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Real Time Management in Manufacturing Systems: A State-of-the-art Review

Terminology, Definitions, and Application Areas

Abstract

The paper presents an introduction to the real time management considering the meta-theoretical framework for the real time management discipline investigation, the terminology and definitions, and application areas through the state of the art review. The paper presents also some directions for the future work.

Keywords

Real Time Management, State-of-the-Art, Terminology and Definitions, Manufacturing Systems, Management, Information and Communication Technologies

1. Introduction

Real time management (RTM) is an emerging management approach building (1) on recent Information and Communication Technologies (ICT) developments such as RFID technologies and other wireless sensor networks, internet of things and other ubiquitous technology devices, that enable real time massive data collection and processing, from intra- and extra-company environment, and (2) on requirements to deal with turbulent environment.

The main objective of RTM is to enable quick adaptation to the dynamic external (market) and internal (organizational) changes and it uses real time data collection, real time data processing and analysis, and real time decision making, resulting in dynamic reconfigurations of production plans, scheduling plans, process plans, organizational architectures, knowledge assets and, virtually, any type of resources, or "tangible and intangible assets", and by a number of criteria such as productivity, cost, agility, environmental, quality, sustainability, among others, intra- and inter-enterprises, including challenges for RTM of emergent organizational forms such as ubiquitous and cloud enterprises, crowdsourcing and other social networks-based organizational forms, which could be characterized as a large open networked systems, "not bounded to a predefined size", and complex systems.

RTM challenges the traditional planning discipline that sees planning as a controlling instrument, virtually not functional in turbulent environment. However, it is still not clear what are the real capacities and limits of RTM approach, being actual RTM applications mainly technologically enabled and heuristically-, experientially- and intuitively-driven.

This paper aims to present a review of some aspects of theoretical and practical developments of RTM in Manufacturing Systems, namely, the

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aspects of terminology, definitions and application areas, as a new manufacturing system management approach for global and sustainable manufacturing in turbulent environment.

2. Relevance

The relevance of RTM can be evaluated, at an initial phase, according to the references to RTM through a number of papers in collections of some of the world leading publishers (Elsevier, Emerald, Jstor, Taylor and Francis, Wiley, ACM, IEEE, Springer) per year and per RTM term, presenting growing intensity of research along the years (Figure 1).

Before 90's, the RTM concepts was present in a high number of papers. Hypothetically, the research of RTM decreased due to the restriction of technological means. The research on RTM has been growing in the last decade perhaps due to the recent ICT developments.

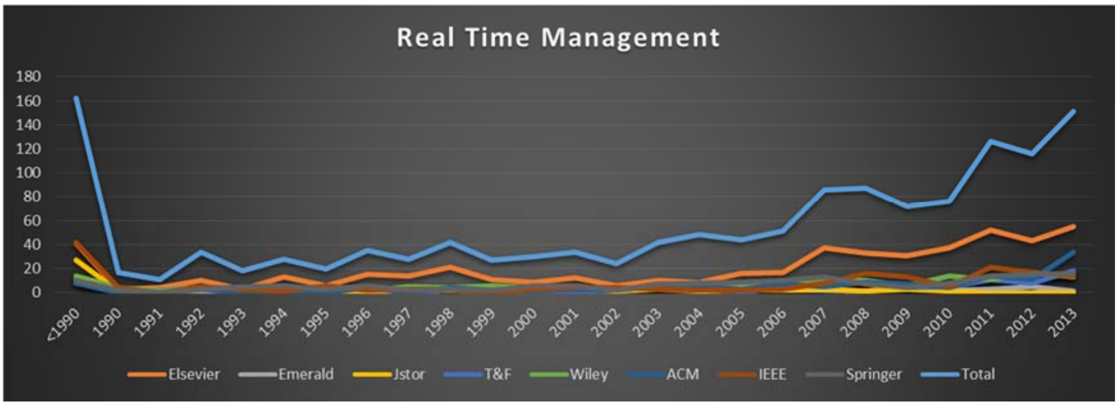

Figure 1. Number of papers by search term "Real Time Management" in different publishers

Some projects were financed and developed by a number of international research programs concerning the adoption of RTM, see e.g. REAL TIME MANAGEMENT SYSTEM[1], NRG4CAST[2], AQUAPOL[3] and FUTUREFARM[4]. Concerning the recent developments on ICT in manufacturing systems, the ICT Work Programme 2010 had a topic designated "Smart Factories: ICT for agile and environmentally friendly manufacturing" focusing the RTM of information (EC, 2009). Pfeiffer, Kádár, Monostori & Karnok (2008) refers that the main goal on R&D projects is "to research and develop new methods for the real-time management of complex technical and economic systems that work in changing, uncertain environments", and to test the research results in an industrial environment.

