Rotation-oriented Collaborative Air Traffic Management

Udo Inden
Cologne University of Applied Sciences
Research Centre for Applications of Intelligent Systems (CAIS),
Cologne, Germany
e-mail: udo.inden@fh-koeln.de

Stephan Tieck
EADS Innovation Works
Research Team "The Future of Flying - Services, Maintenance & Logistics",
Hamburg, Germany
e-mail: stephan.tieck@eads.net

Claus-Peter Rückemann
Leibniz Universität Hannover / Westfälische Wilhelms-Universität Münster (WWU) / North-German Supercomputing Alliance (HLRN),
Münster, Hannover, Germany
e-mail: ruckema@uni-muenster.de

Abstract—Considering developments in aviation industry and ICT a framework of further steps of integration in Air-Traffic Management is drafted. Intelligent management systems and distributed parallel data processing is envisioned for including sequences of flights into collaborative ATM. This includes options provided by latest developments regarding the Internet of Things as well as of Things that Think, i.e. manifesting autonomous behavior in a complex operations environment. Advanced communication system components, verification methods, and mission critical communication networks are utilized to interlink distributed compute, storage, and High End Computing resources and create a fast, secure, and reliable system and operating environment.

Keywords-Air Traffic Management (ATM); aircraft rotation; complex operations system, intelligent organization; "Things that Think", operations flexibility; real-time management; criticality management; High End Computing; distributed resources; high performance communication networks.

I. INTRODUCTION

Aviation operations systems are of considerable complexity and facing an enormous growth of traffic. The SESAR program (Single European Sky Air Traffic Management Research [15]) prepares for a shift from central control towards a stepwise deployment of a self-organizing and intelligent managerial organization which will include the "intelligent aircraft". Future Air Traffic Management (ATM) employs intelligent functionality to track, maintain or if need be recover the plan of flights by hedging it against unplanned events respectively to coordinate its recovery.

Complex operations are marked by large numbers of unexpected, thus unplanned events and *we define intelligence as the ability of a system to targeted and timely response* [5]. But any response needs to re-allocate resources or to employ additional ones – i .e. it needs flexibility in terms of disposable buffers. If they are exhausted the system will be unable to capitalize on any intelligence.

Aviation systems are critical if delays of flights are about to propagate without chance to recover. Criticality [9] is a holistic property of a system in a point of time and likewise it needs a holistic and timely scope of management. For this, we suggest extending the flight-oriented scope of ATM by establishing an additional focus on aircraft rotations. *Rotations are sequences of flights of an aircraft in a period of time (e.g. a day)* and with this include the chance of managing interdependencies of flights. For this we suggest using the capabilities of future "intelligent aircrafts" [1] developed under the regime of the SESAR program. Accordingly we consider examining potential contributions by the upcoming internet of things (IOT) and of "things that think" (TtT) being equipped for some autonomous reasoning and collaborative decision making. [6] [7]

Pursuing this approach among others requires deeper research on the control parameters of aviation systems and on appropriate IT-support particularly with respect to potential contributions of intelligent things and distributed processing of data. Further systems are to be tested effectively integrating communication technologies and the world of things.

The paper provides an initial framework of intelligent real-time ATM applications based on the convergence of growing challenges, current improvement programs and novel developments of ICT. ATM programs and basics of aircraft rotations are explained. Sections four and fife sketch proposed architecture and scenarios of intelligent, rotation-oriented ATM and discuss benefits of managing system criticality. Section six structures related computing strategies. Finally conclusions and an outlook are presented.

II. ADVANCING AIR TRAFFIC MANAGEMENT

With ten-thousands of flights, starts, landings and related ground operations, with millions of passengers (and shipments) air traffic forms a massively distributed system of actors (pilots, air and ground controllers, ground and terminal service providers, customers, etc.), highly interdependent but each deciding with at least some autonomy and with only local, thus limited information.

At the same time raising urgencies of environmental concerns or the growth of travel by 8.8 % and of traffic by almost 5 % annually [2] systemically aggravate the mix of problems, while tight public budgets and political constraints to extend infrastructures and small profit margins in the industry limit options to respond.

