill). Thus, the dependency of the overall network on a few critical hubs (or, more generally spoken, entities) can be determined.

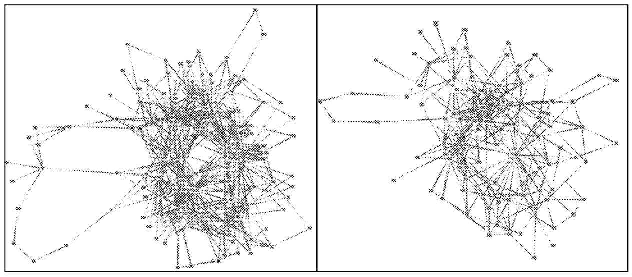

Figure 9: Information objects and process steps

The *clustering coefficient* describes to what extent a graph is similar to a "small world" network (Watts and Sttrogatz 1998). Such a network is characterized by a high probability that two nodes, which are connected via a third one, actually have a direct relation among them as well. Similarly to degree distributions, the clustering coefficient points to groups that are densely interrelated. This way, different domains of the process can be compared. E.g. information objects and process steps as shown in figure 10: On the left, the graph of dependencies of information objects and on the right the dependencies between process steps of the same process are shown. The clustering coefficients (see table 2) are 0.157 and 0.037. In this case, the process steps tend to cluster approximately four times more intensely.

Degree correlations as addressed by (Newman 2003, p17) describe the probability that two nodes are similar in their adjacency. Adapting this to process networks, degree correlations of nodes and edges can be regarded. Figure 10 schematically shows the four possible configurations of the number of incident and outgoing edges (many-few; few-many; many-many; few-few).

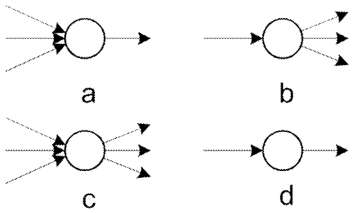

Figure 10: Possible correlations (schematically)

Degree correlations allow examining how susceptible a process is to possible problems with one entity (e.g. a wrong product specification sheet) impact the overall process. As figure 11 shows, the process from figure 1 has only few dependencies of type b or c (as seen in figure 10). Therefore, it is little critical in terms of propagation of errors. Yet, there are a few entities (detectable also through the degree distribution) which deserve particular attention.

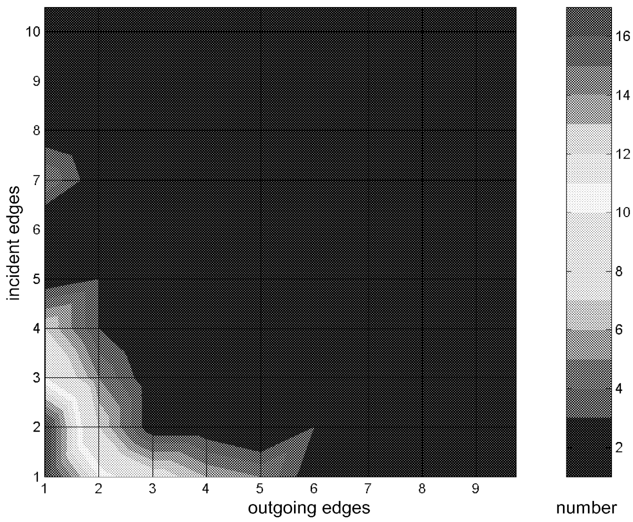

Figure 11: Degree correlations (nodes)

Ultimately, (Cvetkovic et al. 1980) refer to the totality of all eigenvalues as the *graph spectrum*. This approach allows for the identification of a number of characteristics discussed above. If e.g. the characteristic polynomial contains only even exponents, the graph does not contain cycles of odd length and is bipartite. However, this approach has not yet been thoroughly investigated by the authors and will only constitute one of the next steps to be taken in this research.

KEY FIGURE-BASED ASSESSMENT OF ENGINEERING DESIGN PROCESSES

The different algorithms and properties of networks and graphs are not (yet) all applicable in practice due to computational limitations. Table 2 lists those that are manageable to the authors' knowledge.

Number 1 regards how many critical separating vertexes exist (=connectivity). Thus, critical nodes can be identified and, e.g. through redundant interfaces, be defused. Number 2 regards how neighboring nodes can be separated by removing a number of edges (=section). There may be a number of sections that each will dissect a different part of the overall graph from the rest if removed. This way, critical interfaces to subsets of the graph can be detected. The size ω and number n_ω of cliques (3 and 4) regard how intensely networked the structure actually is. They therefore allow for the identification of closed or even self-contained parts of the graph. Often in process modeling, these parts are of a different level of granularity of the model. Number 5 looks into how quickly a piece of e.g. information is spread out throughout the process graph. The bigger r, the faster it spreads. The distribution (number 6) evaluates the number of hubs. If the overall process is dependent on a (small) number of hubs, an exponential law will dictate the distribution of incident and outgoing edges to a number of nodes. These therefore become critical entities in the overall process. Comparable to the connectivity, the clustering coefficient (number 7) explores the intensity of the network. The importance of hubs is put into focus using number 8.

Table 2: Numerical evaluation criteria

#	name	formula
1	robustness of nodes	$r_{node} = \frac{\kappa}{n_{node}}$
2	robustness of information transfer	$r_{info} = \frac{\sum_{i=1}^{k_{section}} \frac{\lvert X_{section,i}\rvert + \lvert Z_{section,i}\rvert}{\lambda_{section,i}}}{k_{section}}$
3	size of clique	ω
4	number of cliques	n_ω
5	robustness of trees	$r_{tree} = \frac{n_{trees}}{\sum_{l=1}^{n_{trees}} k_{crit,l}}$
6	distribution (Poisson or exponential law)	$P(X=r) = e^{-\lambda}\frac{\lambda^r}{r!}$ $P(k) \sim k^{-\gamma}$
7	clustering coeffizient	$C_2 = \frac{6n_t}{n_p}$
8	relative contribution of nodes	$r_{DegCorr} = \frac{n_{crit}}{n}$

The different evaluation criteria can be regrouped into four groups that each focuses on one particular aspect of a process network's character:

- failure of nodes (numbers 1, 6, 8)
- failure of edges (number 2)
- interlinking of nodes (numbers 3, 4, 7)
- distribution of changes (number 5)

The first describes how robust the overall graph is to sustain its structural integrity in case of loosing a number of nodes (e.g. through failure of IT systems or staff falling ill), while the second regards the possible loss of edges, e.g. through bad information transfer or staff not taking their assigned positions in a team. Interlinking of nodes describes the "density" of the graph. While a denser graph is more robust due to the larger number of paths to reach each node, the effort to manage the network rises at the same time. Thus, equilibrium has to be reached. Ultimately, the distribution of information (and mistakes!) is characterized only by tree structures so far.

INFORMATIONAL VALUE OF KEY FIGURES

While key figures will not turn process improvement into an automated process, they open up a field similar to approaching processes via Balanced Scorecards (Kaplan 1992). Thus, they can serve as an indicator to show parts of the process that are of possible interest for improvement or somehow are different from the rest. The idea therefore is not to establish a system for numerical optimization. This is especially important, as no process can be improved without detailed understanding of further details that are usually not modeled. As in each individual project the semantics of nodes and edges is case-specific, an absolute truth about process improvement cannot be reached this way. Ultimately, the deductions have to be made manually.

Yet, understanding the process as a network characterized by a number of graph-based features helps to see how one part of a process impacts others. In today's complex products this is especially important, as "classic" linear methodologies for process improvement often fail under these circumstances.

Ultimately and more of a side effect, key figures allow enable checking the process model for modeling errors. Typically, those parts that are wrongly modeled will stick out first as weak spots of the process.

Implications for engineers

Above all, engineers need to understand that today's processes are not as linear as they used to be and that they are part of a dense network of activities. While graph and network theory still are too abstract for many individuals to fully understand, the detailed description of different characteristics could also help individual engineers to better place themselves in these networks. In design methodology, this trend has already begun, as e.g. a recently published book on networked product design shows (Gausemeier et al. 2006).

Implications for management

Management is, above all, led to a new approach that extends current methodologies in scrutinizing current processes for possible improvement. Especially the analysis of different networks coexisting enables management to harmonize them, especially through the awareness for indirect dependencies as e.g. described as multipartite graphs. (Kreimeyer et al. 2006) exemplifies this further.

Implications for research

While the above implications are true for research as well, the numerical evaluation of different characteristics of design processes makes it possible to describe in detail what concurrent engineering actually is like. Often enough, descriptions otherwise remain vague. E.g. the fact that a design process like the one shown in the beginning contains roughly $4*10^7$ cycles is worth noticing.

While there is no "perfect" process, the numerical analysis of processes makes comparisons easier. On the long run, using criteria like the key figures in this paper could render it possible to compare a number of processes in search for characteristics of "good" and "bad" processes. This way, current knowledge of best practices in design process planning can be extended.

SUMMARY, DISCUSSION, AND OUTLOOK

Process models contain large amounts of knowledge about a company's procedures. Depending on the scope and goal of process improvement, this must be extracted accordingly.

As a first step, this knowledge can be extracted using network and graph theory. This is, on the one hand, possible for each individual domain of the process (e.g. information objects or process steps). For each characteristic, critical elements can be extracted that deserve particular attention. Depending on the scope of the process optimization project, individual measures can be deduced to implement improvements.

Furthermore, the different domains and/or different processes can be compared to harmonize structures between them. The figure-based evaluation of criteria allows for comparisons of these structures.

The approach presented can be criticized in a number of respects. So far, it constitutes an outlook on what is possible in terms of methodical evaluation and access of large, information flow-oriented process charts. However, goals may vary from one improvement project to another and the methods shown may not prove applicable.

Furthermore, a design process cannot be regarded without detailed understanding of the product that is intended as an outcome. While global proceedings may be similar, as e.g. the procedural model by Pahl and Beitz (Pahl and Beitz 2003) shows, the link to the product architecture needs to be established to actually deduce statements about possible improvements.

The necessary detail level is a more global question not just relevant to this kind of process evaluation. This is also true for the examination of global and local characteristics of the process and how – through the use of a systematic approach – the relevant part of the process can be found.

Ultimately, the question about how decision points can be integrated into the process remains unsolved. While engineering design management research approaches this problem mainly through uncertainty modeling, in practice often the information necessary to build reliable uncertainty models is not available. In this research, the overall structure is of interest, i.e. the establishment of a qualitative model that does not quantify it's components further.

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BIOGRAPHY

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PRODUCT MODEL DRIVEN DEVELOPMENT

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ABSTRACT

Product development processes are characterised by a high division of labour to reduce time to market and to optimise cost efficiency. Concurrent engineering addresses these requirements, but at the same time increases the complexity of the product development process. To handle this complexity, appropriate process planning and support for the execution of tasks is needed which arranges product models, controls the information flow and considers the design situation and the process itself. Since product models are considered to be the driving elements of a product development process, this paper proposes an approach called Product Model Driven Development (PMDD) to support managers and engineers, who are in charge of process planning and execution of tasks. Because product models and the design situation are closely related, this approach is based on description methods for both aspects. Hence, this contribution also presents approaches for the description of product models and the analysis of the design situation.
The combination of these two factors builds the framework of Product Model Driven Development. Furthermore a permanent link between project planning and operative work shall be achieved.

INTRODUCTION

Companies need to reduce their costs and to manage their processes more efficiently. The increasing pressure for success and the rapid changes in product development result in a very complex development process. This is especially the case for concurrent engineering, because the requirements for the management of parallel tasks increase. The growing complexity makes it more and more difficult to handle development processes. Since product models are essential for the documentation of results and the execution of the process, a characterization of the process by product models is considered to be useful. Hence, this contribution outlines an approach called Product Model Driven Development (PMDD), which considers product models as driving elements. The approach also includes a description of the design situation, which cannot be neglected in a development process, since there are bidirectional interdependencies between the product models and the design situation. The latter supports the consideration of the specific boundary conditions such as complexity of the task. The consideration of the design situation for development process planning allows further improvement of the retrieval of product models. Both, product models and the design situation have great influence on the process to reach the final product faster and with better quality. To allow the PMDD approach, new description methods of product models as well as the design situation are developed.

MOTIVATION AND PROBLEM ANALYSIS

Problems in today's product development processes are the insufficient integration of product models into the process and the disregard of the design situation in which product development takes place. This hinders the process planning. To give a more detailed explanation of the motivation for this contribution, figure 1 shows the relation between the product development process, the product models, the information flow, the information breaks and the design situation. In this contribution, product models are defined as all documents and artifacts, which describe (intermediate) results and store product information e.g. sketches or prototypes. The design situation is analysed concerning the factors that have the main influence on planning product development processes.
During the development process, several product models are generated, which are required in multiple process steps. Since many product models demand information of other product models, information has to be exchanged (information flow) between them to maintain information consistency. However, information breaks such as communication problems or different data formats interfere with the information flow. Additionally, external and internal conditions that define the design situation influence the execution of the whole product development process.

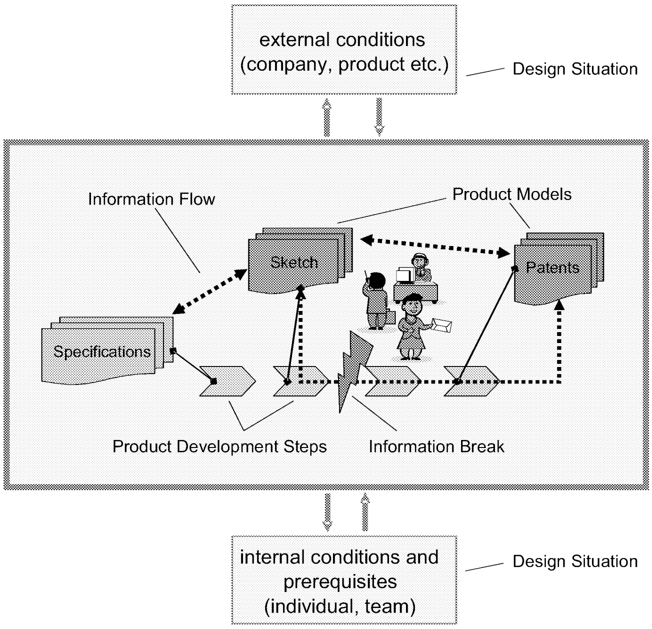

Figure 1. Key Aspects of the Product Development Process

Since product models and the design situation depend on each other closely, the isolated consideration of these two aspects by new description methods is rated not to be enough. For example, the objective of the product model description is the improvement of the retrieval of the right information at the right time. For this definition, the knowledge about the design situation of the designer is essential. Without the design situation, an evaluation of the importance of information cannot be done. Therefore, the decision, if the considered information is the right information at the right time, is impossible. Furthermore, the description method for product models allows the retrieval of relevant information dependent on the position in the process as it is described later on in this contribution. Here it has to be clarified, that the design situation itself delivers the information about the position of the task in the process, which means without the design situation, the current position in the development process is unclear. Vice versa, for the clear definition of the design situation, it is important to know, what product models are already known. This information can be provided by the product model description and design situation analysis. According to the mentioned problems and deficits the objectives of this paper are derived and explained in the following.

OBJECTIVES

The intention of this contribution is to enable a better product development workflow by analysing and connecting the development process, product models and the design situation. A workflow will be supported by this connection because it improves the situation-specific retrieval of information for the process planning as well as for the design engineer. This refers not only to geometrical data but to all data originating from the product development process. The connection will be realised by linking product information to the development process, providing a process-oriented description of product models and defining a product-oriented description of the development situation. All of this sums up in an approach towards Product Model Driven Development. This approach focuses on product models as the main result of development processes.

IMPORTANT ASPECTS OF PRODUCT DEVELOPMENT

In order to be able to describe the approach towards Product Model Driven Development, it is essential to clarify the major aspects regarded in this approach. A characterisation of product models, development processes and design situations as they are understood in this context will be given. A possibility for the integration of these three aspects will be depicted in the PMDD approach later on.

Product Models

The handling of product models is identified as a basic need for the purposeful integration of product models into the product development process. In this contribution, product models are defined as all documents and artifacts, which describe (intermediate) results and store product information e.g. sketches or prototypes. Several researchers have addressed the issue of purposeful integration and have developed different methods and approaches for the description of product models. The state of research can be divided into level based approaches, parameter based approaches and design guidance systems.

Level based approaches use different levels of concretion to classify the information included in the product models. One approach describes product models with the three parameters degree of concretion, completeness and consistency (Rude 1998), see figure 2.

They define a model space and are used to classify (intermediate) results in the context of the product development process. The degree of concretion itself is divided into four levels (requirement, function, principle and embodiment), which can also be found in the model of (Ehrlenspiel 2003). The intermediate results of these levels are documented in partial models of an integrated product model. A similar approach has been developed by (Hartmann 1996), where the idea of a description in a single space of model is basically the same. Especially the four different levels of concretion of Rude and Ehrlenspiel are considered as classifying properties.

Parameter based approaches are expected to address bad information transmissions between product models more effectively than the level based approaches. Some of these approaches consider the linkage of product models to improve the information flow like Suh's Axiomatic Design (Suh 1998). Another approach called Property Driven Development (PDD) has been developed by (Weber 2002). He distinguishes by the number of known properties and values of the product to calculate the stage of maturity.

The approaches using design guidance systems concentrate on the support of the early design phase to reduce the dependency of the designer on personal skills like creativity and experience. Therefore tools have been developed for the support of the designer by automating the synchronisation of the product models of different development phases. The approach of Brix et al. aims on a better consistency of product models by providing a linkage and synchronisation between product models of different levels (Brix 2003). Brix et al. use the three levels of function, principle and embodiment to structure the development process. Another approach of a computer supported product development is described by (Dyla 2002). His model considers aspects like system-neutral interfaces, integrated product models, optimal process management, design guidance systems and the support of early development phases.

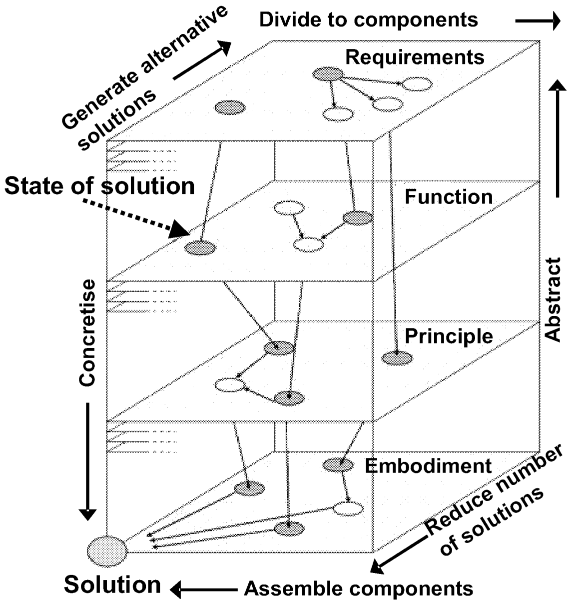

Figure 2. Level Based Three Dimensional Space of the Development Process by (Rude 1998)

The level based approaches are considered to be useful to characterize the product models in relation to the process. Especially the approach by Rude is used as basis for the development of a process oriented product model description as described further on. In particular the design guidance systems support the information flow and the maintenance of consistency, which delivers input for the selection of suitable parameters. Additionally, the approach by Weber gives hints how to measure the degree of maturity, which helps with the characterization of product models in the process.