3. Meta-theoretical frameworks for the RTM SoA presentation

3.1. Meta-theoretical frameworks for RTM

Meta-theoretical framework is "a critical framework for analyses and create a structure that enables elements of different theories and concepts to be located relative to each other" (Love, 2000). Concerning the RTM, the purpose of the meta-theoretical framework for RTM is to provide a better understanding of RTM as well as to improve the capability for effective and efficient development, implementation and validation of RTM.

There could be different meta-theoretical frameworks. For example, one could be based on more traditional approach that refers to functional and application domains of RTM. Another interesting approach could be based on Love's (2000) "abstraction levels" meta-theoretical framework for design theory, that is selected for presentation of RTM discipline.

[1] EU Research Project, ENDEMO C Program: http://cordis.europa.eu/projects/rcn/15938_en.html

[2] EU Research Project, FP7-ICT Program: http://cordis.europa.eu/projects/rcn/106342_en.html

[3] EU Research Project, LIFE 2 Program: http://cordis.europa.eu/projects/rcn/39352_en.html

[4] EU Research Project, FP7- KBBE Program: http://www.futurefarm.eu/

3.2. RTM abstraction hierarchy framework

For the RTM meta-theoretical framework, five abstractions levels are defined, on this stage of research:

1. *Description*: RTM terminology, definitions, elements and objects (referring to applications areas),
2. *Models and behaviour*: models and functions, performance measures,
3. *Mechanisms of choice*: management of RTM,
4. *Methods and tools*: RTM implementation instruments (hardware, equipment, architectures, strategies for implementation, design for RTM)
5. *Epistemology*: how the knowledge on RTM is acquired and used, validity and coherence of knowledge on RTM in social context, RTM phenomenology, critique, human and social dimension, and other epistemological issues.

Concerning the above referred abstraction levels, the 5 hieratical levels are detailed such as:

RTM description: terminology, definitions, elements and objects, referring to application areas and functional domains of manufacturing systems, such as design, planning, control, management, production, maintenance, quality, marketing, Customer Relationship Management (CRM), public sector, education, and others.

RTM models and behavior: dynamic scheduling and stability, dynamic reconfiguration and reconfigurability, real time decision making, problem solving, collaborative decision, interoperability and data analytics, intelligence and heuristics, performance measures, RTM of scalability, for tangible and intangible assets, for co-design and co-creation, for lean, agile and chaordic manufacturing systems, frameworks for RTM, and others.

RTM mechanisms of choice: RTM management, lean, agile, and chaordic RTM, RTM organization/architectures for intra- and inter-enterprise, individual and group (concurrent and collaborative) RTM, real time manufacturing data management, manufacturing Big Data management, scalable RTM, RTM services systems, frameworks for RTM, business models, and others.

RTM methods and tools: sensors, communication networks, processors, ubiquitous and "calm" technologies, sensor networks and large-scale sensor networks, data acquisition, collection, transmission, synchronization and processing (pre-processing, post-processing, analytics, decision making), real-time traceability visibility and virtuality and decision support systems, real-time communication and interaction with decision support systems, Internet of things, Cyber-physical systems, RTM protocols, interoperability for RTM, RTM Dashboards, and others.

RTM epistemology and ontology: RTM knowledge acquisition, use and validity, RTM-based (planning and scheduling) paradigm change and "mind-shift", RTM in social context and value, RTM phenomenology and critique (e.g. limits and sense), roadmaps for RTM science and technology development and implementation, and others.

In this paper, the first RTM abstraction level is presented: *RTM Description: Terminology, definitions and applications areas*.

4. RTM terminology, definitions and application areas

4.1 RTM terminology and definitions

The term "real time", "real-time" or "realtime" (*noun*) is "the actual time during which something takes place" and the "first known use of REAL TIME" was on 1953[5]. The term of RTM definition depends of different assumptions and interpretations that "are too broad", for example:

> *"A real-time management information system – i.e., one that delivers information in time to do something about it"* (Burck (1965) cited by Dearden (1966)). or

> *" A real-time defined as one that controls an environment by receiving data, processing them and returning results sufficiently quickly to affect the functioning of the environment at that time"* ((Martin, W (1965) cited by Dearden (1966)).

[5] Merriam-Webster Dictionary: http://www.merriam-webster.com/dictionary/realtime

Such broad definitions are criticized by Dearden (1966): “The problem with both of these definitions is that they are too broad. All management control systems must be real-time systems under this concept. It would be a little silly to plan to provide management with budget performance reports, for instance, if they were received too late for management to take any action”. It means that the RTM terms and definitions should be more distinguishable in relation to other traditional management paradigms. Dearden (1966) cited Martin’s (1965) definition of real-time as a better one, which is presented in Table 1.