This system inevitably emerges floors of interference, interacting with external events (weather, security …) and preparing the ground for butterfly-effects. E.g., one ownerless suitcase can block a terminal and delay many flights. Along operational relationships then quickly service failures propagate across continental and intercontinental networks.

 ISBN: 978-1-61208-161-8

Thus maintaining planned services or – more general – safe and efficient operations requires material and (close to) real-time management capabilities. An obvious strategy is to advance traffic management for a more efficient use of resources: With the (political) objectives to accommodate a threefold of current traffic, to improve safety by a factor of 10, to reduce environmental impacts by 10 % and to cut ATM costs by 50 % large and coordinated joined public-private undertakings have been started in all major aviation areas, e.g., SESAR (likely to go into its deployment phase by 2014) in Europe and NextGen ATM in the US [2][3].

Future systems include GPS-based control of 4-D flight trajectories, system-wide information management (consistent undelayed data sharing, improved proceedings and algorithms) or a higher degree of automation of control and of procedures to stabilize or recover flight plans. As a major advance aircrafts will get more choice in choosing routes rather than being limited to air-streets. With further improvements and supported e.g., by advanced Airborne Collision Avoidance Systems (ACAS) spatial separations of aircrafts will be agreed by peer-to-peer principles: Therefore the “intelligent aircraft will be a critical element in 21st century ATM.” [3].

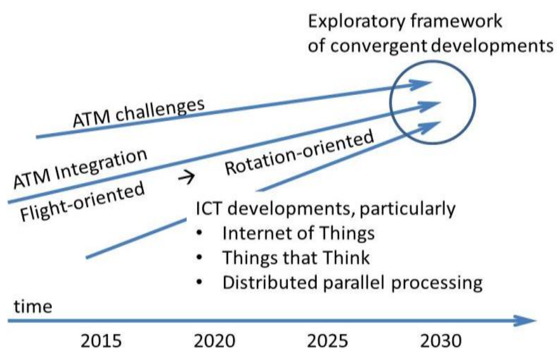

Fig. 1 Converging Developments

These programs have horizons of implementation of 10 to 15 years. In this time and after we assume three developments to converge (Fig. 1): Challenges to ATM will continue to increase, ICT will provide new options to answer and the current generation of ATM innovations will be implemented. With these developments reasons, technology and organizational concepts to integrate a wider scope of ATM converge. And with distributed parallel processing also issues of Grid and High-End Computing are touched. In the following we try an initial framework of these applications scenarios.

III. Management of Aircraft Rotations

Rotations (figure 2) cover deeper interdependencies between flights which cannot be managed on the level of individual ones. The intrinsic complexity of aviation systems – materializing in the form of failure propagation across networks – emerges on the level of rotations which also triggers the complexity of individual flight operations. This shall be explained on the example of scheduled airline services.

Rotations are planned in answer to the demand for transportation between origins and destinations in terms of its volume and distribution in time (daytimes and frequencies of service within a period), to connecting flights (e.g., in hub-and spoke networks), to distances (flight-time) or to availability of slots at airports as well as to the load-factors of aircrafts (utilization of a given fleet of aircrafts). Rotations include a number of legs (flights). I.e., problems which have occurred in the first leg may affect subsequent ones. In case of transfer connections the problem may also propagate to rotations of aircrafts operating connected flights. And with aircrafts also crews move in networks, air-craft maintenance is planned or many inventories of equipment distribute.

Operations footprints – in terms of direct (variable) costs, resource and infrastructure utilization (fixed costs), environmental efficiency (emissions, consumption of water) depend on the efficiency of rotations. For example maintenance footprints are to be managed on that level. While rotations are efficient if all flights are efficient it is not true that maintaining the efficiency of individual flights automatically maintains the efficiency of their interdependencies and inefficiencies are likely to accumulate high expenses.

In competition airlines need to manage conflicts between aircraft utilization asking for short(er) ground times (aircrafts only make money when they fly) and service quality by trend affected by such measures. If propagation of service failures turn into dissatisfaction of customers an airline with e.g., 100 aircrafts, each in average rotating in a network with six legs per day, has to calculate whether and how 5 minutes more ground-time for each of the 600 legs = 3000 minutes = 50 hours (equal to the average employment of 3 aircrafts) of idle time is paid by the avoided annoyance of passengers.