Development Processes

According to (Harrington 1991), a process is an activity or group of activities that takes an input, adds value to it, and provides an output to an internal or external customer. Coming from a more product development oriented view (Vajna 2005) regards a process as a meaningful set of sub-processes and activities to solve a certain task. Here, activities are logically enclosed operations that contain at least one or more working steps. Activities are started by events, require a certain input, and produce certain events and results respectively. (Blessing et al. 2007) point out, that activities may have manifold interactions and that resources are required to produce an output from a given input. In summary, a process can be regarded as the transformation of a defined input into a defined output.
As many of the definitions above have shown, processes can be decomposed into nearly any number of sub-processes, activities and operations, often referred to as process modules. The utilisation of such process modules is commonly suggested for the management of product development processes (see e.g. Bichlmaier et al. 1999, Freisleben 2001, Meissner 2006). The process decomposition enables the differentiation of more defined partial processes as it is necessary for adequate planning and assignment of (design) processes.
Unfortunately, the best level of decomposition cannot be defined in general. Rather it depends on the specific objectives of the modelling and planning issue. While it might be necessary to look at a very detailed process level for example in cognitive design research, it is sufficient to stop decomposition on a very high process level with respect to multi project management. However, according to (Lindemann 2007), four main levels of design process decomposition shall be distinguished in the following (cp. Fig. 3):

- **strategic process level** (with only generic processes and roadmaps respectively)
- **project level** (with rough stages but a clear vision of outcome)
- **operational level** (with interrelated activities but vague certainty of final outcome)
- **action level** (with elementary processes)

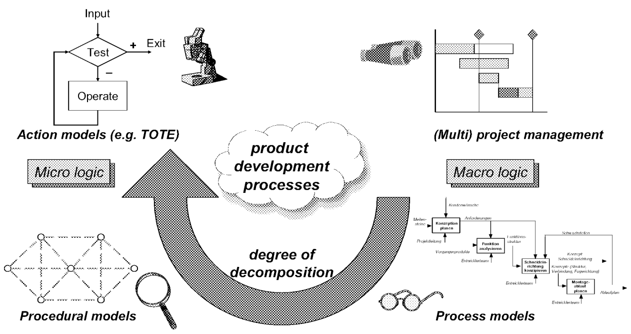

Figure 3. Design Process Models on Different Levels of Decomposition adapted from (Lindemann 2007)

For concrete planning of design processes neither the strategic nor the action level are of much interest. Rather, process planning should take place on the project and the operational level. Both levels are by far more object oriented and thus enable the necessary consideration of design problem structure, product structure, and organisational structure (Ropohl 1999, Beneke 2003). Here, it is necessary to switch continuously between project and operational level, especially with respect to ensuring target oriented navigation through the design process. While the project level suits better to keep the desired project output, the overall project conditions and constraints as well as pre-planned activities (e.g. work packages) in mind, the operational level is more adequate when considering steps/activities to be performed next as well as to allocate resources, means, and methods for process execution. The structure of design processes strongly depends on the situational conditions of the design process in question, which will be addressed in the following section.

Design Situation

In recent years some approaches towards the description of design situations have been introduced. These approaches mainly vary in granularity between a strategic and an operational level. E.g., (Hales and Gooch 2004) as well as (Meissner 2006) cover the analysis of design situations on different levels, whereas e.g. (Badke-Schaub and Frankenberger 2004) focus on the design engineer's daily work. Most approaches want to achieve a holistic picture of the design context (to be understood synonymously to design situation) and therefore establish many different parameters, some of which can only be analysed in hindsight and thus are not applicable for process planning. It is important to note here, that it is not the goal to achieve a complete characterisation of the design situation, but to consider the most important parameters that allow a situation-specific configuration of the development process.
One classification of design context is introduced by (Dylla 1990). The degree of novelty and the amount of given solution elements respectively (new design, adaptive design, variant design), the kind of design problem with respect to the main requirements to be solved, the complexity (as well applied e.g. in Meissner 2006, Hales and Gooch 2004, Badke-Schaub and Frankenberger 2004) and the type of product, the manufacturing type (one off or serial production), and finally the transparency of product characteristics are supposed to be the main characteristics of a design context here.
(Wallmeier 2001), for example, applies amongst others the factors "number of changes in requirements" and "number and duration of discussions" in his situation analysis, which can only be analysed after the task is fulfilled. As another factor he introduces "communication", which is undoubtedly an important factor in development work but which is hard to be measured. In regard to the requirements for situation analysis mentioned above these factors are not applicable in this case, because they cannot be used for process planning.

APPROACH

The intended approach towards Product Model Driven Development is expected to improve product development processes. To achieve this, a special description of product models and analysis of the design situation is needed. After the description of these methods, the approach towards Product Model Driven Development is presented, which includes the connection of product models and design situation.

Product Model Description

This section outlines a generic product model description method for the purposeful integration of product models into the product development process. Thereby product models are defined as all documents or files, which document intermediate results e.g. a list of requirements as the intermediate result of the clarification of requirements. The description method is explained in the following.
Since the quality of the retrieval of product models depends on the structured storage of them, classification and accessibility are necessary for purposeful integration of product models into the development process. This description method claims to be generic to provide the possibility to be adapted universally to different scenarios. It is based on certain parameters addressing the aspects of retrieval, process oriented integration and the design situation. The usage of parameters provides a structuring of product models, which facilitates the retrieval of product models dependent on the position of the designer in the development process. The parameters are used for classification of the product models and are divided in retrieval and process oriented integration as well as parameters addressing the design situation.
The used retrieval oriented parameters are:

- **type of product model** (paper-based, digital or physical product models, etc.)
- **purpose of use** (analysis, synthesis, verification, etc.)
- **degree of concretion** (Function, principle or embodiment, etc.)
- **Development tools** (Electronic Data Management, object modelling tools, groupware, simulation software, etc.)

Another set of parameters consists of process oriented parameters, which follow existing level oriented approaches of product concretion, see section Product Models. The levels of concretion are extended by further dimensions and parameters like degree of detail, consistency, completeness and reliability. The introduction of these further parameters helps to describe product models more detailed. This enables the control of certain processes such as a release process, which can be controlled by the value of product parameters. Using the parameters helps to decide, if the considered product model meets the requirements of completeness and consistency. The decision is supported by the information about the reliability of the identified properties of the product model. The process oriented integration of product models facilitates the support of engineers with their decision about the completeness of the product model.
Amongst the mentioned parameters, an additional set of parameters considers the relation and interdependencies to the design situation. This set allows the linkage of product models to the designer's situation, which itself includes information about the development process. Relevant parameters are identified as follows:

- **Phase of the process**
  Classification by this parameter is essential for purposeful integration of product models, since dependent on the phase of the process different product models are most appropriate. Especially the distinction between early and late design phases allows an efficient classification, because the content of product models of early design phases is conceptual and leaves room for further creative problem solving. Product models of late design phases are more concrete and provide information relevant for the embodiment or realisation of the product.

- **Partial process steps**
  The parameter partial process step is independent from the design phase. Re-occurring process steps

are e.g. goal analysis or finding a solution. This parameter uses a further dimension to classify the product model and thus allows a more accurate classification.

- **Methods**
  Methods of systematic product development can cause changes of the content of product models. To maintain the consistency of product models, it is helpful to know the influence and relation of methods to product models. For instance the application of the method Quality Function Deployment (QFD) can generate new cognitions about the quality of functionality of the product. The determined quality needs to be matched to quality standards and eventually adapted to the new cognitions.

This set of parameters will be extended by considerations of information breaks, which will be part of future work.

Analysis Of The Design Situation

The situation analysis for process planning, as proposed in this contribution, will take place at two levels of decomposition that lead to two levels of planning respectively. These are the project and the operational level as mentioned above. The interaction between these levels of planning, i.e. switching between both levels of detail while planning, is essential in order to achieve a high value of information and transparency of the process plans. To achieve a context description that is feasible for process planning, we focus on factors that can be measured and at least estimated at the beginning of a process. Due to the different levels of detail in planning, these situational parameters have to be described specifically for both levels. Some of these parameters are only relevant for one of these levels of decomposition while others apply for both levels but regard different aspects. There are also parameters that have to be considered in general without taking a specific level of process detail into account.
The general parameters for the situation description chosen in this approach are:

- Design problem and requirements
- Process results (i.e. the required outputs)
- Degree of novelty
- Complexity of the task.

The situation-describing parameters that are considered on the project level are:

- Customer
- Risk
- Project constraints
- Structure of the design problem
- Number of units produced

On the operational level the influencing factors regarded are:

- Product models available/process up to the present point (Input)
- Required output/planned succeeding process steps
- Structure of partial design problem
- Operational constraints (organisational, individual, environmental prerequisites)
- Main DfX requirements
- Interdependency with other process participants (number of interfaces)

Depending on the situation analysis the overall product development process is adapted for the project on hand. Most companies nowadays use generic development processes to plan their projects. Based on this company-specific framework or based on a general approach as e.g. the (VDI 2221 1993) respectively, the situation-specific process adaptation takes place. Project processes usually just give a rough outline of the engineer's work. They involve information about the development task, the project milestones and the people that have to coordinate their work. Thus, elements of the project-specific adaptation can be for example the determination of the length of process steps, the order of the steps or the definition of a suitable project organisation.
It is a focus of this approach to provide a tool the engineer can use for planning his project work as well. After an analysis of the design context on the operational level taking into consideration the factors defined above, recommendations for potential process steps or chains will be given. At this degree of decomposition suitable process steps have to be defined in more detail than the steps applied to the project level. Even though the level of detail varies and the parameters that describe the situation on these levels differ, it is very important to establish the possibility of switching between the levels of planning in order to provide navigation through the development process.
To support this kind of development process planning, a process knowledge base has to be implemented from which process steps can be taken in order to configurate the project processes. Depending on the context specification a search for and recommendation of process steps or process chains will be initiated in the knowledge base. Based on the situation analysis process steps can be modified and finally put together as a complete product development process.
The process planning support will provide the documentation of actions taken during the design processes. This documentation is needed in order to be able to reuse best practice processes and to evaluate which order of process steps maybe did not lead to the designated target and therefore should not be recommended in the future. Moreover the possibility of defining and registering new process steps in the knowledge base will be established in case new situations arise, which cannot be met with already documented process steps. After finishing a development project its process quality is evaluated and thus further information about best practices can be gained and reused over time.

Product Model Driven Development

Based on the product model description and the design situation analysis, the approach towards a Product Model Driven Development process will be illustrated in the following (cp. Figure 4).
This kind of development process shall facilitate the implementation of a better engineering workflow, by specifically supporting the operational working level. The focus on product models, which are the objects (information,

respectively) that have to *flow* through the process, emphasizes this support.

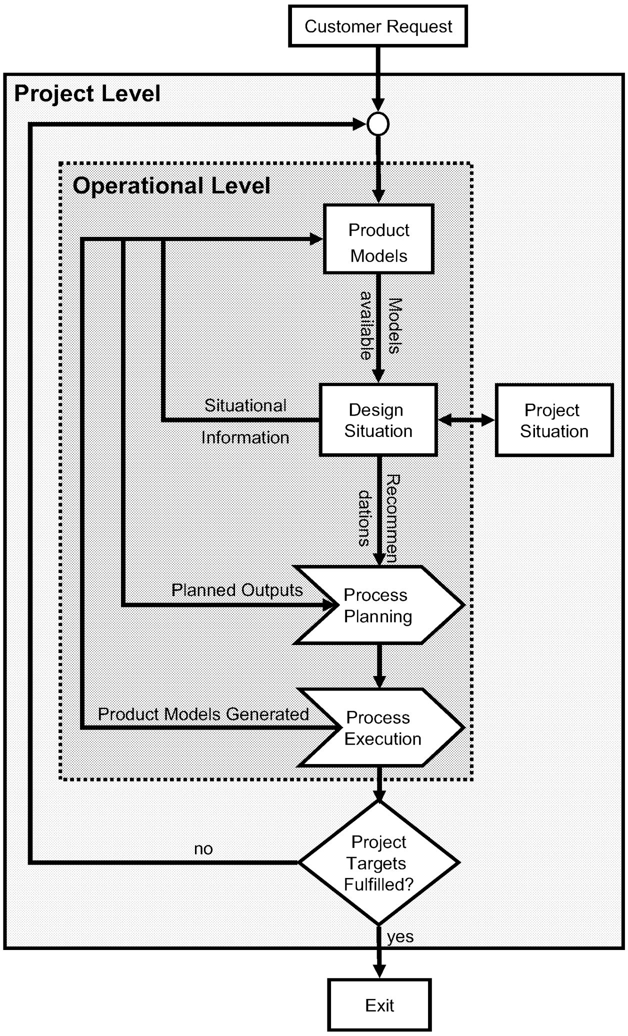

Figure 4 Product Model Driven Development Process

In this model a product development process starts with a request by an internal or external customer. This request initiates a project. On the project level the strategic decision has to be made whether the request shall be accepted or not. If this decision is positive, the project work is executed on the operational level. The first step on the operational level is analyzing, which product models are available. After the first customer request these can be documents provided by the customer or meeting protocols, in later project phases product models can be e.g. sketches, CAD-data, prototypes and so on. The information about product models available is the essential input for the situation analysis on the operational level. Here, the constraints and influencing parameters on the operational level are regarded as well as the project situation.
As described above, according to the situation analysis recommendations for further process steps are provided. At the beginning of a project this can be planning and analysis of the project goals or generating a project plan. In later project phases these recommendations might be e.g. the initiation of a simulation or building a prototype.
The planned process steps are carried out next. After finishing the current process step, the results are matched with the project goals. To achieve the product model orientation, the overall project goals are defined as product models that have to fulfill certain requirements. A project is finished, if the product models generated in the current process step correspond to the ones defined as the project goals. As long as the models do not match, new operational process steps have to be started. This loop implements the connection between the project and the operational level. Within the operational level there are circuits implemented as well, in order to support the product model focus properly. The first loop is institutionalized between the product models and the design situation. As mentioned before, the models available are the essential input for the situation analysis, but on the other hand, information about the situation has to be given to the product models. This information concerns the situation-oriented model describing parameters. These are as illustrated above the process phase, partial process steps and methods, for these are considered in the design situation. Information about the design situation is necessary to anticipate which models should be generated next or which models still have to be built in order to achieve the project goals, respectively.
Another information exchange is implemented between process planning and the product model base. Process planning consists of the selection of the next process step(s) and the assignment of resources, times and further planning details. Since every process step has the goal to develop new product models, the purpose of the model to be developed or complemented in the following step is reflected to the product model base. Taking into consideration the available models and the situational information the product model base suggests a suitable type of product model and the development tool it can be generated with as well as a degree of concretion appropriate for the current design phase. These recommendations are essential for planning an appropriate output for a certain process step.
In the process execution step the product models anticipated are developed. Since the product models developed often do not match exactly the models planned it is the actual available models that have to be considered for the determination of whether the project goals are fulfilled or not. Therefore the actual models are considered on the project level for the decision whether to start a new circuit or to exit the project. The product models generated in a process execution step are added to the product model base, so that these models can be regarded as new input for the next situation analysis.
The focus on product models as the main (intermediate) results of development processes is expected to facilitate a development workflow, because it improves process transparency. This is achieved by providing an overview of the product models available and taking into consideration the design situation for every new process step. The link between project and operational level helps to keep the overall project goals in mind as well as the resources on hand for the next process steps.

CONCLUSION

The complexity of product development processes requires an intelligent and powerful process planning. To provide sufficient support for process planning, an approach named Product Model Driven Development is proposed. On the basis of existing product models and the project situation of a certain development process, the design situation can be defined and used for planning of further process steps. Thereby, for the definition of the design situation, information exchange is required between the description methods of product models and the design situation. The used description methods of both aspects follow existing approaches (e.g. Rude 1998 and Blessing 2007), which are described in this paper. Afterwards, the adapted description methods are explained and integrated into the approach Product Model Driven Development. The connection between product models and the design situation allows the improvement of process planning. It facilitates the information flow, which reduces inconsistencies and uncertainties. Because the design situation is addressed properly in this approach, the process planning becomes more accurate and reliable, which leads to fewer iterations and shorter development processes.

FUTURE WORK

The approach proposed in this contribution is the result of project work in the research alliance ForFlow up to this point. The next step will be the further discussion and completion of the model. The applicability of PMDD has to be evaluated in collaboration with the associated companies in the following. Concepts for the implementation of the single aspects of PMDD have to be generated subsequently in such detail, that a prototypical implementation of PMDD in the associated companies is enabled. The prototypical implementation will be used to evaluate the benefit that can be generated by applying this type of process modelling. Moreover further room for improvement can be identified and integrated into Product Model Driven Development.

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DATAMINING AND MANAGEMENT INFORMATION SYSTEMS

Using the Intermeans Parameter to Model the Textile Demand: Statistical Analysis and Simulations

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ABSTRACT

The well-known "newsboy model" has an elegant analytical solution when playing against an exactly known probability distribution of the future demand. When playing against all the distributions sharing the same mean and variance, the Scarf's rule holds. In a previous paper, we have introduced another measure of the dispersion and we are now examinating hte statistical distribution of this parameter, and the associated information value.

INTRODUCTION

One of the most used paradigm in the area of the supply chain management is the newsboy model. This model has an elegant analytical solution if one assumes the knowledge of the probability distribution of the future demand. But, in all practical cases, only a limited knowledge upon this distribution can be assumed and the newsboy is no more playing against a given distribution, but rather against a family of distributions. This question is usually addressed by a max-min method.

When playing against all the distributions sharing given values of μ, σ, the Scarf's theorem holds (Scarf, 1958; Gallego and Moon, 1993; Yue et al., 2006). In Douillet and Rabenasolo (2005), we have introduced another measure of the dispersion (the inter-means parameter δ) and have proven that assuming an exact knowledge of μ, δ leads to very different conclusions.

The present paper, which is a continuation of Douillet and Rabenasolo 2006, is organized as follows. Section *Min-max and newsboy model* gives a more precise description of the problem, fixes the notations and recalls the requested former results.

Section *Information value of assumptions* examines how these results can be used when only historical data are available. It will be shown that obtaining (μ, σ) or (μ, δ) is neither 'distribution free' nor 'cost free'. Different assumptions lead to different families of models, leading to different results. Comparing these results highlights the information value of the assumptions.

In Section *Information value of parameters,* we examine the influence of the uncertainties related to the confidence intervals surrounding the parameters.

The paper ends by some concluding remarks and a bibliography.

MIN-MAX AND NEWSBOY MODEL

Description of the Newsboy Problem

The "newsboy problem" can be stated as follows (using the Scarf's notations). We have the opportunity to purchase now an amount y of some good, at unitary cost c (regardless of the quantity purchased). It is assumed that the future demand distribution is exactly known by its cumulative density function $\Phi(\xi)$, that the future unit selling price r is known and independent of the number sold and that non sold units are discarded. We have not considered the possibility of a salvation value s, because the only modification is to transform c, r into $c-s$, $r-s$ (Mileff and Nehézg, 2006).

