Facing Ramp-Up Challenges in the RoboCup Logistics League

Sebastian Reuter, Daniel Ewert, Sabina Jeschke
Institute of Information Management in Mechanical Engineering
RWTH Aachen University
Dennewartstraße 27, Aachen 52068, Germany

Abstract

In this paper we discuss the characteristics and difficulties of the production ramp-up processes in general and the resulting challenges for logistics during ramp-up. Ramp-up as a non-linear, socio-technical system presents companies with great challenges with regard to ensuring a satisfactory product quality and quantity. One of the main obstacles of the ramp-up environment is the robustness against informational deficits such as missing availability of data, fast state changes and information uncertainties. Internal turbulences on the shop floor level and a changing target system present the ramp-up system with further challenges. In this context, we discuss the characteristics and difficulties of ramp-up processes in general and the resulting challenges for ramp-up logistics, especially with respect to autonomous logistics by means of mobile transportation robots. To overcome the problem of missing models and simulations for ramp-up management we propose the RoboCup Logistics League as a test bench for new approaches for ramp-up logistics. We therefore map the identified characteristics of ramp-up processes to the RoboCup Logistics League and show the suitability of the game based approach for serious research on ramp-up management. The Robocup Logistics League has an automated referee and an overhead tracking systems. These systems allow for logging of events together with transportation routes and robot positions. With this information the behavior of the logistic system can be analyzed and automated benchmark procedures for logistics tasks can be established.

Keywords
Production Ramp-Up, Autonomous Logistics, Multi-Agent System, RoboCup Logistics League

1. Introduction

The production ramp-up represents a critical factor for industrial enterprises. According to the classic definition of time-related ramp-up, products are qualified from a prototype status to production-ready products (Wangenheim 1998). Against the backdrop of the global assimilation of technical abilities the launch of new products at the correct time is an important differentiation criterion for enterprises in the future. The transfer from the planned system into production is characterized by changes, adjustments, and delays (Schuh 2012). Independently developed production processes have to be integrated into a system. Here, it is important to identify and correct problems that remained undetected in the previous phase: studies show that 20% of all reasons for changes are noticed earliest in the pilot series and 50% even only after the start of production (Wangenheim 1998). During the product ramp-up many different factors and configurations of the production and product development processes have to be considered under a high time pressure.

Ramp-up is a complex process where possible disturbances, causal connections and the variation over time are partially unknown. This uncertainty based on the variety and connectivity of the relevant elements along with the dynamic behavior of ramp-up processes often leads to unforeseen instabilities. Planned ramp-up curves differ significantly from the achieved ones (Renner 2012). Unwanted and sudden changes of the system states make the system time-varying and its course unpredictable. Thus, the ramp-up phase can barely be “fully” modeled and simulated. Nevertheless, in recent literature (Lanza 2005, Renner 2012) several attempts were made to model and simulate specific ramp-up sub-processes. Especially, to ensure the robustness of products and production processes large-scale testing and validation in real-world environments is of high importance.

In practice, about 40% of the time discrepancies in the ramp-up phase arise due to insufficient consideration of logistic processes (Wildemann 2004). Thus, the design of stable, efficient logistics and storage structures is of primary importance for the ramp-up success. Beyond the horizon of today’s market-requirements the European

Commission envisions knowledge-based innovation in process, products and systems at the factory level as a key-concept of their multi-annual roadmap Factories of the Future (EFFRA). Research and development have to address adaptability and re-configurability of logistic and manufacturing systems by modular approaches for maximizing autonomy and interaction capability of machinery. Future production sites will have to enable an agile manufacturing in terms of a “plug-and-produce” interaction of production machines and their connection through logistic agents. This can only be achieved by intelligent robots and industrial IT systems as well as self-learning and adaptive procedures for their process control. From a logistic perspective, the increased demands can only be addressed by a progressive development of automation and robotics enhanced by synchronous information handling as well as powerful planning and control methods.
In this paper, we discuss the challenges of ramp-up logistics, especially with respect to future trends in production. To overcome the problem of missing models and simulations for ramp-up management we propose the RoboCup Logistics League as a test bench for new approaches for ramp-up logistics. We therefore map the identified characteristics of ramp-up processes to the RoboCup Logistics League and show the suitability of the game based approach for serious research on ramp-up management.