A number different terms, that were defined and explored along the time, could be found in literature. A list of selected terms and definitions is presented to demonstrate the different contexts and terms referring to RTM (Table 1).

Table 1. RTM selected terminology and definitions

Real time management selected terminology and definitions	*Reference*
Real-time - "The delays involved in batch processing are often natural delays, and little advantage can be obtained by reducing them. But elimination of the necessity for such delays opens new and relatively unexplored possibilities for changing the entire nature of the data processing system - from a passive recorder of history (which, of course, is valuable for many decisions) to an active participant in the minute-to-minute operations of the organization. It becomes possible to process data in realtime - so that the output may be fed back immediately to control current operations. Thus the computer can interact with people on a dynamic basis, obtaining and providing information, recording the decisions of humans, or even making some of these decisions."	Martin (1965) cited in Dearden (1966)
Real-time system – when referred to a computer system should have the following characteristics: “(1) Data will be maintained "on-line." (…) (2) Data will be updated as events occur. (…) (3) The computer can be interrogated from remote terminals.”	Dearden (1966)
Real time manager – was “coined” by Mintzberg, and “his "real-time managers" are basically concerned with maintaining the organization's internal operations, and operate primarily in the present”. Real-time management, also called *ad hoc management* – is related with “maintaining the functioning of the organization” and is “defined as a set of immediate tasks and activities directed towards maintaining the functioning of the organization”. Time, which is recognized as an important managerial resource (…), is even more important in relation to real-time management.	Borovits & Segev (1977)
Real-time management development – “combines working on the company’s real opportunities and issues with learning” in the author’s “version of management development”	Nixon (1998)
Real time management – “will mean transforming relationships inside companies” to the “intimate and immediate interconnection” of “every sphere of an organization’s activity”	Coviello, Milley, & Marcolin (2001)
Real-time mass customization – means “meeting the needs of an individualized customer market on a real-time basis”	Tien, Krishnamurthy, & Yasar (2004)
Real-time management – is used on “manufacturing execution systems” in order to “assist management staff of the production line to foresee problems or detect problems as they happen and deal with them immediately to avoid delaying production and affecting output.”	Hwang (2006)
Real time production control - has as function “to adapt the production system to the changing environment, while preserving efficiency with respect to cost, time and quality requirement” and provides “decisions for specific problems associated with part manufacturing” among others	Monostori, Kádár, Pfeiffer, & Karnok (2007)
Real-time management of supply chains – implies “effective, efficient and reactive collaboration among participating entities”, once the “parties involved (…) have their own resources and objectives”	Lau, Agussurja, & Thangarajoo (2008)
Real-time management – as one of the three main categories of “the key issues in supply chain management”	Papageorgiou (2009)
Real-time control – consists in three key issues such as “data acquisition, quick response and instantaneous feedback”	Monostori et al (2010)
Real-time management level – has the role to “monitor the planned schedules and correct for any disruptions that occur on a daily basis”	Lusby, Larsen, Ehrgott, & Ryan (2011)
Real or near-real-time information delivery – “is one of the defining characteristics of big data analytics	Tien (2012)
Real-time data management – ensures “temporal consistence data and process transactions within real-time constraints”	Diallo, Rodrigues, & Sene (2012)
Real-time management – “requires access to real-time data from all network sensors” for the “company resources” security.	Kizza (2013)

Real time management - is a real time management due to the nature of the design process, which is unpredictable and must be controlled periodically	Merlo, Vicien, & Ducq (2013)

4.2 Application Areas

RTM has been applied in many different areas, which we will partition in manufacturing and non-manufacturing areas.

Manufacturing

Assembly: In Van der Vaart, De Vries, & Wijngaard (1996), RTM information systems is referred as a one of the results of the major chances of materials procurement's role.

* Badell, Nougues, & Puigjaner, (1998) developed a methodology that “mimics the real world market”, through RTM data of the “state of the business, the process and the market”, to integrate financial and production planning.

In a manufacturing point-of-view, “applying a RFID-based ubiquitous computing model to production systems will help manufacturing companies achieve real-time management of dynamic manufacturing processes” (Chen, Tu, & Jwo, 2010).

Non-Manufacturing

Call Centers: Ridley, Fu, & Massey (2003) modelled a call center, considering their dynamic routing, “as a preemptive-resume priority queue with time-varying arrival rates”, where the call routing must consider some factors such as customer service representative silks and availability, which requires, among others, dynamic and RTM of these skills and availability.

Logistics: Jarugumilli, Grasman, & Ramakrishnan (2006) considers the use of simulations to “develop the framework for the real time control and management of inventory routing decision, under real time information control of current inventory and vehicle status (see also Qin, Miao, Ruan, & Zhang (2014)).