When the actual demand ξ has occurred, the gain is $G(y, \xi) = r \min(y, \xi) - c\,y$. At ordering time, we have to consider its expected value: $G(y, \Phi) \doteq \mathrm{E}(G(y, \xi))$. Defining, for a given y, the overflow probability θ_y, the "lower mean" ξ_y^o and the "upper mean" ξ_y^u by:

$$\theta_y \doteq Pr\ (\xi > y)$$
$$\xi_y^u \doteq \mathrm{E}(\xi \mid \xi > y) \quad ; \quad \xi_y^o \doteq \mathrm{E}(\xi \mid \xi < y)$$

and comparing with the naive value $\widehat{G} \doteq G(\mu, \mu)$, where $\mu = \mathrm{E}(\xi)$, we obtain:

$$\widehat{G} - G(y, \Phi) = (1-\theta_y)\left(y - \xi_y^o\right) c + \theta_y \left(\xi_y^u - y\right)(r-c) \tag{1}$$

Since everything in this formula is positive, the quantity $\widehat{G}$ is an upper bound for $G(y, \Phi)$ and $\widehat{G} - G(y, \Phi)$ appears to be the cost associated with the choice y.

The usual criterion used to determine the optimal value y^* is to minimize this cost. Deriving $G(y, \Phi)$, we obtain the condition $r \int_y^\infty \mathrm{d}\Phi(\xi) - c = 0$, i.e. the well known newsboy result:

$$\Phi(y^*) = 1 - \frac{c}{r} \tag{2}$$

In other words: when Φ is known, the best quantity one can buy depends on the profitability of the product and is generally not the expectation of the demand. Reporting (2) into (1) leads to the following expression (where $*$ is used as index instead of y^*):

$$\widehat{G} - G(y^*, \Phi) = \theta_* (1 - \theta_*) (\xi_*^u - \xi_*^o)\, r. \tag{3}$$

This expression gives the cost of uncertainty, i.e. the loss that remains from the ideal case even when we adopt the best decision.

Min-max Solution for $\mathcal{F}(\mu, \sigma)$

The best order decision must be analyzed under various weaker hypotheses than an exact knowledge of the distribution Φ. For example, it can be assumed that the mean demand is identifiable with enough precision, and that, additionally, some measure of the dispersion of the demand is also identifiable. In such a condition, various families of demand pdfs need to be investigated. The determination of the optimal decision becomes a min-then-max problem, where the objective is to optimize the gain for the worst case over a family of demand models, in order to guarantee a lower bound for the expected performance. In other words, we solve:

$$G^* \doteq G(y^*, \mathcal{F}) \doteq \max_y \min_{\Phi \in \mathcal{F}} G(y, \Phi) \tag{4}$$

The founding result obtained by Scarf (1958) addresses the case where the standard deviation σ is known (together with the mean μ). The key fact is that, over all distributions Φ sharing the given value of (μ, σ), the worse case for a given y is ever a "two Dirac's" distribution. Therefore the best decision against the whole family $\mathcal{F}(\mu, \sigma)$ can be obtained by taking into account only these distributions, leading to the solution:

$$\begin{array}{l} \text{if } c/r > \left(1 + \sigma^2/\mu^2\right)^{-1} \\ \text{then do nothing : } y^* = 0, \quad G^* = 0 \\ \text{else} \left\{ \begin{array}{lcl} y^* & = & \mu + \sigma\,(r/2 - c)/\sqrt{c\,(r-c)} \\ G^* & = & \mu\,(r - c) - \sigma\sqrt{c\,(r-c)} \end{array} \right. \end{array} \tag{5}$$

It can be noticed that, in the "two Dirac's" case, either $\xi = \xi^o$ or $\xi = \xi^u$, while the condition on c/r is needed to ensure $\xi^o > 0$.

The Intermeans Parameter

Knowing that $\mu = \mathrm{E}(\xi)$ is not the optimal decision, we can nevertheless examine what happens when this choice is taken. By the definition of the mean, we have $\forall y : \theta_y\, \xi_y^u + (1 - \theta_y)\, \xi_y^o = \mu$. Using this expression in (1), we obtain the "cost of mean" formula:

$$\widehat{G} - G(\mu, \Phi) = r\,\delta \tag{6}$$

$$\textit{where} \quad \delta \doteq \theta_\mu (1 - \theta_\mu) \left(\xi_\mu^u - \xi_\mu^o\right) \tag{7}$$

Obviously, the "cost of mean" is an upper bound for (3). Being independent of the cost to price ratio, this bound is of interest and places the focus onto the quantity δ, later referred as the "intermeans parameter".

This quantity has some similarity with the interquartile range and therefore appears to be a measure of the dispersion of the distribution. Since this use of δ seems to be new, we have undertaken a comparison between this quantity and the usual measure of the dispersion, i.e. the standard deviation σ. This leads to Tab. 1.

distribution	δ/σ (exact)	δ/σ (approx)
uniform	$\sqrt{3}/4$	≈ 0.433
normal	$1/\sqrt{2\,\pi}$	≈ 0.399
triangular	$1/\sqrt{6} \cdots 8\sqrt{2}/27$	$0.408 \cdots 0.419$
lognormal	$\leq 1/\sqrt{2\,\pi}$	≤ 0.399
two Dirac's	$0 \cdots 1/2$	$0 \cdots 0.5$

Tab. 1: Some values for the ratio δ/σ.

From now on, all θ, ξ^o, ξ^u are relative to the mean as in (7), and subscripts will be omitted. It can be seen that $\mu - \xi^o - \delta = \delta\theta/(1-\theta)$ and $-\mu + \xi^u - \delta = \delta(1-\theta)/\theta$. Therefore, the points $\mu \pm \delta$ are ever situated as in Fig. 1 and the relation $x\,y = \delta^2$ holds.

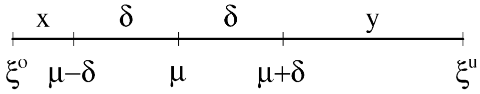

Fig. 1: Meaning of δ : the $x\,y = \delta^2$ property.

Min-max Solution for $\mathcal{F}(\mu, \delta)$

For most of the usual distributions, the assumptions "knowing (μ, σ)" and "knowing (μ, δ)" are quite equivalent. Even for the lognormal distribution, the relation $0.333 \leq \delta/\sigma \leq 0.399$ holds if we assume that the demand has only a chance over a thousand to go outside the interval $[\mu/10, \mu \times 10]$.

When using two Dirac's distributions, both assumptions are no more equivalent, leading to the following result (Douillet and Rabenasolo, 2006).

When playing against the family $\mathcal{F}(\mu, \delta, \mathit{Dirac})$ of all the "two Dirac's" sharing the same values of the mean and the intermeans parameter, the robust decision is no more given by (5) but by:

$$\begin{cases} \text{if } 1-\dfrac{\delta}{\mu}<\dfrac{c}{r} & \text{do nothing}\ :\ y^*=0 \\ \text{if } \dfrac{c}{r}<1-\dfrac{\delta}{\mu} & y^*=\mu \end{cases} \tag{8}$$

INFORMATION VALUE OF ASSUMPTIONS

Let us now discuss the meaning and the potential validity of the hypotheses of the previous Section. Such a discussion is obviously the key point when trying to induce a practitioner to adopt any academic formula to conduct his own business.

About the Meaning of the Distribution Φ

The first point to be mentioned concerns what is modeled. When using a probability distribution $\Phi(\xi)$, we can model our lack of actual knowledge concerning the future demand. We may, for example, think that a better knowledge (at ordering time) can be reached but that its cost would be greater than the additional benefits resulting from this additional knowledge. Another point of view is that markets are intrinsically wild so that the probability function rather models the very nature of market (Corker et al., 1986).

The second point concerns what experimental procedure can be used to determine $\Phi(\xi)$. A "Gedachte Experiment" is as follows: starting with a great number of exact copies of the actual world, put different orders in these worlds, inducing them to evolve (independently) in different manners and observe what happens at selling time. One cannot escape this point of view by considering approximations obtained from times series, since only ergodicity can justify such approximations (without mentioning the fact that actual times series are quite ever too short to conclude, even assuming ergodicity).

About the Not Observed Demand

A third point is that the actual demand cannot be observed (i.e. measured, even afterwards) when the demand overflows the inventory. In such a case, the only actual knowledge is that an overflow has occurred. Obtaining any quantity concerning the demand (i.e. the whole range $[0, \infty]$ of the Φ distribution) only from what happens in the range $\xi \in [0, y]$ (i.e. from only the observed demand) cannot be done in a 'distribution free' manner. Even the mean μ cannot be guessed that way.

This fact is a key point when discussing the meaning of the Scarf's theorem. In the original paper (Scarf, 1958), the author only states: "Let μ, σ be fixed. Then...". Afterwards, other authors have presented this theorem as a 'distribution free' result, on the basis that the "Scarf's rule" is issued from a family of distributions rather than from a given distribution. But, in our opinion, this presentation is too optimistic.

Moreover, any 'educated guess' of the $\xi > y$ part of the reality cannot be 'cost free' either. And this cost must be incorporated into the total income we want to optimize. For example, if the newsboy increases his order quantity to observe more demand, he will certainly increases his knowledge of the demand, but the core question was increasing his income.

Numerical Example

Let us now take an example and examine what can be done when historical data are available. For example, if the last $n = 16$ orders were $y = 999$ and the actual past sales were:

743, 999, 999, 999, 851, 939, 601, 483
999, 655, 999, 856, 821, 810, 999, 999

then we have the following estimators:

$$\text{est}(\theta_{999}) = 0.44 \quad ; \quad \text{est}(\xi^o_{999}) = 751$$

But, as discussed before, nothing can be said on the really interesting parameters, namely μ, σ, δ, $\xi^o = \xi^o_\mu$, ξ^u. To estimate these parameters, we must recreate the missing data, i.e. the exact values reached by the demand when it has overflowed the inventory. This can be done in many ways but, in any case, the figures obtained are only fictional, and have an extra cost. Let us assume the following non fully observed demands:

, 1278, 1418, 1461, ., ., ., .
1176, ., 1016, ., ., ., 1194, 1028

leading to the following estimators:

$$\text{est}(\mu) = 958 \ ; \ \text{est}(\xi^o) = 751 \ ; \ \text{est}(\xi^u) = 1224$$
$$\text{est}(\sigma) = 287 \ ; \ \text{est}(\delta) = 116$$

In Tab. 2, these estimators have been used to compute the best decisions against three distributions and four families. The values $r = 10$ and either $c/r = 0.3$ (left part) or $c/r = 0.7$ (right part, not otherwise commented) have been used. The first five lines describe what are the consequences of "assuming an exact knowledge of μ, σ", while the last two are relative to the consequences of "assuming an exact knowledge of μ, δ".

If nothing else than (μ, σ) is assumed, the Scarf's robust decision ensures a expected gain of 5393. The additional value of an information concerning the shape of Φ is given in Tab. 3. It should be noticed that these values are not obtained by subtracting the corresponding gains from Tab. 2 (when you are not aware that Φ has a given shape then, nevertheless, you are not playing the "Scarf's rule" against the worst "two Dirac's" distribution, but against this given Φ). It can be seen that, in our example, the value of these informations relative to the shape is negligible.

assumed Φ or $\mathcal{F}$	$\frac{c}{r}=.3$	y^*	G	$\frac{c}{r}=.7$	y^*	G
$\Phi(\mu,\,\sigma,\,normal)$		1108	5710		807	1878
$\Phi(\mu,\,\sigma,\,lognormal)$		1117	5916		821	2069
$\Phi(\mu,\,\sigma,\,best\,shaped\,triangle)$		1109	5654		788	1892
$\mathcal{F}(\mu,\,\sigma,\,triangular)$		1103	5607		813	1774
$\mathcal{F}(\mu,\,\sigma)$ (Scarf's rule)		1083	5393		833	1560
$\mathcal{F}(\mu,\,\delta,\,Dirac)$		958	5541		958	1709
$\mathcal{F}(\mu,\,\delta,\,triangular)$		1159	5807		818	1807

Tab. 2: Best decisions, depending on the assumed knowledge.

Factual shape of Φ	Newsboy's knowledge	best y for this knowledge	$G(y,\,\Phi)$	value of information
$\Phi(\mu,\,\sigma,\,normal)$	only $\mu,\,\sigma$	1083	5706	
$\Phi(\mu,\,\sigma,\,normal)$	Φ	1108	5710	4
$\Phi(\mu,\,\sigma,\,lognormal)$	only $\mu,\,\sigma$	1083	5911	
$\Phi(\mu,\,\sigma,\,lognormal)$	Φ	1117	5916	5

Tab. 3: Information values concerning the shape of Φ (for known μ, σ and $c/r=0.3$).

In Tab. 4, the value of an information relative to which is the right measure of the dispersion is computed (assuming that the play is against the "two Dirac's" distributions). It should be noticed that these values are significantly greater than those of Tab. 3.

INFORMATION VALUE OF PARAMETERS

Uncertainties

In fact, an exact knowledge of μ and of either σ or δ can hardly be assumed. If we reexamine the data and assume their independence then, without any other assumption, the distribution of est(μ) is roughly normal, with mean μ and variance $\sigma^2/n \approx 5135$, while the distribution of est$\left(\sigma^2\right)$ is also roughly normal, with mean σ^2 and variance $\left(M_4-\sigma^4\,(n-3)\,/\,(n-1)\right)/n \approx 4.289\,10^8$, where M_4 is the fourth centered moment. In other words, our knowledge is :

$$\mu \in [958 \pm 72\,k_\mu] \quad ; \quad \sigma^2 \in [82166 \pm 20710\,k_\sigma]$$

where the k are the coverage factors.

From the Student's distribution, we know that $k \leq 2$ is an optimistic choice, and all what we actually know is that μ should stay somewhere in an interval at least as wide as [814, 1101], while σ should stay somewhere in an interval at least as wide as [201, 352].

In Tab. 5, the information value of the coverage factor k_μ is discussed when assuming that σ is exactly known. The values obtained in this Table and in Tab. 1 are casually of the same magnitude, but they are not of the same nature since those of Tab. 5 do depend from the size of the history while the others don't.

It must be noticed that having historical data from the $n=16$ last independent periods is out of question in many domains, the textile industry among them. Moreover, disposing of a $n=64$ history will only reduce the uncertainties by a factor 2 and the influence of these uncertainties will remain dominant. In such a case, the search of a robust solution must be enlarged to the family of all the distributions whose parameters fall in the intervals of uncertainty.

Influence of the Dispersion

As said before, the information values concerning the shape of the distribution computed in Tab. 3 were quite negligible due to the quite small value of $\sigma/\mu \approx 0.3$. Let us now consider what will happen if the dispersion is multiplied by a proportionality factor ω. All the deviations $y^*-\mu$ (except from those relative to lognormal shapes) will be multiplied by ω, and therefore the differences between all these "best decisions" (relative to various assumptions) will also be multiplied by ω.

An information value being the variation of a function in the vicinity of an extremum, the information values will rather be multiplied by ω^2. Therefore, the phenomenon described above will therefore be amplified if the dispersion increase, but the relative orders of magnitude will not change.

CONCLUSIONS

Many economical decisions are deduced from historical databases, e.g. sales history. In this paper, we have shown that the best decision for the newsboy problem depends heavily on the choice of the dispersion measure. The

Factual shape of $\mathcal{F}$	Newsboy′s belief	best y for this belief	worst θ against this best y	$G(y, \Phi)$	value of information
$\mathcal{F}(\mu, \sigma, Dirac)$	δ constant	958	$\theta = 0.5$	5273	
$\mathcal{F}(\mu, \sigma, Dirac)$	σ constant	1083	$\theta = 0.3$	5393	120
$\mathcal{F}(\mu, \delta, Dirac)$	σ constant	1083	$\theta = 0$	5389	
$\mathcal{F}(\mu, \delta, Dirac)$	δ constant	958	*all*	5541	152

Tab. 4: Information values concerning how to summarize the dispersion.

k_μ	Factual μ	Newsboy′s belief	best y for this belief	worst case	$G(y, \Phi)$	Value
−2	814	958	1083	$\theta = 0.16$	4277	
	814	814	939	$\theta = 0.3$	4390	113
+1	1030	958	1083	$\theta = 0.41$	5857	
	1030	1030	1155	$\theta = 0.3$	5895	38
+2	1101	958	1083	$\theta = 0.53$	6237	
	1101	1101	1227	$\theta = 0.3$	6397	159

Tab. 5: Information values concerning the mean μ (assuming σ fixed and $c/r = 0.3$).

"Scarf's rule" follows only when assuming an exact knowledge of the variance, while another strategy follows when assuming an exact knowledge of the inter-means parameter δ, defined as:

$$\delta \doteq \theta (1 - \theta) (\xi^u - \xi^o)$$

Therefore any additional knowledge that can be used leads to a better decision and have therefore an information value. We have shown that informations concerning the best method to summarize the dispersion can be more valuable than other informations concerning the shape of the distribution.

In any case, the exact identification of reduced parameters concerning the demand models seems to be questionable, and a description using larger families of pdfs with confidence intervals such as $\mathcal{F}(\mu \pm \Delta\mu, \sigma \pm \Delta\sigma)$ or $\mathcal{F}(\mu \pm \Delta\mu, \delta \pm \Delta\delta)$ seems to be more robust when describing problems relative to the supply chain.

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Directed Access of Multichannel E-Commerce Systems to Data Sources of Integrated SME Information Systems

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Electronic Commerce, Multi e-Channels, Multichannel e-Commerce Modelling, Product Data Management

ABSTRACT

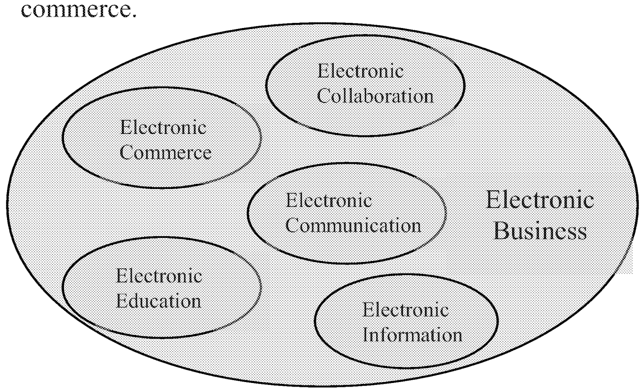
The improvement of competitiveness by better market access, driven by e-commerce systems, requires multichannel support of the sales activities. The precondition for the efficient application of multichannel e-commerce system is the access to the existing data source systems as well as the implementation of the intermediate layer including the part management and the product data management. The integration of existing software packages and standard interfaces enable SME to implement a unidirectional data support of the multichannel e-commerce. The more complex bidirectional support system for the better satisfaction of the customer demands requires an extended software and data flow model in the future.