2. Challenges of Ramp-Up Logistics

Logistic systems are influenced by a large number of overlapping disturbances from different areas (Figure 1). The main drivers of these disturbances can be seen in *informational deficits*, *internal turbulences* due to unstable processes and a *shift of the target hierarchy*.

Informational deficits are one of the main characteristics of the logistics system of early stages. Missing availability of material data, high change rate of parts and high uncertainty regarding the availability of parts make planning difficult (Wildemann 2004). During ramp-up these informational deficits lead to delays, the introduction of work-arounds and re-planning of many downstream processes.

Nyhuis (Nyhuis 2008) claims problems within process control, insufficient supply of materials, poor process quality, unsatisfactory production planning and infrastructure to be the main reasons for *internal turbulences* on an operational level. The problem of process control lies in control errors due to the lack of necessary and valid information and short-term priorities. Instabilities within the material supply arise from missing parts due to communication problems, or short-term disruptions in production. The need for rework due to variations in the process quality cannot be planned and can occur at any step of the production process. Changing customer orders immediately cause turbulences in the production sequence during production planning. Processing times may vary for different product variants involving a higher process complexity and make parallel processes necessary. Infrastructural problems such as blocked transport routes, or machine failures at production as well as transportation machines lead to delays or even to a complete halt of the entire process chain (Günthner 2006).

During the transition from a development status to a steady production, concurrently a *shift of the target hierarchy* from a pure maximization of logistics performance to an additional consideration of logistics costs occurs (Renner 2012). Starting with zero-output, time-to-market is the key parameter for the ramp-up process. Rising expectations of speed and flexibility make time to a critical success factor in the logistics ramp-up system (Baumgartner 2001). Thus, in the beginning of the ramp-up phase the primary objectives are to minimize the ramp-up duration and guarantee high delivery punctuality. With increasing system performance and output rate, minimization of costs by a synchronization of material flow and informational processes gain importance. This *shift of the target hierarchy* poses special demands to the logistic sub-processes. A change in the target system requires a vertical synchronization of all system layers. If the local targets of logistic sub-processes differ from the global targets of the overall system, conflicts arise which lead to sub-optimal system performance.