Legacies accumulating in operations systems are the second major driver of operations complexity. And in the multi-national, very political, hierarchically organized and for good reasons also very risk-avers world of aviation change takes time and time produces “renovation holdups”. Tidying up such holdups is the core of lean-management programs. Since current management principles have been settled shortly after World War II. SESAR or NextGen are of that type. In front of this background a paradigm shift is inevitable (and a challenging change program).

Lean-management programs can provide a respite. But stress will return and the “granularity of object and time” [4] will increase: An ownerless suitcase may block a terminal, a late push-back, a defect stair, literally any disorganized resource may ruin rotations. And under stress it makes a difference whether resources are planned offline and “the next free one” is ordered to service or whether they are continuously tracked and planned online to events. I.e., there is reason considering the integration of the layer of flight rotation into real-time service maintenance. This layer will interact but not interfere with ATM concerned with the flights.

A threefold of current traffic will be reached in 15–20 years, soon compared to the time it needs to realize new airports in Europe. Thus any large airport is under *continuous* physical as well as organizational re-construction. In the words of a senior manager of a large European one: “We are evolutionary driven.” Thus if flights and not rotations are the organizing principle of control achievements of SESAR or NextGen are easier to be consumed by growth or by competition (for example cost cutting, service / quality increase).

 ISBN: 978-1-61208-161-8

IV. On the Architecture of an Intelligent ATM

The capability of timely adapting activity to unexpected change (intelligence) emerges from the capability of acting units (agents) in a distributed system to freely associate or re-associate in a context which establishes interdependence for a certain time. A rotation is an example of such a context. I.e. objectives are achieved by autonomous re-allocation of resources or – if solution space is exhausted – to relinquish minor objectives for maintaining superior ones.

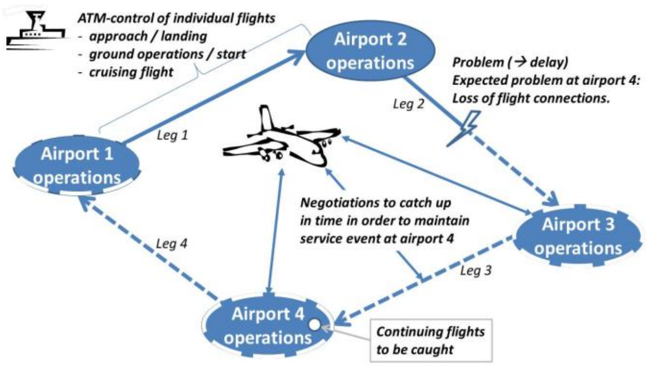

Fig. 2 High-level Model of Rotation-oriented ATM

Ideally, all agents are satisfied with their individual plans and plans of all agents are non-contractively coordinated. Then an unplanned event may cause, that at least one agent has become unable to achieve its objectives and now will try to improve again by re-negotiating its contracts with other agents. I.e., dissatisfaction propagates along services asked from respectively provided to other agents until a new satisfying solution is achieved.

This depiction equals design principles of a multiagent system emerging intelligence from relation-based interactions by associating to each other accordingly to the fit of properties (e.g., need, capability, objectives) as described in ontologies (structured domain knowledge). Market-based coordination is a promising approach. [5] However we do not suggest developing another mirror-MAS for simulating or managing a real operations system.

A. Collaboration scenario

Rather we consider including all relevant stakeholders, whether persons, objects or systems concerned and taking a relevant role in the current operations context by inviting them to a "Service Maintenance Conference" (SMC) taking place in an appropriate network environment (a private, proprietary cloud). It compares to an on-demand conference call which is organized accordingly to MAS principles. Figure 2 gives a basic idea who or "what" may participate:

- The aircraft takes the chair of the conference, possibly supported by the airline flight-center,
- Flight operations:
  - Other aircrafts in the operations vicinity if the current trajectories of the aircrafts are affected,
  - ATM authorities supervising or directly controlling en-route and particularly near-airport ("terminal") flight operations,
- Airport ground operators at airports relevant in the context, particularly subsequent ones in the rotation:
  - Airport control centers.
  - Dispatch centers of ground services for aircrafts, in case also around passengers or cargo.
- Potentially further stakeholders of operations.