INTRODUCTION

The system engineering approach enables the developers and appliers to extend their holistic view to the product lifecycle. [1] It is realted to such kinds of theoretical concepts as Enterprise Modeling and Integration, Enterprise Application Integration, Model Driven Architecture, and Service Oriented Architecture.[8][9][10] There are a lot of dependencies between the separate phases of the product life cycle including backward control loops especially in the period of product manufacturing and product application. The coordination of the forward chaining from the production to the consumer as well as the backward control of the consumer requirements to design, production, and warehousing are very complex and complicated processes, but they have to be controlled by efficient organisation and information flow, in order to improve the market access and success by customer requirement orientation. [2]
One key question is the backward access from the points of sale to the product data needed for the satisfaction of consumer demands. It will be realised by the access of product data management system consisting of a product data description layer and product data management layer in the framework of the integrated enterprise information systems. Prospectively, the problem solution of this question is one of the key factors for the competitiveness especially of the small and medium-sized enterprises (SME).

THE NECESSITY OF MULTICHANNLE E-COMMERCE

The globalisation influences the technological change and the spatial organisation of the economic activities [3] of the large-scale companies as well as increasingly of the small and medium sized enterprises (SME). E-business concerns the development as well as the partly respective complete support, processing, and maintenance of performance exchange processes by electronic networks. The performance exchange processes are procedures including the transfer of material and immaterial goods and services into compensatory accounts. They imply the participation of at least one organisational participant as economic-legal organisation. The main objective of the performance exchange processes from the viewpoint of the organisational participant is the sustainable yield bringing performance creation. [4; p.29] E-business includes e-information, e-education, e-communication, e-collaboration, and e-commerce.



Figures 1: Fields of E-Business

This means that e-commerce is a sub object of e-business. It concerns performance exchange processes of development, brokering, and conclusion of commercial transactions among

business units by electronic networks. The opportunities of information and communication technology are used in order to sell goods and services, and to avoid the costs of the physical presence at the same time. [4; p. 33]
The main objectives of electronic commerce are the increase of efficiency, the decrease of costs, and the user-friendliness of any commercial transaction. Electronic commerce is an interesting alternative especially for Small and Medium-Sized Enterprises (SME) with limited resources for the opening of new markets to improve the market access on different ways. [4; p. 43] The three main distribution channels from the customer perspective are a consumer-induced catalogue often realised as a multi suppliers catalogue, supplier-induced extranets some times related to the consumer intranet for instance as an integrated e-shop system, and online trading communities or third-party catalogues.

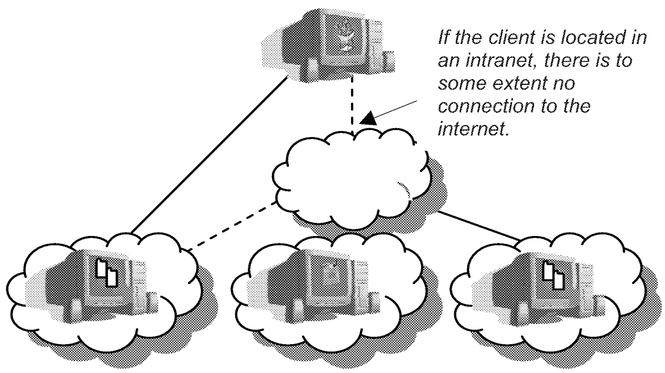


Fig. 2: Outlet Channels of E-Commerce

The actual state will be described by analysing the conditions and key accounts for the e-commerce division of each company. Especially the SME are characterised by a huge backlog in the recognition of the actual market situation. The conditions of the producer, the market, and the customer are essential for defining the e-commerce strategy. A key role approaches the key accounts. Key accounts are customers with corresponding framework contracts and volume of sales. The e-commerce strategy should regard the specific conditions of the key accounts. Regardless of the business size it is expected of a business unit to be able to satisfy all supplier and customer requirements in the commercial channels.
The development of a multilayer concept includes integrated data and information management for a multichannel e-commerce system. It is essential in consideration of the international competition to close the gap in e-commerce strategy by the SME. After describing the conditions of the producer, the customer, and the market, the concept of the e-commerce multi-channel architecture can be defined

DATA AND SYSTEM SOURCES FOR THE MULTICHANNEL E-COMMERCE

Each enterprise needs a general concept for the provision of the right data and information, supporting electronic and non-electronic commerce activities. The concepts have to consider a wide range of commercial activities, methods, and tools. Typically, they include catalogue data demands, customer intranet access specifics, and e-shop requirements in the form of data supply and presenting as one-way, passive kind of consumer support by prepared, static data description.

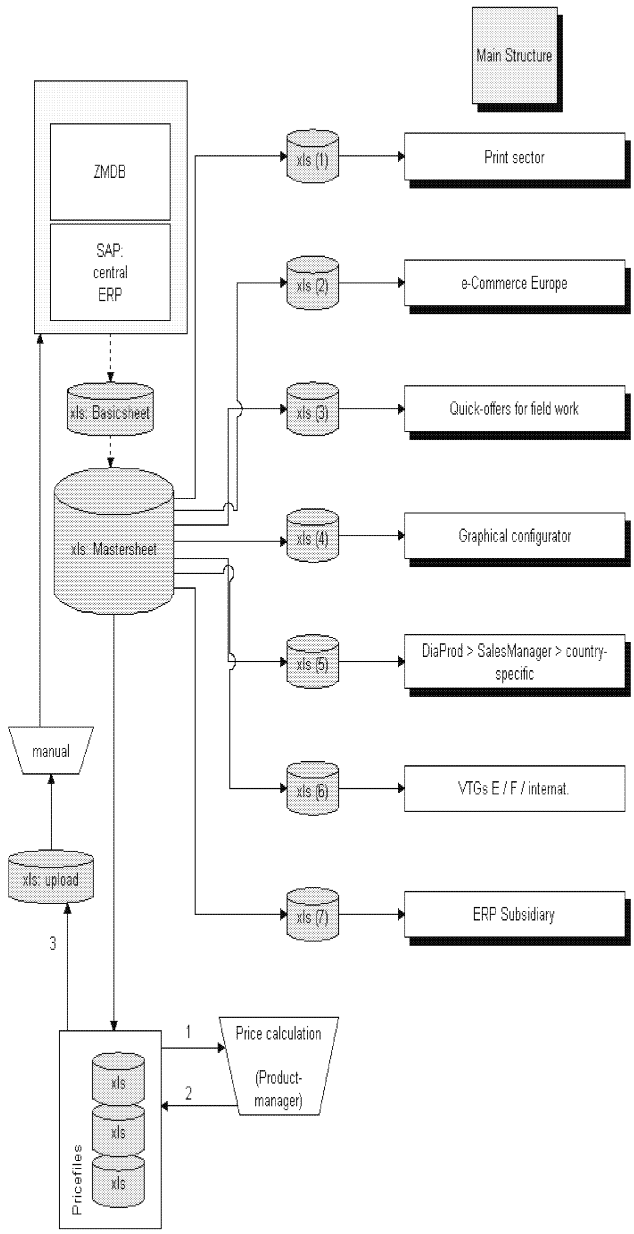


Fig. 3: Mastersheet as Data Source Kernel

Another, more complex case is the use of product configurators, because they include the consumer-related design of the product configuration and as result the dynamic change of the data and data structures. If the producer offers the customer-depended manufacturing of products as unique specimen, it has to organise an active, bidirectional linking of the information and data flow between the enterprise data sources and systems, and the commercial support systems. The product configurators supports capabilities such as guided selling, guidance of the user to recommended options, presentation of alternative

features and options, constrained choices based on compatibility rules, display of price, lead time and availability, support of complex calculations and access to engineering algorithms, etc. It is necessary to develop a network concept of data exchange between the data source systems and the distribution channels.
There are different classes of data sources and data source systems. The first and main class is the product data master class. It implies the product description by product attributes and behaviours. Usually, the source systems are product describing systems such as Computer Aided Design Systems and Animation Systems in interaction with sub domains of the product management systems such as Enterprise Resource System and Part Management Systems. The second one is the product data relation class. It consists of the description of the assortments and compositions of groups of products configured for special application cases. The data sources are available in correspondent systems such as sub domains of the Part Management Systems, Enterprise Resource Planning Systems, and Product Configuration Systems.

PART AND PRODUCT DATA MANAGEMENT AS CONNECTIVE LINK SYSTEM

The solution is an integrated information source for a multichannel e-commerce system. The single, integrated information source approach implies the creation of an integrated data base. The integrated data base should be media-neutral and should have media-specific interfaces. So the variable requirements of the different e-commerce channels can be served by an integrated information source. Special concepts for SME, appearing as product manufacturer and suppliers, have to be developed in order to improve the multichannel market access.
The concept of a multichannel solution for the e-commerce is based on the multi layer architecture. The two kernel layers for the multichannel e-commerce sources are the product data management layer and the product data description layer. The product data management layer contains the integrated data base as a single product information source and should be media-neutral.
It can be done as a centralised data base system or as an integrated, distributed data base system. In any case it should have a unified data base management system. The product data management layer is linked to the main enterprise information systems such as Enterprise Resource Management System, Customer Relationship Management System, Computer Aided System, Controlling System, etc. by special interfaces. The product data description layer involves the different opportunities for publishing product data as consumer information.

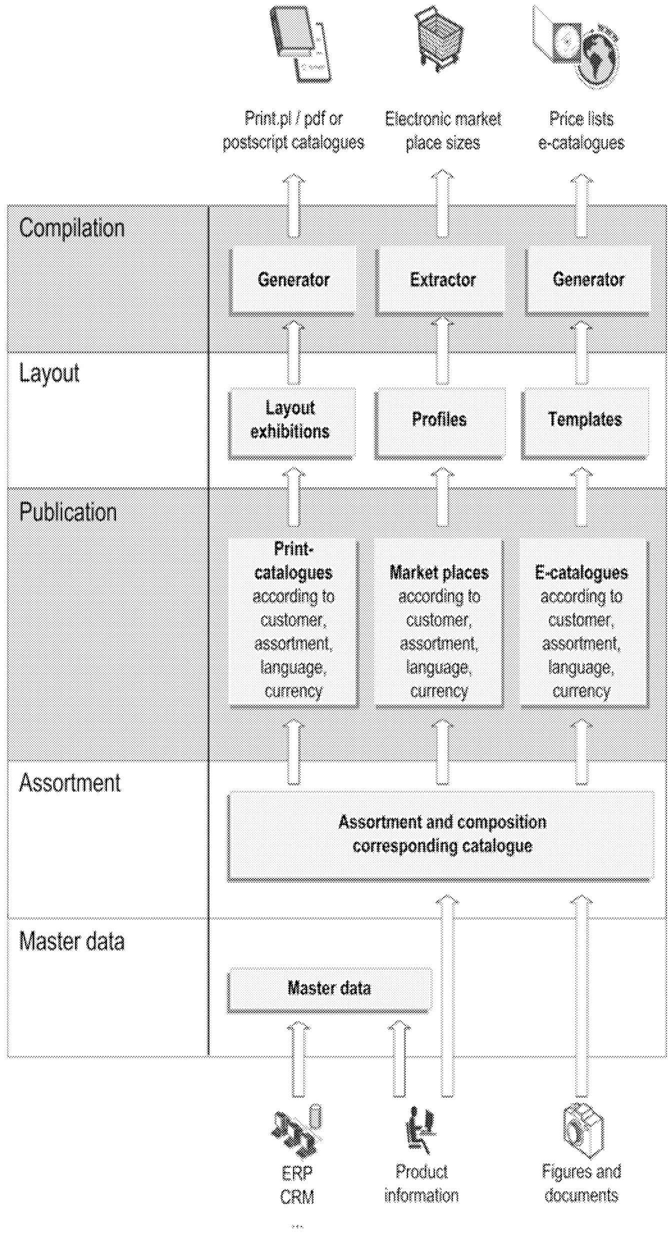


Fig. 4: Multi Level Representation of the Media Neutral Support of the Multi E-Channels

In principle, the product management and the related product data management systems are able to support the unidirectional as well as the bidirectional exchange of data from the data source systems in the enterprise to the commercial support systems. Recently, the problem is the availability of the required interfaces for bidirectional data exchange of the software packages in the practice. The problem is that the prevalent unidirectional data flow is only appropriate for the quasi static data support of multichannel e-commerce systems. It allows only the variation of e-commerce data set in the framework planned ahead by the sales management and realised by using the links to the data sources as well as the media-neutral data base for the multichannel e-commerce.

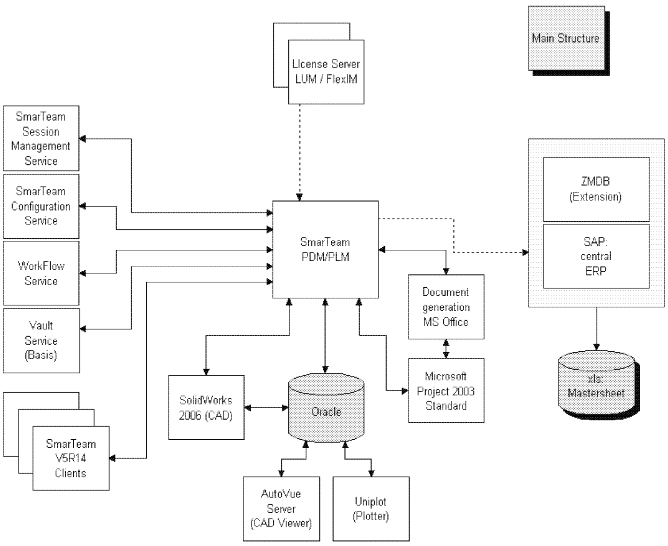


Fig. 5: PDM/PLM System Approach

The effort of offering the customer a wide range of options and alternative choices usually requires bidirectional relations between the data source systems of the enterprise, the part management and product data management systems, and the multichannel e-commerce system including special applications such as product configurators. The task is much more complex but enables the sales management of the enterprise to achieve better competitiveness in customer-dominated markets.

At first, the data supply of the customer by the e-commerce system takes place by a unidirectional information service with quasi static data structures. If the customer changes the parameters over the available limits, the e-commerce system will need the access to more data in the required context and volume enclosed in the enterprise internal data layers and sources. There will be established an interaction loop between sales area and dynamic data support until the demands of the customers are fulfilled. [5]

CASE STUDY IN A MEDIUM-SIZED ENTERPRISE AND ITS EFFECTS

Recently, the state of the art is that SME have usually neither a multichannel e-commerce system nor an integrated enterprise information system and more than never complex solutions for the bidirectional, dynamic data exchange between the data source systems and the sales systems. The result of analysing the state of art for a company as a European market player was the description of the important e-commerce channels. The existing inhomogeneous classic as well as IT-solutions for the distribution have been replaced by an integrated system. [6] The basis will be a media neutral product data description for the different commercial outputs such as print catalogues, electronic markets, and electronic catalogues.

This multilevel representation of the media neutral support of the multi e-channels for the distribution is the basis for the further development of the e-commerce strategy. To result in a strategy, it was necessary to view the electronic markets from a consumer perspective. Starting at the different outlet, or from the customer point of view procurement, channels of e-commerce a combination with the media neutral support system for e-channels was needed. The product information which was provided by the media neutral support system leads directly to the buying decision of the customer. The conclusion was to create an overall model to represent the whole product information flow and visualise possibilities in strategy.

Additionally, the data source systems including CAD and ERP were located. One of the main problems was the analysis and description of the intermediate layer concerning the part management and product data management. It was characterised by a mix-up of separate small applications for solving limited operative problems by simple, semi-professional data exchange and management solutions. The state of the art was listed in a data source and flow map. It is the prerequisite for the replacement of the auxiliary solution by implementing of a part management and product data management system.

The knowledge about the different internal and external data requirements, layers, systems, and sources was the basis for developing a model for an integrated approach. Several related functions and systems ware involved in the integrated information system. The basic layer is dominated by the data source systems such as CAD and ERP, the intermediate layer is shaped by the part management and product data management systems, and the outlet layer will be characterised by the multichannel e-commerce system. [7]

The first prototype of the integrated system will be realised by integration of standard software and data base systems in a new laboratory in the Zwickau Institute of Management and Information. The experiences will be used for implementing a unidirectional solution for professional, data-based information services and support of the multichannel e-commerce by the basic and intermediate layer systems in the included partner companies.

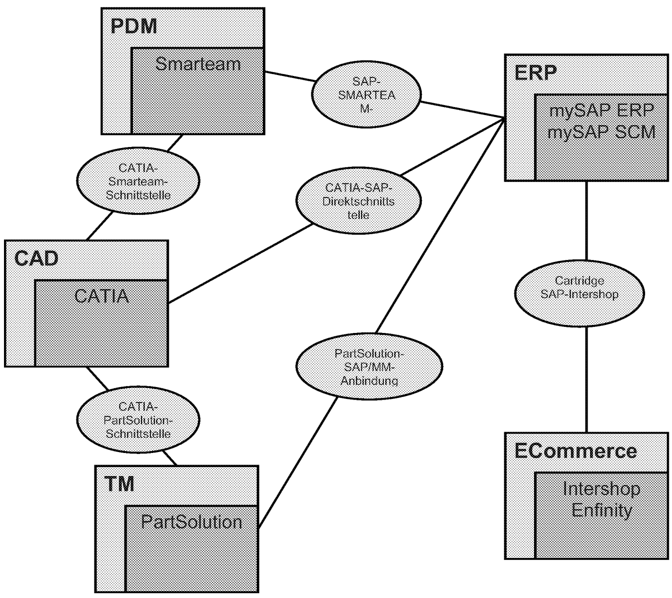


Fig. 6: Model Architecture for one Prototyp of an Integrated E-Commerce Systems

The complex, dynamic bidirectional solution is not only realisable by the available standard software packages and especially not only by the offered interfaces. Therefore, it will require additional research and development activities.

SUMMARY

The e-commerce scene of SME will be dominated by integrated enterprise information systems in the future. Therefore it is necessary to analyse and describe the business processes and models of the future e-commerce solutions for SME. Their requirements influence the planning and design of the information flows and data support systems strongly. Especially, the use of part management and product data management systems as intermediate connectors in integrated enterprise information solutions will enormously increase in the next years.

This is the only way for SME to preserve the competitiveness in the procedure of dynamisation and globalisation. The unidirectional solution is implementable by the existing standard software and interfaces, the bidirectional, dynamic data flow requires add on activities for completion of the available systems enabling the directed access of multichannel e-commerce systems to the enterprise data sources in integrated information systems of SME.

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BIOGRAPHY

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ICT SECURITY MANAGEMENT

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KEYWORDS

Security, Risk

ABSTRACT

Security becomes more and more important and companies are aware that it has become a management problem. It's critical to know what are the critical resources and processes of the company and their weaknesses. A security audit can be a handy solution. We have developed BEVA, a method to critically analyse the company and to uncover the weak spots in the security system. BEVA results also in a general security score and security scores for each security factor. These will be used in the risk analysis.
The goal is to increase the security score Ss to a postulated level by focusing on the critical security factors, those with a low security score.
We will identify the critical threats too, being those with a high risk or expected loss for the company if they occur.
In the next stage it will be resolved to implement some security measures to decrease the probabilities of the occurrence of the threats and as a consequence to decrease the risks and to improve the security situation.

1. ICT SECURITY MANAGEMENT

As a consequence of the fast integration of technologies as Internet, Intranet, Extranet, Voice over IP and e-commerce, a companies ICT-infrastructure will move to more openness to the outside world and as a consequence will become more vulnerable for security threats. This offers lots of new opportunities but also creates new threats. That's why focus and responsibility concerning security become even more and more important. Studies show that attacks come from inside as well as from outside the organisation and bring along large costs. Because of these large costs, companies became more and more aware that they not only deal with a technical problem but also with a management problem.