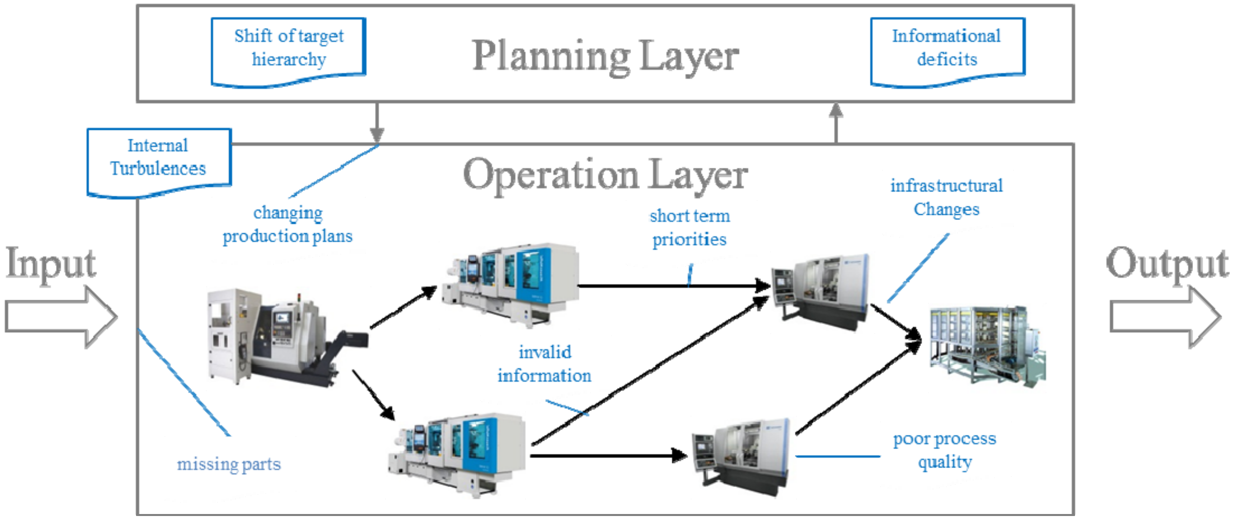


Figure 1 - Challenges of ramp-up logistics

3. State of the Art

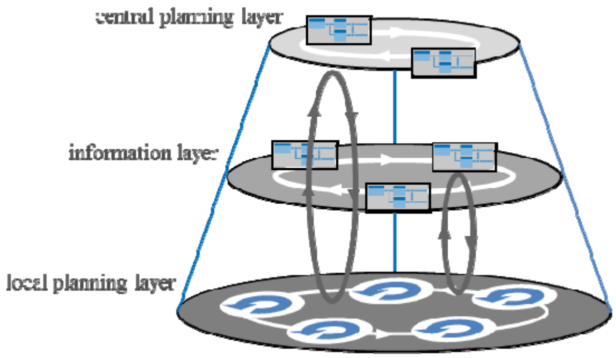
3.1. Principles of self-optimization in production planning

The increasing structural and dynamic complexity forces a paradigm shift from a centralized (top-down) to a decentralized (bottom-up) structure since all necessary decisions cannot be guaranteed to be received in time from a central control location (Jeschke 2013). To meet these new requirements in the context of an increasing automation, recent approaches claim to replace the current static planning and control processes through self-optimizing, decentralized control loops (Hülsmann 2007). By means of decentralized self-optimizing mechanisms, the control system raises on a complexity level comparable to the one of the logistic system. Hence, also the degree-of-freedom increases which enables a more complex as well as flexible behavior of the system (Gehrke 2010). This paradigm shift coupled with modern flexible software systems enables a decentralized autonomous logistic based on real-time data. In decentralized systems, autonomous agents gain real-time data and spread it among each other as well as with supervising agents of higher levels. Within a certain autonomy, autonomous agents analyze their current state and derive fast plans based on their current believe. Planning constraints and global goals induced by higher-level agents guarantee the accordance with the overall targets of the system.

3.2. Stabilizing logistic processes by means of self-optimizing agents

In self-optimizing logistic systems, autonomous objects organize logistic processes with a distributed application of decision rules (Hülsmann 2007). Therefore, these objects need to obtain skills of information retrieval, information processing, decision making and execution. They act in synergy and increase the flexibility and robustness of logistic systems. Such adaptive control methods can efficiently be designed as agent systems (Wetkämper 2009, Wiendahl 2007). In an agent-system each object is represented by a logistic agent. In analogy to autonomous logistic objects these agents have the same properties: they act decentralized, autonomous and self-organizing (Scholz-Reiter 2006). Despite the enormous potential, research on autonomous logistics by means of self-optimizing agents is a very young field which is only slowly entering the logistic sector.

Zaeh et al. developed a communication and control infrastructure for production systems consisting of three different planning levels (Zaeh 2010). A global planning unit is responsible for administration, coordination and dispatching job releases to the underlying logistic system. Local planning agents are assigned a job and have a certain degree of autonomy to adapt process parameters. The underlying system control level is responsible for the physical execution of the task. As the main planning task is done by a centralized planning unit on a high level, the system is based on a holistic data model and thus is very sensitive to communication lags and data consistency.



a) layered system architecture of self-optimizing production/logistic systems

criteria category	criteria	properties			
decision-making criteria	time behavior of objective system	static	mostly static	mostly dynamic	dynamic
	organisational structure	hierarchical	mostly hierarchical	mostly heterarchical	heterarchical
	number of decision alternatives	none	some	many	unlimited
	type of decision making	static	rule-based		Learning
	location of decision making	system layer	subsystem layer		system-element layer
	system behavior	elements and system deterministic	elements non-/system deterministic	system non-/elements deterministic	elements and system non-deterministic
Information processing criteria	location of data storage	central	mostly-central	mostly decentral	decentralized
	location of data processing	central	mostly central	mostly decentral	decentralized
	interaction ability	none	data allocation	communication	coordination
Decision-execution criteria	resource flexibility	inflexible	less flexible	flexible	highly flexible
	identification ability	no elements identifiable	some elements identifiable	many elements identifiable	all elements identifiable
	measuring ability	none	others	self	self and others
	mobility	immobile	less mobile	mobile	highly mobile

b) catalogue of criteria of autonomous control

Figure 2 - Structure and characteristics of self-optimizing systems

The autonomous agents, e.g. CNC machines, assembly robots and high rack storage are linked by a pallet transportation system (Zaeh 2009). Despite of their importance, logistics play a minor role in Zaeh's approach. The fixed transportation links between the production systems enable only small flexibility with respect to material flow. Decentralized approaches are only used for production systems – logistic planning is done by the global planning unit.