In a rough estimate about 100 – 200 instances may be included. Currently airport ground services are only coupled to ATM via flight plans and flight plan updates. In the model we propose to actively engage them in solution finding. The way this inclusion will be organized depends on the vision of the ICT in 10 to 20 years from now.

B. Scenarios and Trends to be Considered

SESAR architectures rely on SWIMs and consistent re-planning. In case of unexpected events stakeholders are responsible to take action accordingly to standard procedures, in future supported by systems developed by SESAR. Thus as a first step this new ICT is to be connected into a peer-to-peer network forming a second layer of ATM which interacts but not directly interferes with the first layer: flight management.

Yet there is another trend, marked by the visions of the Internet of Things [6] respectively of Things that Think [7] e.g., the next generation of aircrafts. The Car-2-Car Communication Consortium [8] is a further example aiming among others at avoiding accidents or the exchange of route information. At airports apron field vehicles (push-backs, tank- or de-icing trucks) will manage their activity. Dolleys (transport carts) will be RFID tagged, motorized boarding stairs with GPS and suitcases be equipped with tags remembering owners not to leave them behind.

In 2020+ not only aircrafts but most critical resources at airports will be able of some autonomy; almost any other will be at least connected. Directly or non-directly they will be able to participate in SMCs.

C. Concluding Scenario

This "internet of things that think" develops because ICT makes it possible and affordable with cheaper and better performing hard- and software. But the fundamental driver is different: Managing under conditions of high complexity and dynamics implies that more single objects become source or subject of events [4] and that reliable, correct and immediate information matters. In these environments centralized control fails and not at least "things" will obtain autonomy. They are equipped with sensors and with capabilities of reasoning or become users of the internet because this enables to capture and exploit first-hand information.

This is summarized in the sigh of a dispatcher "If I would know where it is!". The timely and correct answer makes the difference between a solution and a service breakdown.

Thus, the second scenario is that not just some hundred but thousands of "things that think" will participate in SMCs and because of the interdependence of rotations of aircrafts in several SMC in parallel. The result is a heterogeneous holonic network of ad-hoc SMCs and invitees include complex ATM systems, less complex dispatch systems for ground services, human agents like air controllers and service dispatchers and things: the aircraft and likely many others.

V. BENEFITS: MANAGEMENT OF SYSTEM CRITICALITY

In the scene drawn in Figure 2 interference occurs in the second leg, hours ahead of the event planned at airport 4. Since there is obviously plenty of time to organize response offline - what is the benefit of (almost) real-time re-scheduling in this case? Actually it is the "criticality" of the system, a major control parameter of managing complex systems.

A. Benefit of Real-Time Maintenance of Rotations

Effective response to unexpected events implies that (1) non-expected states of operations occur (and that respective information is valid), and that (2) the system is "intelligent", i.e., able of finding a solution which (3) can be physically implemented: There must be leeway to re-allocate resource. Therefore flexibility (buffers, slack, or redundancy) is the "raw material" of operations intelligence.

But flexibility is a volatile resource. In this moment it is available, in the next it is not: I.e., decisions made in the scene of Figure 2 are bets on the flexibility available 10 hours later. And finally flexibility may be "out of stock".

The benefit of real-time maintenance of aircraft rotations is hedging these bets over the time left – and with this the overall efficiency of the system! There is no steady state in aviation operations. There is constant change only. Even if all internal parameters are controlled (very unlikely) there are enough external ones. Given a threefold of current traffic thousands of maintenance conferences will run in parallel and the "flexibility status" of the system will fluctuate.

B. Criticality

Criticality is a decisive control parameter of managing a complex system. The concept has been coined in physics where it defines the scale-free point of a phase transition (e.g., from liquid to solid) or the transition from stability into instability of a pile of sand or of snow forming an avalanche. [9] In the meantime this concept has been adapted by many sciences, among others in economics, in history science [10] or in business [11].

As a result from experiences and case studies, in the context of the new concept we can define:

- criticality as phase of transition amid capability and incapability to act due to exhaustion of flexibility.
- Intelligent real-time service maintenance (organized in SMCs) as a tool to actively manage criticality.
- the role of the aircraft as a 'supervisor' of criticality management with respect to rotations' efficiency.