ICT-security management consists of a security audit activity and of a risk analysis. Both topics will be discussed in this paper.

2. SECURITY AUDIT

Spending each year a certain amount on security measures is not enough. A company needs a total security approach. It is a must to know what are the critical resources and processes of the company and their weaknesses. A solution to this is a security audit. Based on the results of the audit, a security policy can be developed , adjusted to the company situation. A security audit can be used to analyse and describe the security level.

2.1. Our security audit checklist

We have developed a security audit, called BEVA. BEVA is a method to analyse critically the company and to uncover the weak spots of the security system.
We have developed a standard list that covers all aspects of security in the different areas or of business functions. Each of these areas consists of different security factors. The factors are in their turn tested on the basis of several questions.

We based our security analysis partly on the Marion-AP method. But our list for the security factors is based on the standard ISO 17799. The 38 security factors are spread over the 10 domains, as set forward in the standard ISO17799 model. For example you have the domain "system access control" and in this domain you have the factors: requirements for access, management of user access, user responsibility, control of network access, control access to OS, control of access to applications and information and use of mobile infrastructure.
For each of the 38 factors, a number of subcriteria are formulated. We developed a list of questions, covering the subcriteria we created. The questions are partly based on the "checklists in information management" SDU publishers. (www.riskworld.net/7799-2.htm)

Security Factor Sfi	Importance	Sub Factor	Relevance/weight 1 to 4	Code question	Question	evaluation 1 to 4
Domain: Access control						
Sf20. Business requirements for access controlPremise	B	access control policymanagement	3	20.1	Is the access control policymanagement based on the business security requirements?	3
				20.2	Are aspects of logical and physical access control included?	3
				20.3	Is it clear for users and service providers which rules are applicable?	2
Sf21. User access management	C	registration of users	2	21.1	Is there any formal user registration and de-registration procedure for granting access to multi-user IS and services?	1
		privilege management	1	21.2	are privileges and allocated on need-to-use basis?	3
				21.3	are privileges only allocated after formal authorisation process?	1
		user password management	4	21.4	should the allocation and the reallocation of passwords be controlled through a formal management process?	3
				21.5	are the users asked to sign a statement to keep the password confidential?	1
		review of user access rights	3	21.6	does there exist a process to review user access rights at regular intervals?	4
					Does there exist a procedure to block the	

Figure 1: Questions audit checklist

Security factor Sfi	Security Subfactor Ssfij	Relevance /weight 1 to 4 w(i,j)	Code question	evaluation 1 to 4	mean evaluation 1 to 4 eval(i,j)	Security factor score Sfis
Domain: Access control						
Sf20. Business requirements for access controlPremise	access control policymanagement	3	20.1	3	2,67	2,67
			20.2	3		
			20.3	2		
		3				
Sf21. User access management	registration of users	2	21.1	1	1	2,25
	privilege management	1	21.2	3	2	
			21.3	1		
	user password management	4	21.4	3	2	
			21.5	1		
	review of user access rights	3	21.6	4	3,5	
			21.7	3		
		10				

Sfis = sum [(w(i,j) * eval(i,j)] / sum w(i,j)

Figure 2: Calculation of the Sf I's

2.2. The audit process and the calculation of security factor scores Sfi's and the security score Ss

To collect the information about the current security situation of the company, we start with the questioning of the key persons in the company using the audit checklist questionnaire.
The company determines which systems or processes are critical for them and connected with it, which security factors are important or relevant.

An importance rate is given to the security factors from A (low importance) to E (high importance). Next a weight between 0 and 4 is allocated to the subcriteria of the security factors to indicate the relevance.
Subsequently the evaluation starts and each question is given a score between 1 and 4 (see figure 1).

Sfi s = sum [eval (i,j) * w(i,j)] / sum w(i,k)

Ss= sum [eval (1,38) * w(1,38)] / sum w(1, 38)

For example see factor 21 in the example:
[2*1 + 1*2 + 4*2 + 3*3,5]/10 = 2.25
Ss= in this example 2.66

Security Factor	Security Factor	Security Factor	Sfi
1	1	20	2,67
2	2	21	2,25
3	3	22	2
4	4	23	2,33
5	5	24	2
6	6	25	2,67
7	7	26	2,5
8	8	27	1,75
9	9	28	3
10	10	29	3,25
11	11	30	3,33
12	12	31	2,75
13	13	32	2,67
14	14	33	2
15	15	34	2
16	16	35	2,5
17	17	36	3
18	18	37	2,67
19	19	38	3

Figure 3: Sfi's results

Based on the evaluated questionnaire and the allocated weights, a realistic picture of the security situation of the company can be created as well general as by factor. This is showed graphically in BEWA, see figures below. Figure 5 highlights which security factors are crucial, and points out the security factors which need immediate attention by placing them in the red area.

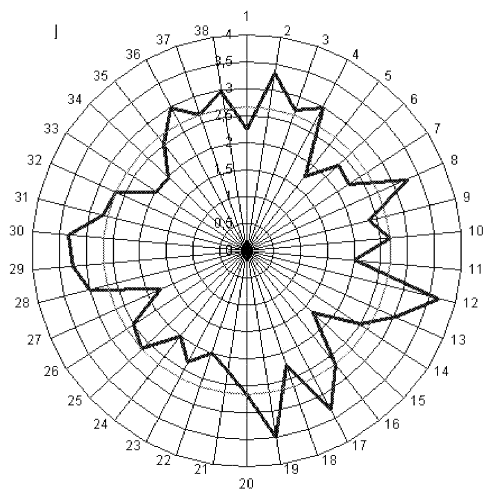

Figure 4: Graph of the security scores

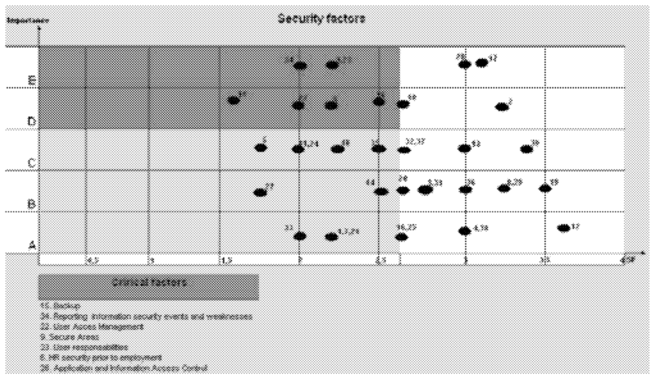

Figure 5: Graph of security factors and their importance

Feedback is given to the company and the evaluation states immediate points of action.
A list of action points is created. Taking into account the stated security budget and the factors and their importance, an action plan is suggested.

3. RISK ANALYSIS

As stated earlier ICT security management is based on a security audit and on a risk analysis. The security audit gives us an average security score Ss for the enterprise and a SFi for each of the security factors as explained in the previous chapter. In this part we will take a closer look at the risk analysis and use the outcomes of the security audit to do our risk analysis. Our risk analysis is partly based on the Marion-AP method.

3.1. Potential losses linked with the occurrence of threats.

Companies loose large amounts of money on violations. A table which states the relation between the threats and the types of incurred losses is constructed.
Losses due to the occurrence of threats or security risks have to be measured in the company.

Threats	Function in the company				Loss
	Type of loss 1	Type of loss 2	Type of loss 3	…	
T1= Virus	x		x		L1
T2= Laptop/ mobile theft	x				L2
T3= Insider abuse of net access		x			L3
…					

Figure 6: Threats versus losses

As types of loss we choose the categories :

- material damages and supplements
- additional costs and exploitation losses
- loss of money and material
- other losses

Other categories are possible. But what we are interested in, is the total loss for each risk (being L1, L2,L3,…).

3.2. Probability of risks

The yearly organised CSI/FBI-study delivers the following probabilities for the threats:

Threat	(CSI/FBI 2006)	Kans	(CSI/FBI 2006)
T1	Virus	Pt1	0.65
T2	Laptop/mobile theft	Pt2	0.47
T3	Insider abuse of net access	Pt3	0.42
T4	Unauthorised access to information	Pt4	0.32
…		…	

Figure 7: Probability of risks

3.3 The risks of the threats and the list of critical threats

Our final goal is to influence the occurrence of the threats, or the probability of the occurrence of them, by implementing selective security measures in the company. This will impact in the long run the security situation.

We must concentrate on the critical security factors, following the results of the audit. If the security factor is critical, than the threats linked with it have a critical risk too.

In figure 8 we figure out the relations between the threats and the security factors.

Threats	Security factors					
	Sf1	…	Sf20: require-ments for access	Sf21: mgt of user access	…	Sf38
T1	x		x			
…						x
T4			x	x		
T5	x					
…						

Figure 8: Relations between security factors and threats

We can base our study on the probabilities found in the CSI/FBI study

We assume that the probabilities in the CSI/FBI study are averages of the security situation of a large number of companies.

Our company's security score Ss can be seen as a representative of this average situation and so the probabilities can be interpreted as being prior probabilities of our company's security situation.

We can recalculate the probabilities of the threats by weighing them with the corresponding security factor scores Sfis of the related security factors.

The security score of the threat j = STjs

Taking into account the individual security factor scores Sfis of those security factors which have a positive relation with the threat, we need to adjust the probability

.

By calculating the average security score of each threat and their adjusted probability.

Threat	Ssi / Probab.	Security factors				Ss	Average Secur. score Risk	Adjusted proba-bility
		Sf1	Sf2	Sf3	…			
		Ss1	Ss2	ss3				
T1	P1	x		x			SsT1	P1'
T2	P2				x		SsT2	P2'
T3	P3	x	x	x			SsT3	P3'
…								

Figure 9: Adjusted probability of the threats

SsT1= the sum of all the scores of the questions of the factors that have a relation with T1 divided by the the assigned weight of those factors;

Pi = (1-Pi)* SsTi/Ss

After calculating the adjusted probability, we can now calculate the risks of the threats for our company.

Threat	Probability	Loss	Risk
T1	P1'	L1	P1' * L1
T2	P2'	L2	P2' * L2
T3	P3'	L3	P3' * L3
T4	P4'	L4	P4' * L4
…			

Figure 10: The risk of the threats

In this table we can identify the critical risks, or the threats raising a high risk for the company.

4. DECISION ON SECURITY MEASURES

The next stage is to resolve on to security measures. First a table wit the most used measures along the CSI-study.

Most used measures (CSI-study)
Firewall
AntiVirus Software
AtiSpyware Software
Server Based Acces control list
Intrusion detection system
Ecryption for data
Reusable account system
Intrusion prevention system
Log management software
Application level firewall
Smart card/one time password token
Specialized wireless security
Training personel
Endpoint security client software
Update server
Firewall
AntiVirus Software
AtiSpyware Software
Server Based Acces control list
Intrusion detection system

Figure 11: Most used measures

The critical threats should be restrained by taking the necessary safety requirements. For each of the threats a security measure can be taken but it is also possible that one measure can resolve or effect several threats. It's important to evaluate the costs of the measures and the possible loss of a threat. It is obvious that the cost can't be higher than the expected loss.

	Threats Ti				
Measures	T1	T2	T3	…	Costs
M1= firewall				X	C1
…		x	x		C2
					…
M14	x				C14
M15	x				C15

Figure 12: Measures for the different threats

5. FOLLOW UP

After a period of approximately 3 months after implementing the security measures, a new security audit should be taken. The new security score Ss is calculated and compared to the stated aimed Security score using the security measures.
If there are security factors that score too low, these should be investigated and adjusted;

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KRIGING IN CONSTRAINED OPTIMIZATION OF COMPUTER SIMULATIONS

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KEYWORDS
Kriging prediction, Latin Hypercube Designs, response surface methodology, constrained optimization, discrete-event simulation

ABSTRACT

This paper describes a procedure for utilizing kriging in constrained simulation optimization. The procedure begins by deploying $8n \le k \le 12n$ design points in a Latin Hypercube Design throughout the design space $a_i \le x_i \le c_i$, $i = 1,...,n$. The system is simulated using r replications of the simulation model at each design point. The mean response is recorded for each of the $m+1$ system responses y_j, $j = 0,1,...,m$. Kriging is applied to these experimental results using the DACE toolbox in the Matlab application. From the predicted optimum (X^*, Y^*), kriging is alternated with one-trial-at-a-time simulation trials to verify the estimated optimum.

1 INTRODUCTION

A *metamodel*, also called a *response surface*, is an approximation of an Input/Output (I/O) function that is defined by an underlying simulation model (see Kleijnen, 1998). The metamodel is the surrogate for the real-world system that is used for experimentation and analysis; that is, experimentation with the actual system is far too costly and time consuming, so that computer-based experimentation, or *simulation*, is preferred. The next two sections describe the types of experimental designs that are usually applied to (a) response surface optimization, and (b) kriging optimization, respectively. An Arena model of an *(s, S)* inventory control system (Kelton et al, 2007) is used to make this comparison.

2 RESPONSE SURFACE OPTIMIZATION

Most metamodeling studies focus on low-order polynomial regression using factorial-based designs. The *central composite design* (CCD) is a popular experimental design for estimating a quadratic regression in a local, unimodal region of the design space. Figure 1 illustrates a spreadsheet showing the deployment of the $k = 2^n + 2n + c$ design points, where n is the number of input parameters or design variables, and c is a number of replications of the center point of the design space which is selected to achieve some desired statistical performance in the regression models. In the case shown in Figure 1, $n = 2$ and $c = 5$, therefore $k = 13$. There are $2^2 = 4$ points arrayed in a square (generally, an n-dimensional hypercube), $2x2 = 4$ points along the axes (generally, $2n$), and $c = 5$ replications of the center point.

S s	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	Sum
40								1								1
45																0
50			1										1			2
55																0
60																0
65																0
70																0
75	1							5							1	7
80																0
85																0
90																0
95																0
100			1										1			2
105																0
110								1								1
Sum	1	0	2	0	0	0	0	7	0	0	0	0	2	0	1	13

Figure 1: A Central Composite Design Applied to the (s,S) Inventory System

To illustrate this procedure, an Arena (Kelton et al, 2007) model of the *(s,S)* inventory system was simulated. The constrained optimization formulation of this system is to find the values of maximum inventory position *S*, or x_1, and the reorder point *s*, or x_2, so as to minimize total cost $y_0(X)$, subject to limitations on holding cost $y_1(X)$ (as there is a scarcity of storage space for the product) and shortage cost $y_2(X)$ (as management wishes to maintain customer satisfaction); that, is,

$$\min y_0(X) \tag{1}$$

subject to the non-negativity conditions $x_1 \ge 0$ and $x_2 \ge 0$ and the constraints

$$y_1(X) \le 25 \text{ and } y_2(X) \le 10 \tag{2}$$

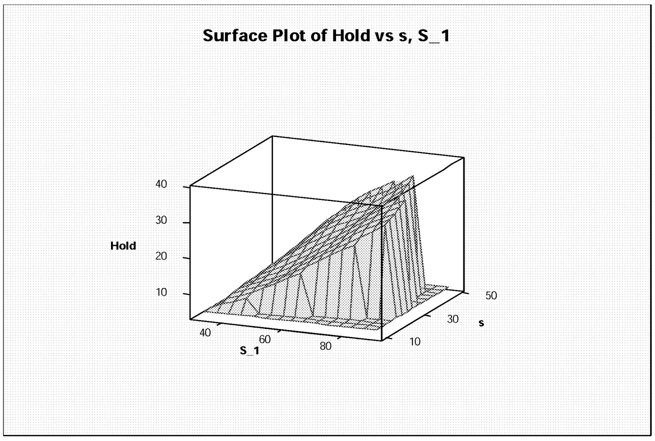
The Arena-based *(s,S)* model was simulated for $r = 5$ replications at each of the 13 design points in the CCD, yielding the results shown in Table1. The surface graphs for holding cost, shortage cost, and total cost are shown in Figure 2. The response surfaces for holding cost and shortage cost are both highly planar in the experimental region, while the total cost graph is nearly quadratic. (It should be pointed out that the Minitab (2007) surface graph function utilizes the raw data and does not necessarily produce very regular looking surface graphs).

Excel *Solver* was used to obtain a solution to the constrained optimization problem stated in (1) and (2), with the solution $x_1 = 25$, $x_2 = 63$, and *y(total) = \$118.47*, *y(hold) = \$20.56*, and *y(short) = \$8.13*. Another simulation run of $r = 5$ replications was run at $s = 25$ and $S = 63$ to confirm these results, and produced the solution *y(total) = \$120.36*, *y(hold) = \$20.15*, and *y(short) = \$9.20*. Thus, the standard CCD design gave a very accurate prediction of the optimum solution. This results was expected, given the highly regular behavior of the *total cost* function in the experimental region.

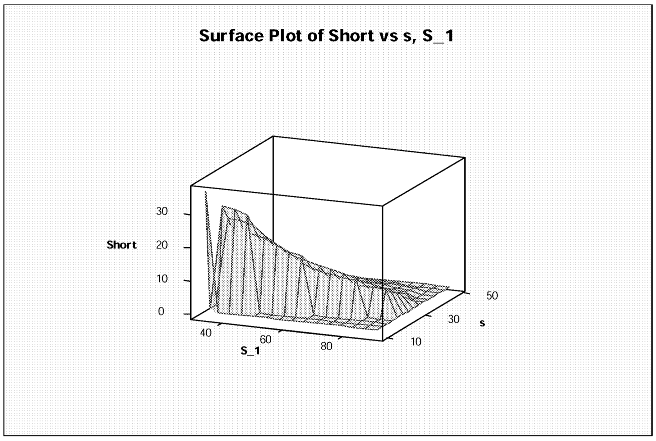
When the kriging procedure described above was applied to the data set in Table 1, the solution procedure *collapsed* due the having several input values at the same settings. Thus, kriging cannot be applied to an experiment employing a CCD design.