Within the Collaborative Research Center on Autonomous Logistic (SFB637) a technology demonstrator integrates research advances in a "Factory of Autonomous Products". The concept organizes the material flow between autonomous workstations which are connected via autonomous transport agents. These agents are guided by a rail system. RFID technology enables identification of logistic items. Each item is also represented by a software agent which enables the autonomy of the item during its production cycle (Ganji 2012). The implemented logistic system consists of a decision, information and execution layer. It aims to decentralize control strategies by monitoring of real-time data, synchronizing material- and information flow and the connection of logistic entities in an "Internet of Things" (Gehrke 2010). Nevertheless, due to the rail-based transportation links the logistic system is limited by fixed connections.

These examples show, that most of the self-optimizing approaches in production and logistic systems aim to introduce agent technology in layered system architectures (Figure 2 a)). The agents act self-optimizing with a certain degree of autonomy on a local planning layer. However, these self-optimizing sub-systems are mostly limited to the adaption of parameters within production processes. Fixed transportation links still dominate the logistic systems and limit them by restricting their flexibility. Böse and Windt introduced criteria in order to compare autonomous system according to their level of autonomy which can be seen in figure 2 b). The catalogue clusters several criteria into decision, information and execution system. Each criterion expresses an individual degree of autonomy for this criterion. As can be seen by benchmarking the introduced examples for self-optimizing agents according to Böse and Windt's catalogue, their grade of autonomy can only be ranked as intermediate. For dealing with complex systems such as the production environment during ramp-up these systems are not adequate. The autonomy of agent systems has to go farther to cope with the high demands of flexibility.

4. Simulating Ramp-Up Logistics in the Robocup Logistics League

4.1. The Robocup Logistics League Scenario

A promising approach for enhancing the flexibility and adaptability of logistic systems is the use of mobile robots for transportation. Mobile transportation robots are equipped with sensors, actuators, communication systems and processing units. Therefore, transportation robots differ from other transportation systems in that they are able to perceive their environment, reason and derive plans in accordance with goals of the overall logistic system. Models of the environment are then enriched with the gathered data and continuously updated to adapt to changes in the environment. These models enable the robot to reason about its current situation - this forms the belief of the robot. Based on its belief and a model of its capabilities the robot is able to derive and select an optimal plan in accordance with its assigned task. Thus, unmatched levels of flexibility and adaptability can be achieved by embedding autonomous transportation robots into logistics systems.

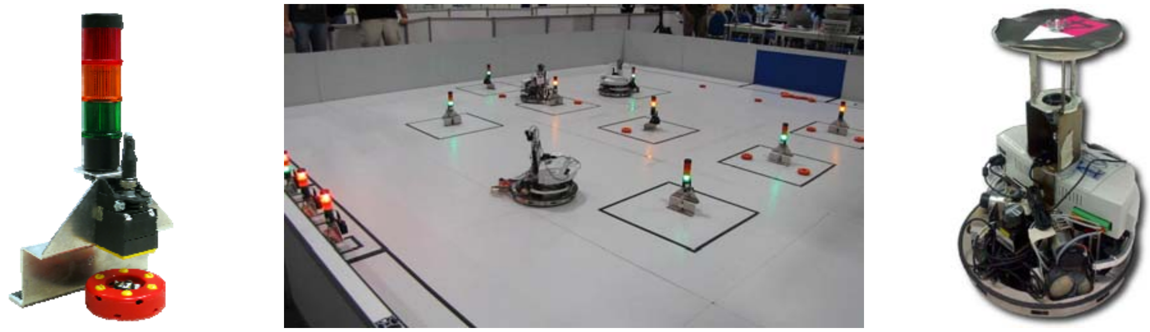
The RoboCup Logistics League is an important step to promote the research in the field of mobile robots in logistics. RoboCup (Kitano 1997) is an international competition to push developments in the field of robotics and artificial intelligence. In 2012 the RoboCup Logistics league (Niemueller 2013a) was founded in order to foster the development of new creative implementations of artificial intelligence methods in the field of autonomous production logistics. The scenario of the Logistics League abstracts a factory automation scenario consisting of production machines, test stations for quality control, recycling stations and autonomous transportation robots. (Niemueller 2013b) The task is to organize an efficient material flow in a staged production process (Riedmiller 2010).