The parameter of criticality focuses intelligence on the system-wide management of the most critical resource: flexibility (for an example see [12]). It is to be expected that this holistic approach combined with aircrafts which actively manage their rotations and related interdependencies will increase the economic efficiency of the overall system.

C. Focus of further Research

Resources of aviation systems are massively distributed in terms of functionality, space, organization or time – as flexibility is: Successfully responding to unplanned event may require coordinated, timely action of resources providing different functionality at different places, controlled by different organizations. In accordance with the market-based multi-agent approach explained above managing criticality equals managing liquidity (the volume of circulating money) by a central bank. This induces questions like

- How can flexibility be measured and criticality be estimated?
- Do operations' processes and performance (costs, quality, resilience …) exhibit "typical" patterns?
- Can patterns of causal behavior be exploited respectively how will non-causal patterns be treated?
- How does the distribution of flexibility (e.g., buffers) affect measuring and managerial options?
- How can SMCs be efficiently organized and technologically facilitated?

Answers to these questions will have impact to a theory of augmented intelligent organizations and the theory of volatile resources and both research as well as implementation will have to rely on technological advancements.

VI. COMPUTING STRATEGIES

In the past, ATM has not yet been apprehended as a domain of High End and High Performance Computing. High Performance Computing can be essentially defined to make use of the current high end resources available for a specific purpose. Making use of these resources can help to solve the performance barriers for practical ATM implementations in a next stage of development.

There are many practical problems with ATM systems that require immense computing power, for example, solutions that have to consider a large number of mesh points or locations need a huge number of operations to be calculated. On the other hand, one single processing step can otherwise afford a huge amount of memory. Complexity and state of basic high end technological development so far refrained from considering HPC technologies and HPC resources for implementing the components needed. With the last year's improvements in understanding these complex systems, integrated High End Computing has got into the focus of development. From the past studies we understand:

- how to create a SOA concept for rotation management, compatible to the SESAR SOA ATM-model.
- how to create collaboration models for system and architectures management and operation.

The main research topics resulting include:

- Distribution, job allocation to distributed resources.
- Capacity constraints versus size and granulation of problem.
- Robustness of algorithms and overall systems.
- Security of information and computing.
- Management and operating of HEC and HPC networks and resources.

The research program being defined by these issues includes the main sections (a) collaboration, management, and operating issues, (b) trust in information and computing, and (c) robustness and criticality.

 ISBN: 978-1-61208-161-8

When an unforeseeable change within existing planning occurs, the triggering of schedule modifications events from airplanes will be a suitable means for improving capability to respond. For optimizing the processes and sequences it is necessary to develop a performance based approach using HEC and High Performance Computing (HPC) strategies.

A. Collaboration, Management, and Operating

The resulting conceptual work used is based on the experiences and case studies done within collaboration projects over the last years. Based on the collaboration framework operation and management can consider multidisciplinary collaboration and legal aspects and integrate Service Oriented Architectures (SOA) and Resources Oriented Architectures (ROA) as with the GEXI framework studies [13, 14]. With the common heterogeneous structure necessary to build networked systems naturally strengths, facilities, and capabilities of disciplines, services, and resources provider groups differ. Collaboration aspects are the basic requirement for efficient and reliable systems engineering and maintenance, especially with complex multidisciplinary distributed systems and algorithms.

Two general computing paradigms and derivative combinations are available for organizing and particularly for coordinating across SMCs envisioned: ground-based computing and mobile airplane-based computing. In both cases compute requests have to be scheduled. In the case of ground-based solutions, requests and data will have to be sent to a ground based computing infrastructure. In the mobile airplane-based case a request has to be scheduled in order to get up-to-date information from the ground-computing and do pre-calculation on-board. Both architectures are clearly defined by capacity computing requirements.

B. Trust in Information and Computing

The implementation for a mission critical logistics computing chain has to rely on fast broadband networks and a secure network infrastructure which first of all needs to be interoperable with standards defined by SESAR or NextGen. Information exchange can be handled by means of verification [14]. The implementation considers signatures from a Certification Authority (CA) and checksums. The communication network used for air-ground communication will preferably be based on a dedicated network, highly protected, among other things against intrusion and Denial of Service (DoS) occurrences.