Table 1: Simulation Results for the (s,S) Inventory System Using a Central Composite Design

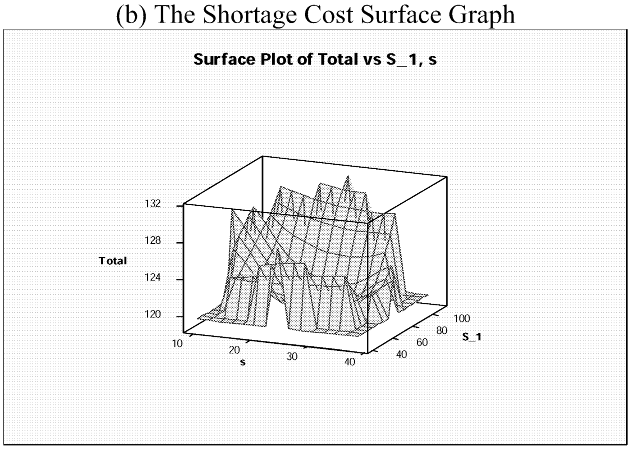
Trial	s	S	s^2	S^2	s*S	Hold	Short	Total
1	24	75	576	5625	1800	25.57	7.79	119.78
2	34	50	1156	2500	1700	17.56	4.63	125.24
3	34	100	1156	10000	3400	42.50	1.68	128.74
4	14	50	196	2500	700	11.64	22.15	123.66
5	14	100	196	10000	1400	32.75	13.53	130.34
6	24	40	576	1600	960	9.73	15.04	128.18
7	24	110	576	12100	2640	41.47	5.90	131.55
8	10	75	100	5625	750	21.11	22.16	129.23
9	38	75	1444	5625	2850	31.40	1.95	123.37
10	24	75	576	5625	1800	26.07	6.77	118.98
11	24	75	576	5625	1800	26.03	7.43	119.50
12	24	75	576	5625	1800	26.49	7.05	119.38
13	24	75	576	5625	1800	25.94	7.01	120.30



(a) The Holding Cost Surface Graph



(b) The Shortage Cost Surface Graph



(c) The Total Cost Surface Graph

Figure 2. Surface Graphs for the (s,S) Inventory System Resulting from a 13-Point CCD Experimental Design

3 LATIN HYPERCUBE DESIGNS

The difficulty with factorial-based designs such as the CCD is that they are *non-space filling*, as was shown in Figure 1. An experimental design is said to be *space-filling* if the k design points are deployed throughout the design space in such a way that they are as nearly as possible equidistant from one another. Clearly, the CCD design points in Figure 1 do not possess this feature. The "sum" values at the right end of each row and the bottom of each column in Figure 1 show this situation quite clearly; that is, the many zeros among these "sum' values demonstrate the non-space filling characteristic of CCD designs. The presence of "sum" values > 1 also signify another undesirable feature of CCD designs from the standpoint of kriging; that is, CCD designs are *collapsing*, and as such are undesirable for the application of kriging.

An alternative to factorial-based CCD designs are *space filling designs* such as the Latin Hypercube Design (LHD) (McKay et al, 1979). These designs have especially favorable characteristics when applied in a constrained optimization experimental setting, in that there is a high probability that one or more design points will not only fall within the feasible region (which is not known *a priori*), but will actually fall close to a constrained optimum solution ***(X*, Y*)***. LHD designs are also especially well-suited for kriging in that they can be made to cover the design space in such a way that design points are almost equidistant from one another in n-dimensional space. Figure 3 illustrates a *non-collapsing, space-filling* LHD. Non-collapsing, space-filling designs such a illustrated in Figure 3 are preferred when applying kriging to simulation experimentation. The fact that all the "sum" values are 1 is an indication of the non-collapsing, space-filling features of LHD designs.

To evaluate a space-filling LHD design, the Arena-based *(s,S)* model was simulated for $r = 5$ replications at each design point in the 20-point Latin Hypercube Design (LHD) shown in Table 2. Note the row and column of 1's, which verify that the LHD design satisfies the requirement that there be one and only one design point at each of the selected values of the input variables x_i, $i = 1,\ldots,n$. The model was run for a period of 120 weeks in each replication, with a starting inventory of *S* units.

The three rightmost columns in Table 2 show whether a design point violates either the holding cost constraint (CVh) or the shortage cost constraint (CVs). The (CV) column indicates the Boolean OR for these results.

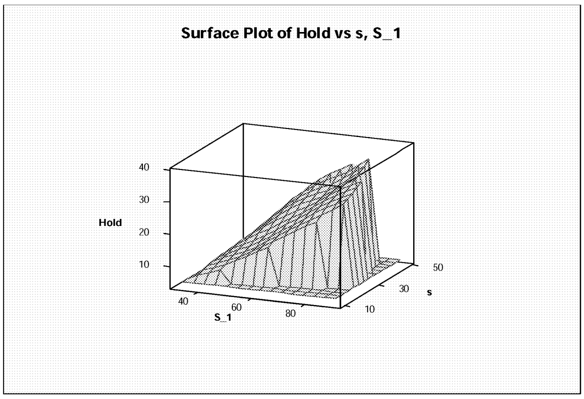
s S	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	Sum
20					1																1
21										1											1
22															1						1
23																				1	1
24	1																				1
25						1															1
26											1										1
27																1					1
28									1												1
29		1																			1
30							1														1
31												1									1
32																	1				1
33														1							1
34			1																		1
35								1													1
36													1								1
37																		1			1
38																			1		1
39				1																	1
Sum	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20

Figure 3: A Latin Hypercube Design Applied to the (s,S) Inventory System

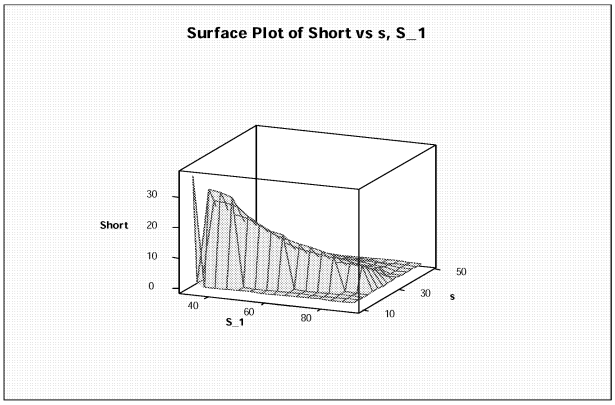
Table 2: Simulation Results for the LHD Applied to the (s,S) Inventory System.

Trial	s	S	s^2	S^2	s*S	Hold	Short	Total	CVh	CVs	CV
1	20	48	400	2304	960	11.60	18.84	124.99	0	1	1
2	21	58	441	3364	1218	16.53	13.33	119.63	0	1	1
3	22	68	484	4624	1496	21.45	10.49	121.41	0	1	1
4	23	78	529	6084	1794	26.69	8.88	123.27	1	0	1
5	24	40	576	1600	960	9.73	15.04	128.18	0	1	1
6	25	50	625	2500	1250	14.18	12.23	122.06	0	1	1
7	26	60	676	3600	1560	18.89	8.68	118.24	0	0	0
8	27	70	729	4900	1890	25.03	6.27	120.27	1	0	1
9	28	56	784	3136	1568	17.71	8.01	120.62	0	0	0
10	29	42	841	1764	1218	12.16	8.95	125.62	0	0	0
11	30	52	900	2704	1560	16.98	7.46	121.96	0	0	0
12	31	62	961	3844	1922	20.79	6.06	120.23	0	0	0
13	32	72	1024	5184	2304	27.38	4.03	124.79	1	0	1
14	33	66	1089	4356	2178	24.08	4.18	119.68	0	0	0
15	34	44	1156	1936	1496	14.16	6.68	126.22	0	0	0
16	35	54	1225	2916	1890	20.41	3.86	125.45	0	0	0
17	36	64	1296	4096	2304	24.63	3.55	128.19	0	0	0
18	37	74	1369	5476	2738	30.60	1.98	125.95	1	0	1
19	38	76	1444	5776	2888	31.70	2.35	126.97	1	0	1
20	39	46	1521	2116	1794	15.95	4.91	127.47	0	0	0

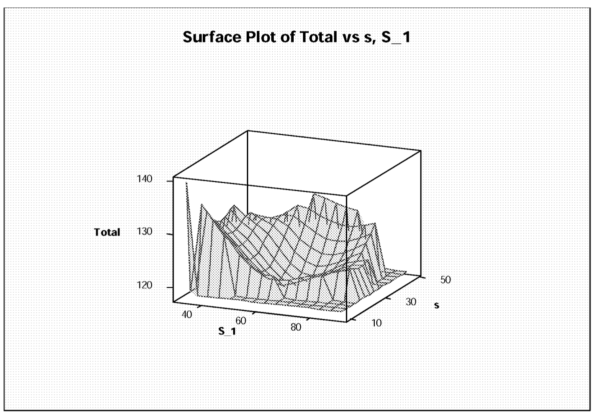
When a purely response surface approach is taken with the experimental results shown in Table 2, one obtains the surface graphs shown in Figure 4. Excel *Solver* was applied to the second-order response surfaces produced by the LHD design, with the following results: $s = 25$, $S = 63$, $y(total) = \$120.00$, $y(hold) = \$13.78$, and $y(short) = \$9.18$. This solution is almost exactly the same as that obtained using the CCD design. That is to be expected, since the response surface of the objective function $y_0(X)$ is unimodal in the region of interest. The advantages that accrue to a kriging approach, and with an LHD experimental design, are more evident with a multimodal surface.



(a) The Holding Cost Surface Graph



(b) The Shortage Cost Surface Graph



(c) The Total Cost Surface Graph

Figure 4. Surface Graphs for the (s,S) Inventory System Resulting from a 20-Point LHD Experimental Design

4 KRIGING IN SIMULATION

Kriging is an interpolation method that predicts unknown values of a random function; see, for example, Cressie (1993) and Wackernagel (2003). More precisely, a Kriging prediction is a weighted linear combination of all output values already observed:

$$\hat{Y}(\mathrm{x}_0) = \sum_{i=1}^{n} \lambda_i \cdot Y(\mathrm{x}_i) = \lambda' \cdot \mathrm{Y}$$
$$\text{with } \sum_{i=1}^{n} \lambda_i = 1 \qquad (3)$$

The weights $\boldsymbol{\lambda} = (\lambda_1, \ldots, \lambda_n)'$ depend on the distances between the input to be predicted $\mathbf{x}_0$ and the inputs already observed $\mathbf{x}_i$. Kriging assumes that *the closer the input data are, the more positively correlated the prediction errors are*. This assumption is modeled through the correlogram or the related variogram. A popular class of permitted correlograms is

$$\rho(\mathbf{h}) = \prod_{j=1}^{k} \exp(-\theta_j \cdot |h_j|^{p_j}) \qquad (4)$$

where $\mathbf{h} = (h_1, \ldots, h_k)'$ is the distance vector between two inputs, say $\mathbf{x}_i$ and $\mathbf{x}_{i'}$, θ_j denotes the importance of factor *j*; that is, the higher θ_j is, the more effect input *j* has, and p_j denotes the smoothness of the correlogram function. Often, these powers p_j are chosen as $p_j = p = 2$. Then, the resulting correlogram is the infinitely differentiable Gaussian correlation function.

The criterion to select the weights $\boldsymbol{\lambda}$ is mean-squared prediction error σ_e^2 defined as

$$\sigma_e^2 = E\left((Y(\mathbf{x}_0) - \hat{Y}(\mathbf{x}_0))^2\right) \qquad (5)$$

Differentiating (3) under the assumption (1) gives the optimal weights $\boldsymbol{\lambda}$

$$\boldsymbol{\lambda}' = \left(\boldsymbol{\gamma} + \mathbf{1}\frac{1 - \mathbf{1}'\boldsymbol{\Gamma}^{-1}\boldsymbol{\gamma}}{\mathbf{1}'\boldsymbol{\Gamma}^{-1}\mathbf{1}}\right)' \boldsymbol{\Gamma}^{-1} \qquad (6)$$

where $\boldsymbol{\gamma}$ denotes the vector of (co)variances $(\gamma(\mathbf{x}_0 - \mathbf{x}_1), \ldots, \gamma(\mathbf{x}_0 - \mathbf{x}_n))'$, $\boldsymbol{\Gamma}$ denotes the $n \times n$ matrix whose (*i*, *j*)th element is $\gamma(\mathbf{x}_i - \mathbf{x}_j)$, $\mathbf{1} = (1, \ldots, 1)'$ is the vector of ones; also see Cressie (1993, p. 122). Note that some of the weights λ_i may be negative.

The optimal weights (4) give the minimal mean-squared prediction error (also see Cressie (1993, p. 122))

$$\sigma_e^2 = \boldsymbol{\gamma}'\boldsymbol{\Gamma}^{-1}\boldsymbol{\gamma} - \frac{(\mathbf{1}'\boldsymbol{\Gamma}^{-1}\boldsymbol{\gamma} - 1)^2}{\mathbf{1}'\boldsymbol{\Gamma}^{-1}\mathbf{1}} \qquad (7)$$

However, in (4) and (5) $\gamma(\mathbf{h})$ is *unknown*. The usual *estimator* is

$$2\hat{\gamma}(\mathbf{h}) = \frac{1}{|N(\mathbf{h})|} \sum_{N(\mathbf{h})} \left(Y(\mathbf{x}_i) - Y(\mathbf{x}_j)\right)^2 \qquad (8)$$

where $|N(\mathbf{h})|$ denotes the number of distinct pairs in $N(\mathbf{h}) = \{(\mathbf{x}_i, \mathbf{x}_j) : \mathbf{x}_i - \mathbf{x}_j = \mathbf{h}\,;\, i, j = 1, \ldots, n\}$; see Matheron (1962). With these estimates $2\hat{\gamma}(\mathbf{h})$, the parameters the θ_j and p_j in (2) are fitted. Standard software uses Maximum Likelihood Estimation (MLE) for this fitting, though Van Beers and Kleijnen (2003) used Weighted Least Squares (WLS) estimation.

Note that the estimator in (8) is unbiased, if the process $Y(\cdot)$ is second-order stationary; see Cressie (1993, p. 71). Kleijnen and van Beers (2004) applied kriging to the problem of stochastic simulation metamodeling of a single response function *y(X).*

5 KRIGING IN CONSTRAINED SIMULATION OPTIMIZATION

When applied to a constrained system, kriging is applied experimentally to the objective function $y_0(\boldsymbol{X})$ and an assessment is made whether one or more of the constraint functions $y_j(\boldsymbol{X})$, $j = 1, \ldots, m$ are violated.

The *kriging* feature of the Matlab *DACE* toolbox was applied to the data $\boldsymbol{x_1}$, $\boldsymbol{x_2}$, and $\boldsymbol{y_0}$. The optimal solution $\boldsymbol{(X)^*}$ was predicted at x_1, x_2, y_0. Note that as applied here, the *kriging* solution does not involve the constraint functions $y_1(\boldsymbol{X})$ and $y_2(\boldsymbol{X})$. Therefore, the next step in the proposed procedure is to evaluate these constraint functions at the 2^n sets of discrete values for x_i, $i = 1, \ldots, n$ surrounding the predicted optimum $\boldsymbol{(X^*, Y^*)}$ to determine whether the constraints are met. Figure 5 shows the surface graph for the predicted optimum obtained through kriging.

The kriging operation gave an optimum solution at $s = 23$, $S = 65$, $y_0 = \$118.64$, $y_1 = \$25.00$, *and* $y_2 = \$8.75$. Hence, the shortage cost constraint y_1 is binding, while the holding cost constraint has a slack value of *$1.25.*

6 SUMMARY AND CONCLUSIONS

This paper has described a workable procedure for applying kriging to a constrained optimization problem via simulation. Until this point, kriging has been applied chiefly to deterministic simulations. Kleijnen and van Beers (2003) have demonstrated its application to stochastic simulations in which there is a single response y_0. The present paper demonstrates that kriging can also be applied to the constrained optimization problem by kriging only the objective function $y_0(\mathbf{X})$, with provisions for adjusting the predicted kriging solution to satisfy constraints.

Additional work is underway to find ways to apply kriging to the entire set of response functions y_j, $j = 0,1,\ldots,m$ simultaneously. A "multivariate kriging" toolbox is being investigated for this purpose.

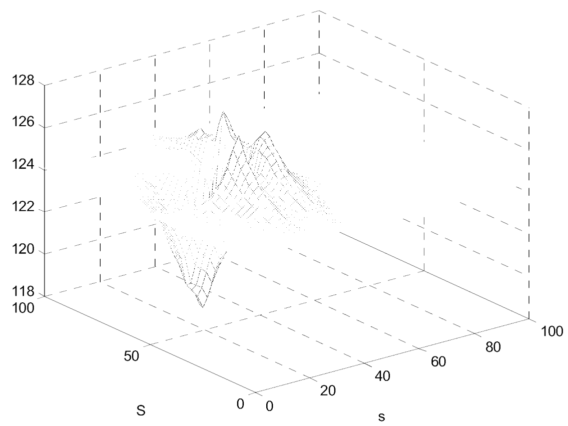


Figure 5: Surface Graph Showing Predicted Values for the (s,S) Inventory System from the Kriging Operation

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BIOGRAPHIES

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GUIDED VEHICLE SIMULATION

Lightweight UAV Simulation for use in Multi-Agent Human-in-the-Loop experiments

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INTRODUCTION

Effective use of robotics for large scale applications such as wilderness search and rescue will depend on coordination of large teams. Automating an aerial search, for example, would not only require automating the piloting of planes but also leadership functions, support roles, and incidental forms of cooperation such as hand-offs and refueling. While automated run time coordination is an active research area, work up to now has failed to produce coordination algorithms that could be used to coordinate large numbers of heterogeneous actors in complex and dynamic environments.

Automated coordination involves many challenging problems including distributed task allocation, resource allocation, dynamic formation and re-formation of teams and coalitions, deciding when and what to communicate, how to coordinate for sensing, information fusion and coherent action, all of which have NP-complete or worse computational complexity.

If we look closely at the notions of large cooperating groups, it appears that the strict assumptions present in the theoretical teamwork model do not necessarily need to hold for most cases of coherent coordination. For many tasks, especially those with high degrees of uncertainty, such as the coordination for emergency response, large groups of cooperating agents need to coordinate only loosely. In other words, they do not need to adhere to the tight communications and maintenance of accurate models of other agents and the state of the team. Yang et al. (2004) have recently proposed and implemented teamwork (Tambe 1997) algorithms that package communications as tokens and use small world properties of networks to provide highly efficient heuristic coordination at a fraction of the cost of prior approaches. This approach, however, is difficult to test in realistically complex domains because of the need to simulate the many entities being controlled.

In the absence of realistic simulation, the robustness of the algorithms with respect to noise, data loss, uncertainty, and the complexity of physically based calculations cannot be evaluated. An additional difficulty arises from the requirement of human controllability and interaction with such systems. This forces the simulations to run in real time as well as adhere to realistic physics and scale to large numbers of UAVs. The challenge of designing such a simulation is that it must be extremely lightweight so that 30+ UAVs can be simulated in real time on a single personal computer while maintaining sufficient fidelity to provide the uncertainties and complexities needed to evaluate coordination algorithms for actual applications.

SIMULATION ARCHITECTURE

To properly simulate a UAV, an aerodynamically correct aircraft model has to be used as the basis of the simulation. Aircraft models come in many different shapes and sizes. For modeling large numbers of UAVs, however, the most important quality of the aircraft model is a low number of calculations. This means that the simulation must be lightweight enough for a regular personal computer to run several dozen of them simultaneously.

Traditional flight simulators, such as Microsoft Flight Simulator, FlightGear and X-Plane have very accurate aerodynamics models incorporated in their programs, but they need a lot of memory and computing time to accurately calculate the airplane's position and attitude. Running two or more on a computer will result in undesirable waiting time. Therefore, they cannot be used for a multi-UAV task.

A number of multi-UAV simulations have already been developed. These simulations can be divided into two categories; those that use MATLAB and Simulink, thus obtaining a very accurate aircraft model, or those that have only three degrees of freedom.

Programming a multi-UAV simulation using MATLAB and Simulink, although delivering a very accurate simulation, results in the computer using too much computing time and memory for scaling upwards to larger numbers. Therefore, the simulation can only be run for up to eight UAVs simultaneously (Rasmussen & Chandler 2002).