The production area consists of a field of 5.6m x 5.6m which is bounded by walls as shown in figure 5 b). Ten production machines are distributed on the field and each machine is assigned with a certain function type T1-T5 representing their different capabilities. The production machines, test and recycling stations are simulated by industrial 3-colored (red, orange, green) LED signal lights equipped with RFID read/write devices (see figure 5 a)). The signal lights indicate the current state of the production machines – idle, processing, waiting or broken down. The flow of materials through the production scenario is organized by a team of three Festo Robotino Robots (see figure 5 c)). The mobile robots are equipped with several types of sensors for perceiving their environment, a bar for handling pucks and a WLAN device for communication.

Products are represented by pucks with attached RFID tags. The RFID tags specify the product states – raw material (S0), intermediate product (S1, S2) and three variants of a final product (P1, P2, P3). Initially, all products are of type raw material and are placed in an input area at one side of the production area. In each production step, a machine transforms one or several products into an output product. Final products have to be delivered to certain delivery gates in a delivery zone at the opponent side of the production area. The task of the team of robots is to enable a production process by fetching raw-material from the input store, carrying intermediate products between machines and delivering finished products to the delivery zone. A production step is triggered in the way that a robot moves a product underneath the RFID device of a machine. The machine reads the RFID of the product and reprograms the RFID tag depending of the product state and the machine capability. A so called Referee Box announces a production program to the robots. The production program defines which product variants have to be delivered within the current time period. At random points in time, the Referee Box announces Late order which have to be produced and delivered in short time windows.

4.2. Simulating the Challenges of Ramp-Up Logistics in the RoboCup Logistics League

During the game of the RoboCup Logistics League the robotic agents are confronted with situations as they occur during production ramp-up. Induced instabilities due to *informational deficits*, *internal turbulences* and a *shift of the target system* have to be autonomously regulated by the agents. In the following, we are going to describe these instabilities in more detail.



a) Machine processing product b) Production area of the Robocup Logistics League c) Autonomous transport agent

Figure 3 - The production area, machine with RFID device and autonomous transport agent

The robots are inserted into an initially unknown production environment. They must explore and analyze the environment for machine positions, their corresponding types as well as transportation routes and storage spaces. They have to be able to draw assumptions in the context of *informational deficits* and to plan based on their current belief. This includes the planning of machine scheduling as well as planning transport routes which interconnect individual machines. When more data becomes available (by external sources or derived by the agents), the robotic agents are to re-plan or refine their plans based on this changed situation. Furthermore, they have to be able to switch to an exploration mode whenever the data quality makes this necessary. To overcome the problem of informational deficits the robots have to exchange their worldmodel whenever possible. Therefore, the realization of appropriate interfaces has to embed the agent system into the vertical and horizontal process chain. In vertical direction, it must receive the production program from the hierarchically higher control logic and has to communicate obtained information like machine status and the state of the production progress. On horizontal direction it has to offer information (about the products) to the machine processes as well as the downstream processes at the delivery gates.

Internal turbulences due to problems within process control, insufficient supply of materials, minor product quality, unsatisfactory production planning and infrastructure present the robotic agents with further challenges. As a result of these unforeseen changes or inaccurate assumptions the agents have to be able to flexibly adapt their behavior to these new situations. A blocked path by another robot or a machine failure requires a re-planning of the path and the dynamic adjustment of the machine assignment. The robots have to detect low product quality due to production process failures and autonomously re-process the product or dispose it. If the robot lacks of raw-material or intermediate products which are needed for the current production step, they have to re-plan a switch to the production of the necessary intermediate-products. To optimally use the production plant and avoid self-inflicted turbulences, the robotic agents have to cooperate in terms of sharing the machine usage and the reservation of transportation routes.

To cope with a changing production program, the robotic agents have to be able to divide the assigned tasks into solvable sub-problems, to distribute sub-tasks among each other and synchronize their local targets. Short-term priorities have to be included into the production sequence and changes have to be continuously adapted by re-scheduling. Moreover, the agents have to be able to pause or abort their actually processed task if the changed production program does not require products of the type which is currently processed by the robotic agent.

The *shift of the target system* is presently not realized by the scenario of the Robocup Logistics League. Nevertheless, an adaption of the scoring scheme would also enable the league to simulate this challenge. By assigning points for machine and robot utilization as well as for cycle-time and delivery punctuality, a shift of the target system can be simulated. Starting with high scores for short cycle-times and delivery punctuality and low scores for machine and robot utilization the pointing scheme could increase scores of machine and robot utilization to shift the target system. The robots then have to match their optimization targets with the scoring scheme announced by the RefBox.