C. Robustness and Criticality

In order to work out in-time compute tasks, communication and computation have to be completed within less than about five minutes wall clock time. Certified information transfer is the base for secure any reliable information system usage and computing. In any case with mission critical implementations of distributed computing and mobile components a fallback solution is essential, based on data replication and emergency procedures. As non deterministic aspects will reduce the robustness of systems, the problem size is reduced to problem cells with defined conditions, like resources consumption and wall clock times, so that safe fallback states will be available for ongoing operation. This will facilitate the application of control procedures and intelligent automation of required operational tasks.

D. Concepts and Requirements

Various strategies and technologies can be used to make practical use of integration with HEC resources. Current base for providing computing power are:

- High End Computing (High Performance Computing, Supercomputing).
- Distributed and Services Computing (Cloud Computing, Grid Computing, Distributed Computing, MultiCore and ManyCore technologies).

The requirements to exploit high end resources and mobile highly performant resources leads to interlink intelligent systems with High End Computing and Distributed and Services Computing resources, mostly for capacity computing purposes. Integration of information and computing systems is commonly implemented using framework interfaces. Therefore a modularization of interactive and batch access to resources is mandatory. The solution is based on flexibility with parallelization: Loosely and massive parallel computing can be achieved using dynamic event triggering and on the other hand MPI and OpenMP implementations.

Regarding data and information exchange there is a strong need for dedicated high end networks. As with the environment middlewares and modular facilities, like accounting and communication services are needed for practical operation. Essential system components have to be build on common standards. Network, system, and data security is most important for mission critical systems.

VII. CONCLUSIONS AND FUTURE WORK

With the results presented in this paper we have shown that the new paradigm with rotation-oriented Air Traffic Management for extended collaborative ATM can be a solution for future economic management. High end computing resources, communication networks, and High Performance Computing architectures are used to deliver the compute power needed. The concepts on criticality do support the need for mission critical systems. Operating complex dynamical system architectures, computing and information system resources can be handled with flexible collaboration frameworks in order to achieve efficient complex systems integrating information system technology and the world of “things that think” as well. This will allow a flexible and economic change and risk management and sustainable operation concepts. Advanced communication system components, verification methods, and mission critical communication networks are utilized to interlink distributed compute, storage, and High End Computing resources and create a fast, secure, and reliable operating system environment.

The goal for the near future is to make use of HEC resources like cloud computing and future High Performance computing systems. High end resources can be integrated with information, communication, and logistics systems by creating appropriate interfaces and services. The systems supported will gain access to distributed computing and storage power not available locally under any economic aspects otherwise. The demands for High End Infrastructure as a Service and provisioning of services will lead to a definable level of reliability and quality (QoS, QoD, QoE).

For the next generation of large complex intelligent systems we need fully integrated network and component management solutions. Following the technology improvements of services implementation, the mid-term focus is the integration of "High End Computing as a Service". In the future, developments and concepts will focus on bringing this concept into life with industry scale systems.

ACKNOWLEDGEMENTS

We are grateful to all partners in past and current programs for fruitful discussions and collaboration in projects and project developments contributing to concepts presented in this paper. Particularly we want to name Airbus R&T Management, Hamburg, DE; KölnBonn-Airport, Cologne, DE; Modular Galley Systems GmbH, Elchingen, DE; Vienna University of Economics and Business, Institute for Transportation and Logistics Management, Vienna, AU; FGM-AMOR, Graz, AU; Controlling Chaos Technologies, Hannover, DE; Knowledge Genesis, Samara / Swisttal, RU/DE; Institute for Control of Complex Systems / Russian Academy of Sciences, Samara, RU; Manchester Business School, Centre for Service Research, Manchester, UK; Rzevski Solutions, London, UK; Intelligent Communications and Broadband Networks Laboratory (ICB-Net) Athens, GR; Westfälische Wilhelms-Universität Münster, Zentrum für Informationsverarbeitung, Münster, DE; European Legal Informatics Study Programme, Partner University: Hannover, DE; North-German Supercomputing Alliance (HLRN), We also owe our thanks to the German Federal Ministry for Economics and Technology as well as to the German Aerospace Center / Project Agency for financial and managerial support of related research projects.