The simulations with three degrees of freedom are a lot more efficient for use in multi-UAV simulations. Unfortunately, by using only three degrees of freedom, a lot of details about the aircraft, as well as aerodynamic properties are left out of the equations. Therefore this strategy of using only three degrees of freedom may not be accurate enough to simulate the complexity and uncertainty needed to evaluate the coordination algorithms and the human controller.

Meeting the requirements for both accuracy and low computation in a simulation design is very difficult, as they are for the most part mutually exclusive. More accuracy means more equations, which means that the simulation will require more computing time. Therefore, every decision taken in the development of our -UAV simulation was focused on achieving the right balance between accuracy and minimizing calculations.

Keeping the importance of reducing the number of calculations in mind, the choice was made not to use integrals in the calculations. Rather than that, linear estimations are used. Although this means a small sacrifice is made in accuracy (which is dependent on the sampling frequency), it results in a significant decrease in computations.

In order to keep the design simple and comprehensible, modular design was followed. Starting at the core, the aircraft model, modules can be added of subtracted at will, adding detail where needed. This way, it is easy to substitute modules with new modules or even replace modules with other programs.

For modeling the aircraft dynamics, one of many options must be selected. Traditional flight simulators use the linearized equations of motion. These can however only be used for steady, straight, symmetric and trimmed flight conditions. The conditions in which the UAVs are flown are significantly different and the linearized equations can therefore not be used. Furthermore, the equations are quite complex and therefore are not suited for a lightweight application.

A second option for modeling the UAVs is as a Rigid Body. Rigid Body equations assume that distance between any two points on the body is time independent. Although this is a simplification, it is acceptable in the case of most UAVs. The equations used are very simple and therefore the model can be lightweight.

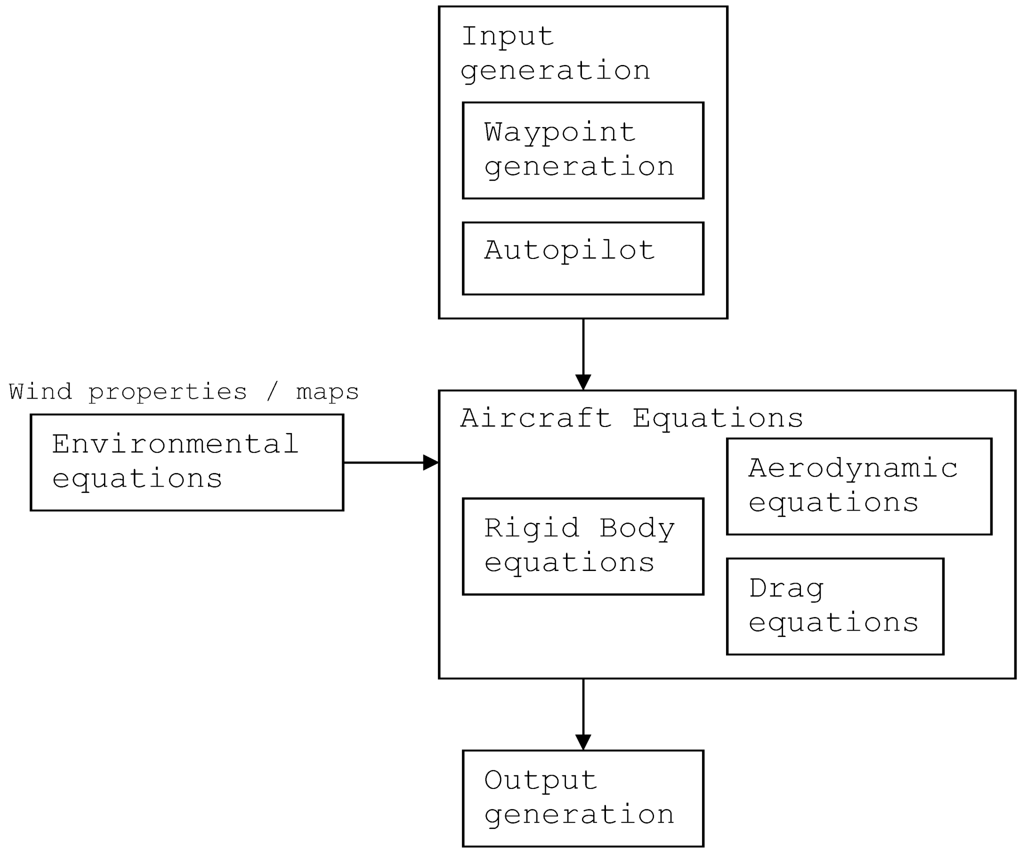

Figure 1. Setup of the simulation

The biggest downside to using a Rigid Body, as opposed to the linearized equations, is that all of the aerodynamic and drag effects have to be added by hand.

Rigid Body UAV Simulation

Using a Rigid Body to simulate an aerial vehicle may seem illogical, since it is so easy to implement the dynamics equations. The linear equations of motion of an aerial vehicle come in convenient state space form and are decoupled for symmetric and asymmetric motions.

In order to build a six degree of freedom simulation with the dynamics equations, however, non-linear equations of motion need to be used. These are six differential equations, which all need to be solved every update. Furthermore, the symmetric and asymmetric motions are coupled.

Using a Rigid Body instead of these equations means the only equations that need solving are three instances of Newton's second law for translations and three instances of Newton's second law for rotations. This can be simplified even further by taking linear estimates of the integrals instead of the integrals themselves. The price for this simplification is a decrease in accuracy, though this decrease should be small if the sampling frequency is high enough.

The big disadvantage of using a Rigid Body instead of dynamics equations is the lack of aerodynamic properties. Gravity, lift and drag forces need to be added to the equations. These are, however, simple equations compared to the differential equations.

RESULTS

By using a Rigid Body instead of the traditional dynamics equations, the amount of calculations required per update is decreased dramatically. Taking lines of code as a surrogate for computation our Rigid Body simulation is more than an order of magnitude shorter than its closest competitor among popular six degree of freedom simulations (Zipfel 2000).

Table 1.

Name of simulation	Lines of code
SRAAM6	5812
GHAME6	4726
FALCON6	1339
Rigid Body	116

To make performance comparisons we have chosen FlightGear (Perry 2004), a widely used open source flight simulator. FlightGear developers assisted us through answering questions and helping us set up the comparison runs. Our comparisons address two basic questions:

1. efficiency: what are the actual differences in computational costs between the two models?
2. accuracy: can the rigid body model approximate the behavior of a FlightGear model based on flight equations?

Efficiency

Computer-based simulations are discrete in nature, because of the time it takes for a computer to evaluate the equations that make up the simulation. This means that values are only known at specific points in time. Values between these "known values" can only be estimated with the assumption that the intermediate values have a certain relation to the nearest "known values". This is, however, not always the case.

Based on informal experimentation a 20 Hertz simulation frequency seems to be the best choice for this application. A lower frequency would result in too little accuracy (causing unreliable results) and a higher frequency would require more calculations per second (reducing the maximum number of UAVs that can be simulated simultaneously).

The main purpose of using a Rigid Body for the UAV simulation was the speed with which the new state can be calculated. After re-programming the simulation in C (to achieve the highest possible computing speed), the time needed for calculating one time step was measured. Since this time was not constant, the average of 100 calculations was taken.

The time needed for calculation of the Rigid Body equations is $1.83*10^{-4}$ seconds. This means the simulation can be run 5400 times per second on a single computer. This also means that, using the previously determined simulation frequency of 20 Hertz, the simulation can be run for up to 273 separate UAVs simultaneously for a real-time application on a single computer.

The same calculation can be made for the FlightGear simulation. The average time needed for the FlightGear simulation is much higher than that of the RB UAV simulation. The variance of the calculation time is also a lot higher. FlightGear needs on average $8.1*10^{-3}$ seconds for calculating the dynamics equations. This means that, when taking the same 20 Hertz simulation frequency, it can run only 6 simultaneous simulations on one computer for a real-time application. The RB UAV simulation performance therefore is comfortably in excess of our 30+ UAV target and the 6 UAV limit found for the FlightGear dynamics equations confirms the limitations of conventional approaches we were trying to overcome.

Accuracy

To determine whether the RB UAV model could approximate the behavior of a flight equation based model, FlightGear, we flew both models over a series of paths. Figure 2 shows the flight paths of the FlightGear flight simulator (pale gray) and the Rigid Body UAV simulator (dark gray and black) for the same set of constants and a similar autopilot (because of the differences between the two simulations, small alterations had to be made to the autopilot algorithms).

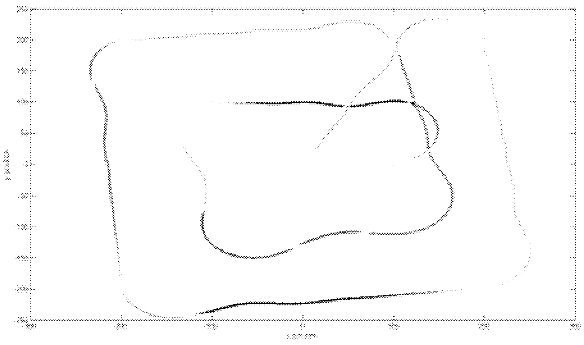

Figure 2. *Flight path FlightGear flight simulator (pale gray) and Rigid Body UAV simulator (dark gray and black)*

There are some obvious differences between the two flight paths. The FlightGear path is straighter than that of the RB UAV simulation. To determine what the reason for the difference was, the errors of both systems were compared.

Figure 3 compares the heading angle error and altitude error for both the simulations. The heading angle error shows that the FlightGear simulation has much more damping in its system than the RB UAV simulation. This results in errors being eliminated much faster. The overshoot and oscillations are therefore absent in the FlightGear graphs. This means the airplane followed a more direct path through the waypoints.

When comparing the altitude errors, there was also a large difference between the two simulations. In this case the error of the FlightGear simulation was much larger than the error of the RB UAV simulation.

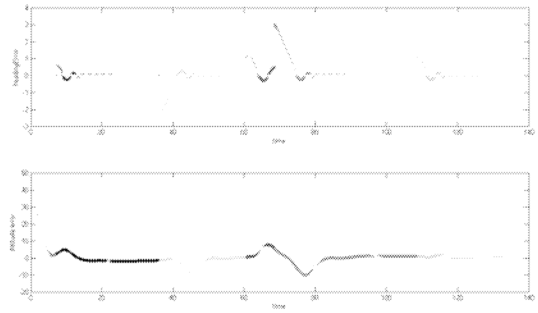

Figure 3. *Flight and altitude path errors FlightGear flight simulator (pale gray) and Rigid Body UAV simulator (dark gray and black)*

For purposes of approximation both heading and altitude of the simulations appear to agree closely enough to make the highly efficient RB UAV simulation a suitable substitute for use in the multiple vehicle control experiments for which it was designed.

Autopilot and Other Components

A simple controller was used for the autopilot, since low complexity of the controller reduces the number of calculations necessary and thus increases the speed of the simulation. For the current application, a very simple PID controller was used to steer the UAVs towards waypoints.

At present, no collision avoidance has been built into the simulation, as this higher level of control is meant to be performed by coordinating agents. Collision avoidance could be added later, however, as anything can be linked to the program, as long as it has the right inputs and outputs.

Figure 1 shows the setup of the simulation. The inputs of the aircraft equations are forces, which means the output of the autopilot and the environmental modules have to be forces. The output of the aircraft equations are position (in inertial frame), velocity (in vehicle frame as well as in inertial frame), attitude and angular velocity. The inputs can come from any source, as long as they are in the right format. The same goes for the outputs. These can be used in any program or application that can interpret the numbers correctly (for example: OpenSceneGraph).

CONCLUSION

Our lightweight UAV simulation balances efficiency with fidelity by abandoning traditional flight equations in favor of rigid body modeling adding in effects of gravity, lift, and drag to the result. While conventional flight simulations are difficult to integrate with physics-based game engines that typically use OpenDynamics, Karma, Novodex or Havoc physics engines relying on rigid body modeling; enhanced rigid body models such as ours should prove more compatible.

For our present objective of simulating large numbers of UAVs in real time this lightweight model meets all of our design objectives.

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BIOGRAPHIE

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Simulation of a Sensorguided Industrial Robot for Add-on Part Mounting

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Process Modelling, Sensor and Robot Assisted Machining, Practical Applications

ABSTRACT
Due to shorter product development cycles, strong international competition and an increasing number of product variants, it is necessary for the automotive industry to develop methods, which enable an efficient product and manufacturing process development. The simultaneous engineering concept with modern simulation techniques is a promising idea to counter the above mentioned challenges.
The aim of the present work is to demonstrate the benefits of process simulation using an example of a multi-body simulation (MBS) of a sensorguided industrial robot for automatic add-on part mounting in the automotive industry. Therefore a coupled simulation method consisting of a standard robot controller, a multi-body simulation tool and an external control application has been developed and validated. A generic approach is used to cover different types of add-on parts and to generate virtual sensor signals for this real-time simulation method.

INTRODUCTION

The current scenario in automotive industry is characterised by saturated markets, an increasing number of product variants and shorter product development cycles. To ensure competitiveness it is necessary for an OEM to efficiently use their resources during all phases of the product development process.
Besides methodology, information technology affects productivity of engineering work and product quality. Numerous software tools exist for product design, analysis and simulation (Anderl and Kleiner 2000).

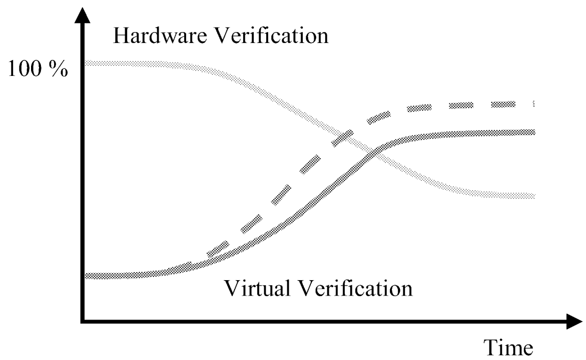

Figure 1: Vision of process simulation

The vision of virtual production is a model, which describes the product in its production environment and which can be used during the entire product life cycle (Zäh et al. 2003). To tap the full potential of digital development and planning methods it is necessary to consider the process chain continuously from design to virtual production.
Describing the whole process chain, current systems run into capacity and interface limits (Debschuetz et al. 2004).
The amount of virtual verification increases continuously and replaces expensive hardware experiments (Figure 1). Compared to other numerical simulation areas in the automotive product development process (e.g. crash simulation), the process simulation has not been exploited completely. Depending on further development of simulation methods, the utilisation of virtual verification will reach the same level as hardware verification. The benefits of process simulation will only be realized if the methods are integrated into the product development process at an earlier time.
The conventional product development process is characterised by product design followed by production planning whereas the simultaneous engineering principle is marked by an overlap of the product design process and production planning process. The benefit of this approach is to reduce the time-to-market by Δt (Figure 2).

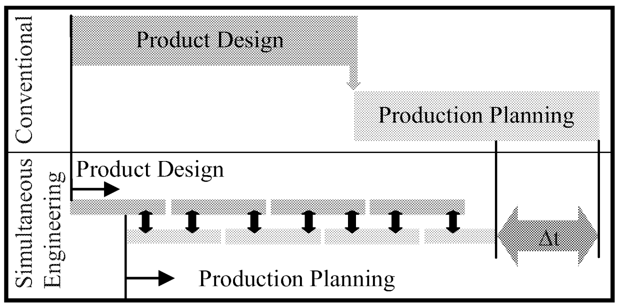

Figure 2: Principle of simultaneous engineering

The necessary cross-functional collaboration of product development engineers and process development engineers covers the entire product development process (Eversheim et al. 1995).
There are many benefits of simulation methods including cost and length of experimentation, safety and the fact that it gives the experimenter an overview of the complete system. With all these benefits, it is obvious that simulation is a natural step in showing the benefits of simultaneous engineering techniques (Melling et al. 1996).

Similar to digital prototypes in product development, process simulation can increase the maturity of manufacturing processes and production facilities at an early development stage. These frontloading-effects allow a steep ramp-up at the start of production. Process simulation can be considered as a driving force of simultaneous engineering.

Automatic add-on part mounting with a sensorguided industrial robot in automotive industry

Due to increasing quality requirements at the outer skin of the car body, assembly techniques have been developed that allow a gap- and flush-oriented positioning of add-on parts (e.g. bonnet, fender or doors) relative to the car body.
The difference to conventional assembly techniques is that the add-on parts are not fixed in a predefined position, but in an iteratively calculated position where all tolerances are accounted in each assembly operation. This “best-fit” technique allows the compensation of positioning tolerances of the add-on part and of the fixed car body up to a marginal deviation.
The closed-loop control uses the “least square method” to find a position for the add-on part where shape tolerances are equally distributed at each gap and flush. Consequently, the tolerance chain gets shorter because tolerances are balanced directly at the part and tolerances do not accumulate along the assembly sequence.
Mainly, the hardware of such a “best-fit” technique consists of an industrial robot, its associated controller, a gripper tool with sensors and interpretation units to measure gap and flush along the edge of the add-on part and an external controller which guides the robot during the final positioning stage (Figure 3).

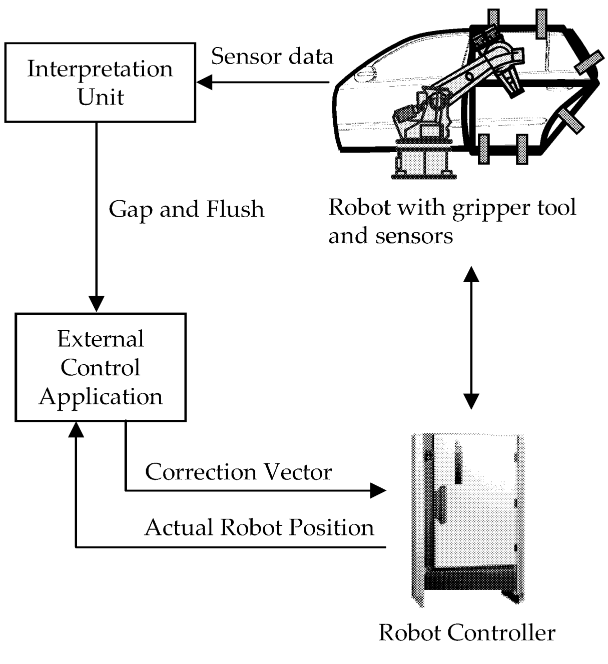

Figure 3: Components of a sensorguided industrial robot

The raw sensor signals are created by two-dimensional profile sensing laser scanners and get converted by interpretation units into the controlled process variables, which are input values for the best-fit control algorithm. This external controller communicates with the robot controller via its Robot Sensor Interface (RSI) and transfers the calculated correction vector for the trajectory of the robot tool. The RSI-interface is used for sensor applications with real-time requirements.
In addition to the extensively used two-dimensional laser triangulation scanners, there are some other sensor types which can be used for special measurement tasks (e.g. a one-dimensional point sensor or a two-dimensional camera).
During the fit-in procedure of the add-on part, the best-fit algorithm compares the actual sensor values with ideal sensor signals, which have been recorded during the teaching process. The algorithm continuously calculates correction vectors for the robot trajectory, which guide the add-on part to the ideal mounting position. Different types of exit conditions as time or variation of gap and flush values during the last correction steps can be defined to abort the fit-in process. Following the closed-loop controlled positioning process, the add-on part is fixed at its final position. Due to the over-determination of information in the sensor signals, it is possible to weight certain measuring points in order to prioritise important gap or flush values.
Sensors, mounted on the robot tool, can be used for a final quality measurement besides the data acquisition for the control process and replace fixed measuring systems. The main benefit of the use of sensorguided industrial robots for add-on part mounting is better product quality and a reduced amount of re-work.