5. Summary and Outlook

In this paper we gave an overview of the new RoboCup Logistics League. The leagues idea is to simulate the logistics of a factory automation scenario with mobile robots. The robots have to realize an efficient material flow to enable the production of a final product. Therefore, the robots have to transport different semi-products between production machines and deliver the final product to a certain delivery gate. The robot team has to explore the factory environment by identifying machine types, plan feasible production sequences and deliver the individual products in time. Furthermore, they have to cope with instabilities during production that may occur. Pallet carriers have to be recycled and high-priority orders disturb the planned production sequence. The robot team has to be robust against these instabilities to optimize the output of the factory.

The RoboCup Logistics League maps the characteristics of ramp-up logistics very well. To be robust against the specific challenges of the ramp-up phase, the agents need planning abilities, self-optimization behaviors and cooperation strategies. Therefore, we proposed the RoboCup Logistics League as a test bench for new approaches for ramp-up logistics.

We described the rules of the league and how certain challenges of the ramp-up phase can be simulated within the logistic leagues scenario. Based on this abstracted factory automation scenario agent technologies can be developed that can be more easily adapted to real world scenarios. The Robocup Logistics League enables the evaluation of different agent strategies such as Kanban motivated job separation approaches, concurrent job-marketing approaches and cooperative game-theoretical approaches in one scenario. To evaluate these approaches we are going to extend the testing environment to enable a detailed analysis of the different agent-strategies. Overhead-camera tracking of the robots will give ground-truth data and the use of extensive data logging of the agent decision state will make agent decision transparent. By benchmarking the different strategies their applicability to real life ramp-up scenarios can be estimated. Thus, total costs of development and expensive tests within the real production environment can be avoided.

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Biography

Sebastian Reuter is a scientific researcher and PhD student at the Institute of Information Management in Mechanical Engineering (IMA) of the RWTH Aachen University, Germany. He studied Mechanical Engineering and Business Administration at the RWTH Aachen University and earned a Master of Science in Automotive Engineering from Tsinghua University Beijing, China. Sebastian holds a scholarship of the German Research Foundation DFG. Within the Research Training Group "Ramp-Up Management - Development of Decision Models for the Production Ramp-Up" he deals with the application of “Self-optimizing autonomous agents in Ramp-Up Logistics”. Sebastian is part of the Organizational Committee of the RoboCup Logistics League where he tries to promote the research in the field of mobile robots in logistics.

Daniel Ewert is a scientific researcher and PhD student at the Institute of Information Management in Mechanical Engineering (IMA) of the RWTH Aachen University. Daniel Ewert studied computer science with a subsidiary subject in neurobiology at the RWTH Aachen University. His areas of specialization were artificial intelligence and knowledge-based systems. Within the research group “Production Technology” he deals with autonomous assembly planning and intelligent control systems for production within the project “Selfoptimizing Production Systems” of the Cluster of Excellence “Integrative Production Technology for High-Wage Countries”. Further fields of interest are robotics and human-machine interfaces. Furthermore, he is the responsible lecturer for the courses “Informatik im Maschinenbau I” and “Informatik im Maschinenbau II” (Computer Science in Mechanical Engineering I & II).

Sabina Jeschke is a Professor and Head of the Institute of Information Management in Mechanical Engineering (IMA) of RWTH Aachen University, Germany. Sabina Jeschke is Vice Dean of the Faculty of Mechanical Engineering of the RWTH Aachen University, chairwoman of the board of management of the VDI Aachen, a member and consultant of numerous committees and commissions, alumni of the German National Academic Foundation (Studienstiftung des Deutschen Volkes) and IEEE Senior Member. She studied Physics, Computer Science and Mathematics at the Berlin University of Technology. After research stays at the NASA Ames Research Center/ California and the Georgia Institute of Technology/Atlanta, she gained a doctorate on "Mathematics in Virtual Knowledge Environments" in 2004. Following a junior professorship (2005-2007) at the TU Berlin with the construction and direction of its media center, she was Head of the Institute of Information Technology Services (IITS) for electrical engineering at the University of Stuttgart from May 2007 to May 2009, where she was also the Director of the Central Information Technology Services (RUS) at the same time.