REFERENCES

[1] C. Scherer, “Executive VP Strategy & Future Programmes”, Airbus, quoted in D. Thisdell, “*Aircraft must be smart swimmers to make next-gen ATM work*”, Flight International 14/01/11 News Article.

[2] P. Hotham, “SESAR & NextGen Working together for Aviation Interoperability”, Presentation to the Royal Aeronautical Society Annual Conference, London, April 14th 2011; original source: ICAO, International Civil Aviation Organization, 2011, URL: http://www.sesarju.eu/news-press/news/sesar-ju-royal-aeronautical-society-annual-conference-815 [accessed: 2011-05-10].

[3] booz & co., “Final Report, Adequate and Innovative Funding Mechanisms for the Preparation and Transition to the Deployment Phase of the SESAR Programme”, Sept. 2010, URL: http://ec.europa.eu/transport/air/sesar/doc/2-2010_09_28_funding_and_financing_of_sesar.pdf [accessed: 2011-05-20].

[4] M. Rauer, S. Karadgi, D. Metz, and W. Schäfer, “Real-Time Enterprise – Schnelles Handeln für produzierende Unternehmen”, in *Wirtschaftsinformatik, Mai 2010*, download / purchase link URL: http://www.wirtschaftsinformatik.de/index.php;do=show/site=wi/sid=c51138b3f49d6d3de7ae7bf711bde1ac/alloc=12/id=2730 [accessed: 2011-05-20].

[5] G. Rzevski, “A practical Methodology for Managing Complexity”. Emergence: Complexity & Organization - An International Transdisciplinary Journal of Complex Social Systems. Vol. 13, Nos. 1-2, 2011, ISSN 1521-3250, pp. 38-56.

[6] “Radio Frequency Identification and the Internet of Things”, European Commission, Information Society, URL: http://ec.europa.eu/information_society/policy/rfid/index_en.htm [accessed: 2011-05-20].

[7] Things That Think, “TTT Vision Statement”, URL: http://ttt.media.mit.edu/vision/vision.html [accessed: 2011-05-14].

[8] Car to Car Communication Consortium, URL: http://www.car-to-car.org/ [accessed: 2011-05-14].

[9] K. Christensen and N. Moloney, “Complexity and Criticality”, Imperial College Press Advanced Physics Tests – Vol 1, 2005, ISBN: 978-1-86094-504-5.

[10] R. Cliver, “Tremors in the Web of Trade: Complexity, Connectivity and Criticality in the Mid-Eighth Century Eurasian World”, The Middle Ground Journal, Number 2, Spring 2011.

[11] “Complexity-Based Crisis-Anticipation for Corporations, Investors and Policy-makers”, Ontonix, 2008, URL: http://www.ontonix.com [accessed: 2011-05-20].

[12] U. Inden, R. Franken, “Final Report: CESSAR – Configuration and Evaluation of Service Systems with RFID”, Cologne University of Applied Sciences, (Sub-Research project 2011-5-7 in collaboration with Airbus, EADS. Funding: German Federal Ministry of Economics and Industry, Program Management: PT DLR Cologne, Project Number: MT06005), (in publication).

[13] Rückemann, C.-P., “Integrating Future High End Computing and Information Systems Using a Collaboration Framework Respecting Implementation, Legal Issues, and Security”, in *International Journal on Advances in Security*, 3(3&4):91-103,2010. ISSN:1942-2636, URL: http://www.iariajournals.org/security/sec_v3_n34_2010_paged.pdf [accessed: 2011-05-01].

[14] Rückemann, C.-P., “Envelope Interfaces for Geoscientific Processing with High Performance Computing and Information Systems”, in Proceedings of the International Conference on Advanced Geographic Information Systems, Applications, and Services (GEOProcessing 2011), DigitalWorld 2011, February 23-28, 2011, Gosier, Guadeloupe, France, pages 23-28. XPS, Xpert Publishing Solutions, 2011, ISBN: 978-1-61208-003-1, URL: http://www.thinkmind.org/download.php?articleid=geoprocessing_2011_2_10_30030 [accessed: 2011-05-20].

[15] http://www.eurocontrol.int/sesar/public/standard_page/overview.html