ON THE USE OF RFID FOR SUPPLY CHAIN SCHEDULING AND EXECUTION CONTROL

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Abstract

In this paper, we investigate the issues of establishing adaptive feedbacks between supply chain (SC) scheduling and execution from the perspectives of modern control theory. In using optimal control for scheduling stage, feedback adaptive control for the execution stage, and attainable sets for the analysis of the achievement of the planned performance in a real execution environment, we provide mathematically unified framework for SC scheduling and execution control. The proposed frame-work makes it possible to analyze the correspondence of RFID (Radio Frequency Identification) functionalities and costs to the actual needs of execution control and support problem-oriented SC adaptation for the achievement of the desired performance. The developed framework can be applied as an analysis tool for the decision support regarding the designing and applying RFID infrastructures in supply chains.

Keywords: Supply Chain, RFID, Optimal Control, Feedback, Adaptation.

Boris Sokolov's biography

Prof. Dr-Eng. Boris Sokolov, born in 1951, is a Deputy Director for research in Saint Petersburg Institute of Informatics and Automation the Russian Academy of Science (SPIIRAS). He received his M.Sc., PhD, Dr. Sc. Eng. and Prof. in 1974, 1983, 1993 and 1994 respectively. From 1966 to 1999, he has developed his military career at the A.F. Mozaisky Academy in Leningrad/St Petersburg, from a cadet to a colonel. Since 1999 he has been a professor in St Petersburg State University of Aerospace Instrumentation. In 2008, he became an honoured scientist of Russia. He is the author and co-author of 3 books on systems and control theory and of more than 200 scientific works published in various academic journals. Professor B. Sokolov supervised more over 50 research and engineering projects.

1 Introduction

Supply chains (SC) subject to the dynamics and uncertainty of an actual execution environment. An SC schedule may be subject to numerous unplanned changes/disruptions and, therefore, need continuous adaptation. The study by Mulani and Lee [1] showed that SC managers spend about 40-60% of their working time handling disruptions. Recent studies indicated that the scheduling needs to be considered with regard to a real SC performance and perturbed execution environment [2], [3]. The challenge is no more to schedule “ideal” optimal SCs that fail in a real execution environment, but adaptable and robust SCs [3], [4], [5].

The achievement of the planned SC goals can be inhabited by perturbation impacts in a real execution environment [6]. SC execution is subject to uncertainty at the planning stage and disruptions at the execution stage. Therefore, SCs are to be reliable and flexible enough to (1) ensure agility and (2) to be able to adapt their behavior in the case of perturbations impacts in order to remain resilient by recovering disruptions once disturbed [7].

Modern developments in information technologies (IT) such as RFID (Radio Frequency Identification), SCEM (SC Event Management) and mobile business provide a constructive basis to incorporate the stages of SC planning and execution. However, the IT serve in SCs as organizational systems the decision-support role (and not automatic decision execution role). Hence, the analysis frameworks for the decision support regarding the designing and applying IT, incl. RFID, infrastructures in SCs are practically needed.

The existing studies underline that, along with numerous potential benefits from RFID utilization, the expectations from RFID utilization and reality are frequently parted [8]-[14]. RFID does neither explain nor solve the fluctuations of customer demand, the delays in transportation, the level of inventory, etc. [10], [14], [15]. It identifies and processes the data in the volume according to the tags, readers and middleware functionalities and at the places where they are installed.

RFID also does not propose and control actions that should be taken to adapt a SC in the case of changes or disruptions at the execution stage. Quality of adjustment adaptive actions’ efficiency at the execution stage depends on two factors: (1) control actions that are taken in operations’ execution dynamics and (2) control actions that have been taken at the planning stage. Hence, the planning and execution models are to be inter-reflected, which means, in both of the models, that the decision-making principles of the other model are to be reflected. The preferable way to ensure such integration is to apply the same modeling methods [16]. In these settings, the extensive development of approaches and models to dynamic SC scheduling under the attracting adaptation methods is becoming a timely and crucial topic in SCM.

It is quite natural that the designing RFID infrastructures should be interconnected with the analysis of management issues in SCs to achieve the consistency of the RFID costs and impacts on the SC performance. Surprisingly, there is a gap in this research direction. The application of RFID for SCM is frequently not supported by the analysis of the correspondence of RFID functionalities and costs to the actual needs of execution control and SC adaptation for the achievement of the desired performance. This frequently results in redundant or not justified investments in RFID or negative assessment of RFID project results [14], [15], [17]-[20].

In this study, we investigate the issues of establishing adaptive feedbacks between SC scheduling and execution from the perspectives of modern control theory. The aim of this paper is neither to provide a rigor mathematical formulation nor a novel RFID data management infrastructure, but to deliberate conceptually and to approach the existing gap between the management and IT levels from constructive engineering positions and formal methods.