OBJECTIVE OF THE SIMULATION METHOD

The closed-loop control of a sensorguided industrial robot for automatic add-on part mounting is a complex process with many parameters (e.g. weighting of sensor signals), which have to be determined in time-consuming and expensive experiments with hardware prototypes. To keep up with shorter development cycles, it is necessary to shorten the experimental phase with hardware prototypes and to support tests using digital methods. Hence it is reasonable to develop a simulation method, which describes the assembly operation precisely with respect to the robot trajectory to enable assembly feasibility studies before the hardware prototypes exist.

The developed method is based on CAD data, is independent from hardware prototypes and allows planning of production facilities as soon as digital geometry data of a new car series is available. The resulting time gain due to early maturity of production facilities contributes to time-to-market reduction. On the basis of the developed simulation method, it is possible to determine the number of sensors needed for the assembly operation and to find an ideal sensor position on the robot tool. An important application area is testing and optimisation of control strategies. The procedure of such an analysis starts with a specification of simulation parameters (Figure 4). This

parameter set (e.g. number and position of sensors) can be used for the real assembly process, if the virtual teaching process and the virtual fit-in process are successful.
Evaluating the system behaviour in the event of sensor failure and riskless testing of control parameters are also within the scope of the developed method.

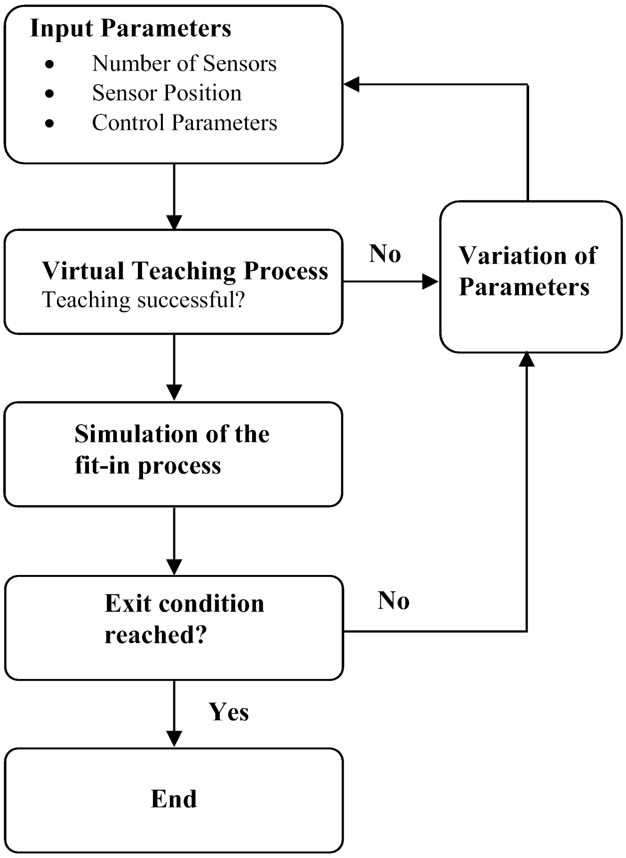

Figure 4: Procedure of the digital verification process

CAD data without tolerance information is not a sufficient base for a simulation model to determine the expected accuracy of the planned real assembly system. Shape tolerances of the add-on part on certain measuring points have an influence on the gap and flush values at other measuring points. It is possible to calculate the process limits by integrating tolerance information into the model.
The result of this analysis shows the maximum shape tolerances of car body and add-on part at the measuring points where the simulation still guarantees a stable fit-in process within the tolerance limits of the scheduled gap and flush values.

APPROACH

Methods to create programmes for robot controllers can be divided into two groups: the on-line and off-line programming. Online programming requires a robot, while off-line programming can be accomplished by the help of simulation tools (Johansson et al. 2004).
Computer Aided Robotic (CAR) tools can be used for an environment without tolerance afflicted geometries to generate or to edit robot programmes.
These conventional robot simulation environments are not suitable for the simulation of more complex robotic systems, such as sensorguided robots [Siegert and Bocioneк 1996). The trajectory of a sensorguided industrial robot differs from one assembly operation to another because of shape tolerances of the add-on part and the body of the car. Thus, it is not possible to simulate a complex fit-in process of an add-on part with conventional CAR tools. The software tools for off-line programming of industrial robots include Robot Controller Simulation (RCS) modules for path planning (Uhlmann and Foitzik 2000), but the integration of external controller devices, complex virtual sensors and their interfaces is not possible.

Elements of the Simulation System

The simulation requires an accurate model of the robot's kinematics and detailed geometry data of the add-on part and the car's body as basis for the generation of virtual sensor signals. Among other things, the result of the controlled fit-in process depends on the frequency of the virtual sensor signals. Therefore, fast processing of subroutines for the generation of virtual sensor signals and the possibility to represent arbitrary kinematic systems are important criteria for the choice of simulation environment. The MBS system MSC.ADAMS offers an adequate programming interface and the feasibility to implement virtual sensors. The calculation of dynamic loads on structures as done with any conventional MBS application area is not in scope of this method. This analysis focuses on the generation of virtual sensor signals by extracting geometry information from CAD data by using complex kinematic constraints.
A simulation model of a sensorguided industrial robot requires three main components (Figure 5): a realistic robot controller, a MBS system and an external application for the robot guidance. A good representation of a KUKA KRC 2 controller is an office-programming-system. This stand-alone robot controller has a network connection to the external control application that hosts the fit-in algorithm. As in the real process, the communication uses the RSI interface for transferring the robot's actual position (joint axis angles) and the correction frame.
The external controller sends a description of the actual robot position via a TCP/IP interface to the MBS system, where the data gets converted into state variables which describe the joint motions of the robot. The kinematic model of the robot is determined by six axis angle variables, as the manipulator has six degrees of freedom. The MBS representation of the industrial robot corresponds with the preset joint angle description of the robot controller.
For every simulation step, actual sensor values are calculated by subroutines and transferred to the external controller which uses the sensor values as input variables for the fit-in calculation.

The output of this control process is a correction frame which changes the robot trajectory continuously to arrive at the ideal position of the add-on part.

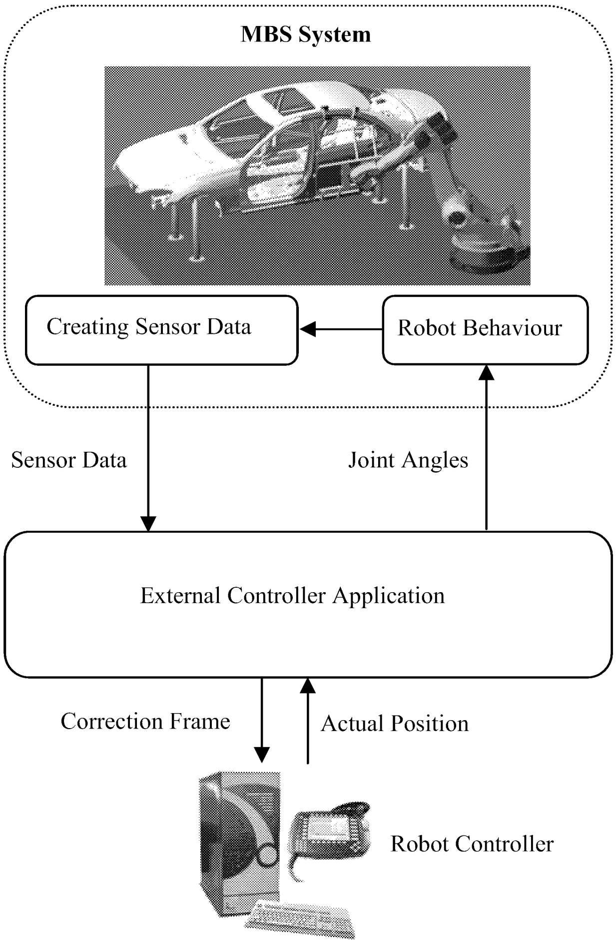

Figure 5: System components of the simulation method

The representation of the robot in the MBS system is updated whenever the external controller acquires new sensor data (10-20 Hz).
To compare the real and the simulated robot behaviour, the same external controller is used in both processes. Additionally, a communication interface to the MBS system is implemented in the external controller application.

Creating virtual sensor signals with a MBS system

Compared to sensor signals of the real process, virtual signals differ in two ways: firstly, noise-induced errors as a result of changing ambient light do not exist and secondly, shadowing effects do not occur in the first step of the simulation, as the signals are ideal. Since sensor-noise has an influence on the result of the fit-in process, these effects have to be reproduced in a second step. The exact emulation of the physical measuring principle of laser triangulation sensors is not within the scope of this method.
The MBS system is used to analyse the geometrical position of the add-on part and the car body. "Marker"-positions of characteristic geometry features are determined with utility-subroutines. A "marker" can be considered as a coordinate system which has a fixed relation to the geometry. The analysis of the marker configuration contains information about the relative position from the add-on part to the car body and is described by gap and flush values. The following approach describes a model of a two-dimensional profile sensing laser scanner. A typical cross section in the measuring plane shows an add-on part with a folded edge and a deep drawn edge of the car body (Figure 6).

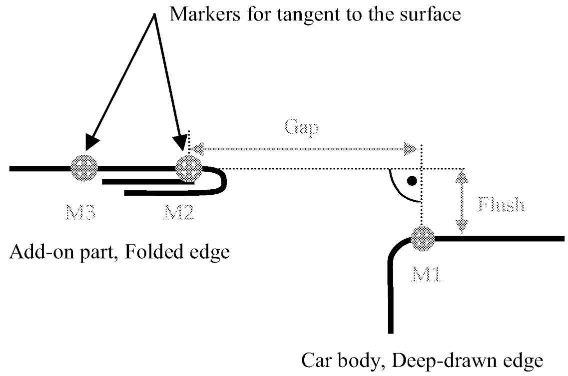

Figure 6: Intersection of a measuring plane as example of gap and flush definition

The sensor hardware of the real process has a rigid mechanical coupling to the add-on part and consequently the marker positions on the add-on part of the virtual process do not change during the simulation process. The measuring points on the car body have to be created for every iteration step because the sensor changes its relative position to the car body. Constraints on markers M1 and M2 assure the position on characteristic geometry features (e.g. beginning of the radius of a folded edge) and within the measuring plane, simultaneously. On both measured parts, tangents are determined by the appropriate markers (M1 – M4) and the analysis of the gap and flush value starts from the car body side. The remaining three rotational degrees of freedom per marker are bound by orientation constraints. Characteristic points are calculated whereas the distance between C1 and the projection of C2 on the tangent represents the gap value. The distance of C2 to the tangent is defined as the flush value. After a successful iteration, these parameters (maximum 12 signals) are transferred to the external controller where they serve as input parameters for the fit-in calculation.
The procedure for other sensor types (such as virtual one-dimensional point sensors or two-dimensional cameras) is the same as the above described process.

Simulation Procedure

The sequence of the simulation method can be divided into three sections (Figure 7). During the pre-processing phase the MBS model is created. This includes the modelling of the robot's kinematics and the positioning and aligning of the robot tool. The CAD geometry of the car has to be imported into the MBS system along with its predefined geometrical features (e.g. splines) for the calculation of the tangents. Then the virtual sensors have to be created and positioned at the designated measuring points.

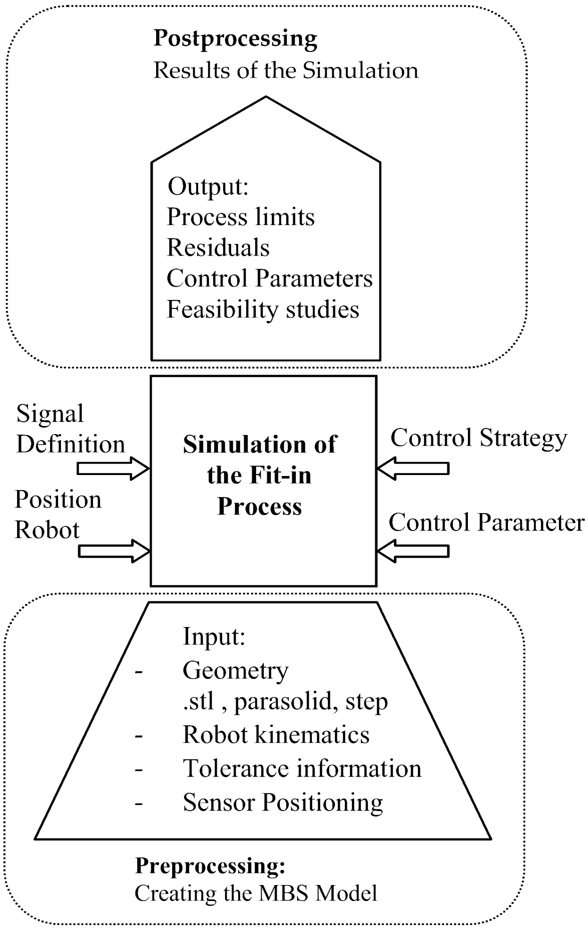

Figure 7: Procedure of the simulation method

For the connection to the subroutines the marker identification numbers (IDs) have to be entered in dialog boxes. A control strategy has to be defined before the teaching process. Similarly to the real process, the teaching procedure must be repeated when basic control settings like the signal definition or the sensor configuration of the MBS model is changed.
This method helps in calculating the accuracy that can be expected of the real assembly process (residuals at the measuring points). Variation of geometry and control parameters allows the determination of the process limits.

VALIDATION

The developed simulation method has been validated with a two step test. The first approach proved the comparability of the system behaviour using a KUKA KR240 and a simple gauge setup. The second test series uses a rear side door mounting scenario for further system optimisation.

The comparison of the robots joint angles during the fit-in process between the experiment and the simulation shows that both trajectories converge to the same end position (Figure 8). A difference in the system behaviour concerning the convergence speed is noticeable. It is assumed that the simulation converges faster due to its ideal sensor signals. This result leads to a necessity of a noise function with the same statistical behaviour like the real process, to be implemented for the second test series.

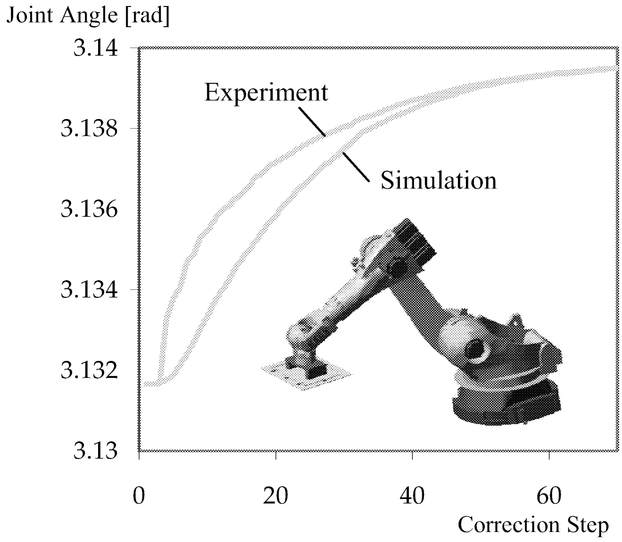

Figure 8: Results of the experiments

The first test series proved that the simulation and the real process react in the same way if changes in geometry (e.g. shape tolerances) happen. On comparison of sensor residuals between the real and simulated fit-in process, there is a maximum deviation of 0.1 mm (Figure 9).

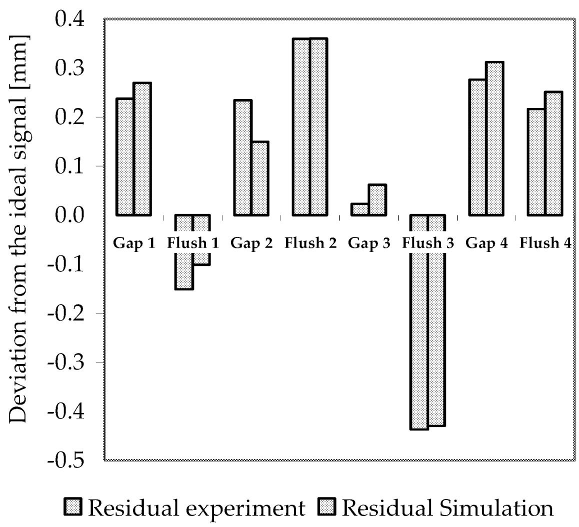

Figure 9: Results of the experiments

Cycle time estimation for the real process is not in scope of the simulation method as the time for the real and simulated process depends on hardware performance.

The simulation method can give qualitative information about the runtimes of different system configurations.

CONCLUSION

Digital simulation methods make an important contribution to reduce time-to-market in the sense of simultaneous engineering. The application of simulation methods improves process knowledge and supports the planning process of manufacturing facilities.
This has been shown by an example of a generic real-time simulation method for a sensorguided industrial robot for add-on part mounting in automotive industry. The main benefit is a stable real process at an early time due to frontloading effects. These studies are conducted on base of CAD models of car prototypes and allow the determination of process parameters and lead to configuration data for a feasible assembly process.
The next test series for validation will be conducted with modifications on the gap- and flush definitions and the possibility to create sensor noise.
The signal noise of real sensors will be analysed by non-linear regression to determine the distribution type for every signal (Figure 10).

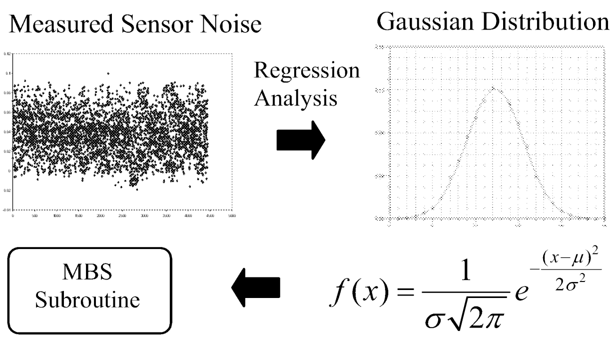

Figure 10: Creating virtual sensor noise

Different random functions (e.g. gaussian) will be implemented to the subroutines. This second step in validation uses real car geometry instead of the gauge setup (Figure 11).

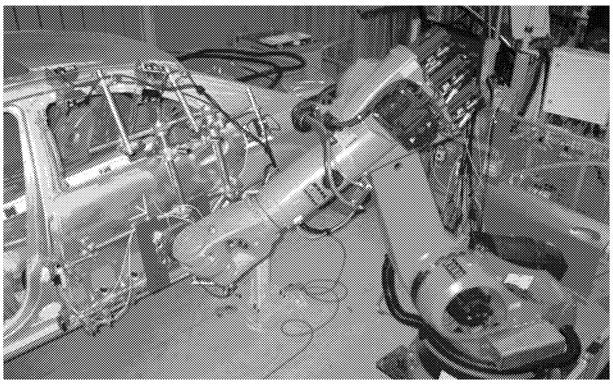

Figure 11: Hardware setup for the second test series

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