2 Integrated Analysis of the SC scheduling and RFID-based execution control

The main question in the proposed execution adaptation approach is to define rules what control actions should be taken by what deviations to maintain the planned performance. In addition, we emphasize that these actions are strongly interconnected with the RFID infrastructure of SCs. Hence, a method is required to consider simultaneously: (1) SC performance and adaptation and (2) control actions (RFID functionality) and perturbation impacts, and (1) and (2) together (see Figure 1).

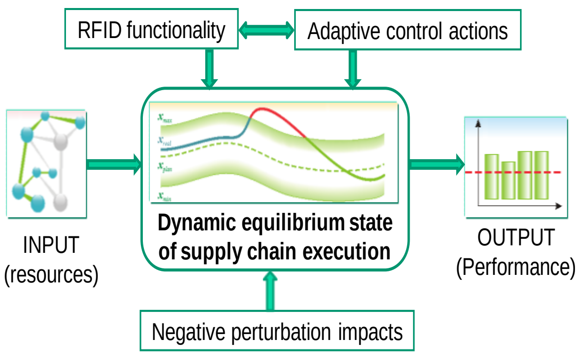

Fig 1. SC execution control

To approach these complex interrelations, we propose to use the concept of SC global stability and the method of attainable sets. Global stability is the ability of an SC to maintain such an execution trajectory which allows the achievement of the planned output performance despite of perturbations in a real execution environment with the help of corresponding control adjustment actions. This approach commits to principles that are laid down in the globally stability by Lyapunov, hyperstability by Popov, which allows uncertainty in dynamics, the system's parameters, and control actions [21], [22].

In the approach, stability is considered as a dynamic property that emerges through feedback loops. Hence, stability can be considered as a system behaviour property that should be maintained despite perturbation influences by means of corresponding adaptive control actions. This approach commits to stabilizing adaptive systems [23]. As such, stability becomes interconnected with adaptability within the so-called stabilizing feedback control.

Let's consider the general logic scheme of decision making on the elimination of disturbances in SCs.

Step 1. *The analysis of conformity of actual and planned goals.* At the given stage, a comparison of the actual values of parameters and the goals of SC execution with the planned values is carried out. If the arisen deviations in aggregate do not lead to a loss of stability and the SC maintains a stable state, necessities for correcting control influences are not present. Otherwise, a transition to step 2 is necessary.

Step 2. *Alerting managers about the necessity for taking regulating decisions.* In the case where perturbation influences lead to a loss of stability and the SC loses its stable state, regulating control influences. On the basis of the actual stability analysis data and the planned scenarios of recovering the SC operability, a certain set of actions on the restoration of a planned (or wished for) course of events is proposed to managers.

Step 3. *Decision making on the SC adaptation.* Taking operative decisions is based on a system comparison of various kinds of control influences with various levels of parameter deviations of the SC gained on the basis of the stability analysis.

The quantitative of model global stability analysis is based on the control theory-based dynamic interpretation of the SC's functioning process and attainable sets. The results of the stability analysis can be brought into correspondence with different SC adjustment measures with regard to SC schedules. In addition, the usage of attainable sets makes it possible to quantify the stability in the form of a stability index.

The essence of a stability index calculation is based on the construction and comparison of two attainable sets (the area of admissible values of SC performance metrics and the approximated area of SC attainability under the influence of perturbation factors). The stability index is expressed as the area of intersection of these two rectangles

Based on the quantification of stability with the help of attainable sets (AS), it becomes possible to compare different SC and RFID structures with different scope and scale of the resource consumption regarding both the performance indicators and stability. This analysis can be performed with regard to different execution scenarios and different areas of control impacts in order to achieve the planned output performance in a real perturbed execution environment. Hence, the results of the stability analysis can be brought into correspondence with different SC performance and resource consumption scenarios.

Summarizing, we emphasize that the proposed approach makes it possible to approach the issues of both (1) analysis of the mutual correspondence of the investments into RFID infrastructures and the SC performance and (2) analysis of the selection of appropriate SC adaptation actions responding to changes in SC execution environment..

3 Experimental Environment

3.1 Analysis of the compliance of an RFID infrastructure with the requirements for execution control

For the investigating of the RFID-based feedbacks within the developed modeling framework, a simulation program (Fig. 2) and experimental stand with a transport network and some production and warehouse facilities is currently under development (the transportation network with an RFID infrastructure is already elaborated).

We note that the RFID experimental environment is not intended (at least, in its current version) to the full implementation of the developed models. It is much simpler as the modeling framework and serves to gather experimental data for the modeling complex. The modeling complex itself is implemented in a special software environment, which contains a simulation and optimization "engine" of SC planning and execution control, a Web platform, an ERP system, and APS system, and a SCEM system. The kernel of the computational framework is the decision modeling component, that is, the simulation and optimization "engine".

The schedule optimization is based on an optimal control algorithm that is launched by a heuristic solution, the so-called "first approach". The seeking for the optimality and the SC scheduling level is enhanced by simultaneous optimizing and balancing interrelated SC functional, organizational and information structures.

The schedules can be analysed with regard to performance indicators and different execution scenarios with different perturbations. Subsequently, parameters of the SC structures and the environment can be tuned if the decision-maker is not satisfied with the values of performance indicators. In analyzing the impact of the scale and location of the adaptation steps on the SC performance, it becomes possible to justify methodically the requirements for the RFID functionalities, the stages of an SC for the RFID elements locations, and the processing information from RFID.

In particular, possible discrepancies between actual needs for wireless solution of SC control problems and the total costs of ownership regarding RFID can be analyzed. In addition, processing information from RFID can be subordinated to different management and operation decision-making levels (according to the developed multi-loop adaptation framework). Pilot RFID devices with reconfigurable functional structure are developed.

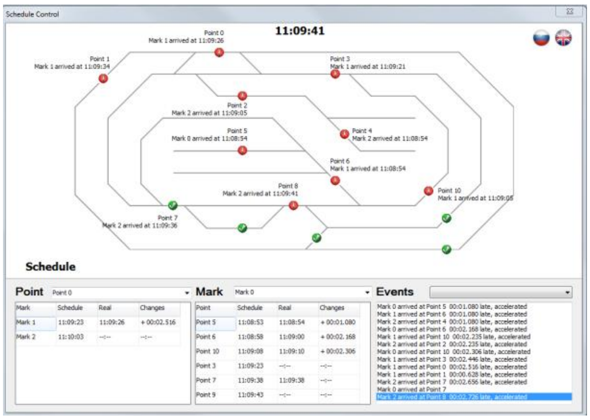

Fig. 2 Screenshot from the transport network simulation program

3.2 Observations from the designing an RFID infrastructure

Let us discuss some observations and results. At the first stage of the establishing the experimental stand, we came to the conclusion that traditional networking technologies tend to be expensive for integration of many readers. In this work some efforts have been made to analyze and optimize RFID network structure to be more suitable for SC control tasks.

The most valuable property of RFID technology is wireless data interchange with objects (tags) without power source (passive RFID). Main advantages of passive tags such as low cost, size, weight, make them ideal candidates to be agents for data accumulation and transmission along with physical objects [24]. Most of tag access protocols are international standards. This improves interoperability of readers and tags of different manufacturers. Cost of a tag is continuously decreasing that enables their applications in real life.

Although main function of readers is reading data from tags, readers can also perform many additional functions such as writing data, setting password, locking data and killing tag. However, readers do not have well defined protocols to be controlled with. Each manufacturer offers its own solution for data interchange between a reader and computer. In fact, there is no interoperability between readers of different manufacturers.

One of the most important issues from the system integration point of view is a ratio of readers being used to the computers which control them. Today, only a few readers can be directly connected to a single PC. However, future RFID systems will need to be distributed RFID networks.

For many RFID systems with a single reader the wider reading range is the preferable way. However, the wide detection range decreases the resolution for locating objects. For pure storage operations, the wide range has two drawbacks. First, increased number of tags located in the field of the reader decreases the reading performance and enlarges the storage cycle. This has negative effects on the systems designed to monitor especially valuable objects. Second, the wide range is equivalent of poor resolution in case of localizing objects. So, for the tasks where object location is important (e.g. tasks of object storage and logistics) many readers are required to arrange a wide zone totally covered with RFID field. Distributed reader networks tend to be expensive if based on readers optimized for the wide range operation.

Several changes in system architecture can be proposed to achieve desired properties of the system. First, readers should be integrated in a special bus that will provide both power and data path to readers using the single coaxial cable to be easily mounted and minimize connections. Second, software can be split according to client server model based on TCP/IP sockets using well-defined portable interface. Thus, application programmers can use the same command set to access any reader in a bus behind the server. Since the TCP/IP is an Internet protocol user applications can be spread over the network and talk to both local and remote servers [25].

The Sim-Sim architecture [26] can be treated as a basement of distributed RFID networks which will be the future of RFID technology. Once the readers get inexpensive, other factors start to determine overall system cost. Sim-Sim architecture potentially offers both hardware and software solutions to reduce these costs. Existing readers can be easily integrated into Sim-Sim Server using back-end drivers. Thus, Sim-Sim architecture provides both reader manufacturers and application programmers with cost-effective, stable, scalable and portable RFID solution.

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4 References

[1] Mulani, N.P., Lee, H.L. (2002). “New Business Models for Supply Chain Excellence”. In: Mu-lani, N., Achieving Supply Chain Excellence Through Technology (Vol. 4). San Francisco, Montgomery Research, Inc.

[2] Proth, J.M. (2006). Scheduling: New trends in industrial environment, In: Dolgui, A. et al. (Eds.) Information Control Problems in Manufacturing. Elsevier, Amsterdam, 41-47.

[3] Chauhan, S.S, Gordon, V., Proth, J.-M. (2007). Scheduling in supply chain environment. European Journal of Operational Research, 183(3), 961-970.

[4] Van de Vonder, S., Demeulemeester, E. and Herroelen, W. (2007). A classification of predictive-reactive project scheduling procedures. Journal of Scheduling, 10(3), 195-207.

[5] Ivanov, D., Sokolov, B. (2010) “Adaptive Supply Chain Management”, Springer, London et al.

[6] Kleindorfer PR, Saad GH (2005) Managing disruption risks in supply chains. Prod Oper Manag 14(1):53–68.

[7] Christopher, M. (2005), “Logistics and Supply Chain Management: Creating Value-Adding Networks”, Financial Times, Prentice Hall, Dorchester.

[8] R. Angeles, “RFID technologies: supply chain applications and implementation issues”, Inf. Syst. Manag., winter, pp. 51-65.

[9] S. Chalasani, R.V. Boppana, “Data architectures for RFID transactions”, IEEE Trans. Ind. Informat, vol. 3, no. 3, pp. 246-257, august 2007.

[10] Huber, N., Michael, K., McCathie, L.Barriers to RFID adoption in the supply chain (2007) IEEE RFID Eurasia, pp. 1-6. 5-6 September, Istanbul, Turkey

[11] M. Henseler, M. Rossberg, G. Schaefer, “Credential management for automatic identification solutions in supply chain management”, IEEE Trans. Ind. Informat, vol. 4, no. 4, pp. 303-314, November 2008.

[12] Rong, C., Cayirci E. RFID security. Computer and Information Security Handbook, 2009, pages 205-221.

[13] H. Lee, Ö. Özer, “Unlocking the value of RFID”, Prod. Oper. Manag., vol. 16, no. 1, pp. 40-64, 2007.

[14] M.L. Chuang, W.H. Shaw, “RFID: integration stages in supply chain management”, IEEE Eng Manag Rev, vol. 35, no. 2, pp. 80-87, 2007.

[15] Cannon, A.R., Reyes, P.M., Frazier, G.V., Prater, E.L. RFID in the contemporary supply chain: Multiple perspectives on its benefits and risks. (2008) International Journal of Operations and Production Management, 28 (5), pp. 433-454

[16] Ivanov, D. (2009a), “DIMA – A Research Methodology for Comprehensive Multi-Disciplinary Modelling of Production and Logistics Networks”, International Journal of Production Re-search, Vol. 47, Nr. 5, pp. 1133-1155.

[17] M. Tajima, “Strategic value of RFID in supply chain management”, J. Purch. Supply Manag., vol. 13, pp. 261-273, 2007.

[18] Wamba, S.F., Chatfield, A.T A contingency model for creating value from RFID supply chain network projects in logistics and manufacturing environments. European Journal of Information Systems Volume 18, Issue 6, December 2009, Pages 615-636.

[19] Helders, B. & Vethman, A.J. (2003), “Beyond 2005: How RFID Will Change the Global Supply Chain”, Chain Store Age; VOl. 79, No. 12; pg 39–48.

[20] S. Li, J.K. Visich, “Radio frequency identification: supply chain impact and implementations challenges”, Int. J. Int. Supply Manag., vol.2, no. 4, pp. 407-424, 2006.

[21] Casti, J.L.: Connectivity, complexity and catastrophe in large-scale systems. Wiley-Interscience, New York and London (1979).

[22] Liao X., Wang L., Yu P. Stability of Dynamical Systems. Elsevier. Amsterdam et al., 2007.

[23] Narendra K.S. (2005), Stable adaptive systems (2nd edition). Dover.

[24] Dias, J.C.Q., J.M.F. Calado, A. Luís Osório, L.F. Morgado. RFID together with multi-agent systems to control global value chains. Annual Reviews in Control, Volume 33, Issue 2, December 2009, Pages 185-195.

[25] EPCglobal Inc., The EPCglobal Network: Overview of Design, Benefits, & Security, 2004, Tech. Rep.

[26] V. Dashevsky, B. Sokolov “New concept of RFID reader networks structure: hardware and software architecture”, Proc. Of International Conference on Ultra Modern Telecommunications – ICUMT-2009, Saint-Petersburg, Russia, October 2010.