Coalmines: RTM was also applied in a Coalmine, through the real time information from data collected from the coalmine “as well as a simulation model of the material handling network”, which can be displayed in the control center (Figure 2), in different screens (Nageshwaraniyer, Son, & Dessureault (2011a) cited by Nageshwaraniyer, Meng, Son, & Dessureault (2011b)).

Figure 2: Control center (Nageshwaraniyer et al. 2011a)

Greenhouse control: Fisher, Heins, Ehler, & Lieth (1996) developed a decision support system that provides a model for the development of a “real-time decision support system for greenhouse control”.

Hydro-electric power systems: Following Dror (1997), Dantzig and Infanger applied “Operations Research methodology of stochastic optimization to the real time management of hydro-electric power systems”.

E-commerce: A framework to create an “economics-embedded intranet resource management approach” is provided by Gupta, Stahl, & Whinston (1998), capable of “allocating the network resources in real-time”.

Services: Nixon (1996) presents the principles for RTM development and describes a method to “facilitate the continuous improvement and learning”, in a broad “variety of settings”, such as “insurance, avionics, information technology, higher education, retail, the probation service, the prison service, local government, pharmaceuticals, health care and consulting”.

Forest Fire Management: RTM is also applied for “Planning for Forest Fire Management”. The first approach to the “problem real time management of forest fires is the Phoenix project” (Avesani, Perini, & Ricci, 2000), which simulates the environment for forest fires management in real- time, and explores the “constraints the environment places on the design of intelligent agents”.

Healthcare: Bouet, & Pujolle (2010) describes the potential challenges on RFID use in healthcare that increase safety, provides the “optimizing in real-time management” and the “support for new ambient-intelligent services”.

Fleet management system: Minis, Mamasis, & Zeimpekis (2012) modelled the case of vehicle breakdowns and proposed a new heuristic, which was tested in a real-time fleet management system. The authors presented a sample graphical user interface of the real-time fleet management system (Figure 3).

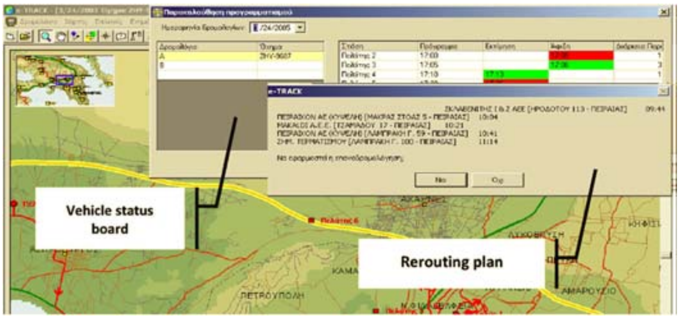

Figure 3: Sample GUI of the real-time fleet management system (Minis, Mamasis, & Zeimpekis, 2012)

Metro rail terminus: Flamini & Pacciarelli (2008) “addresses a scheduling problem arising in the real time management of a metro rail terminus”, once the rail operations management and control are “based on off-line generated timetables for every train” which working in real time “with strict adherence to these timetables”.

Education: In Zurita et al (2008), a framework was developed to “support the implementation of Collaborative Learning through Participatory Simulations” and was applied to simulation management that allows teachers assign roles to participants in a RTM way.

Foodservice management: RTM is referred as experience methodology for the advanced foodservice management course, where the students are “evaluated for their management skills” (Beldona & Ismail, 2002).

Water resources management: RTM has been studied on water resource management, as an enabler for the scheduling and efficiency improvement and for the reservoirs systems losses reducing (Hallowes, Pott, & Döckel, 2008). Hughes & Mallory (2008) presents an operational management method “based on near-real time observations” and shows the main screen of a real-time water resource management system, see Figure 4.

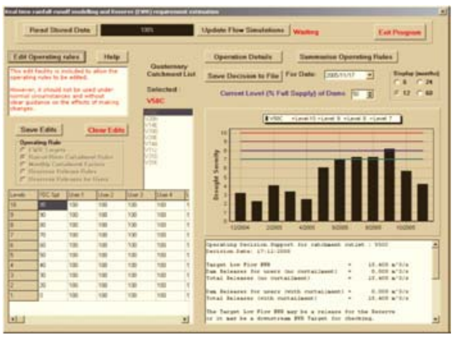

Figure 4. Main screen of the real-time water resource management system (Hughes & Mallory, 2008)

3. Conclusions

Besides the initial review of the terminology and definitions state-of-the-art it is necessary to continue investigation on RTM concepts on other abstraction levels. Special attention by the future research should be paid to how RTM may enable real-time decision making and dynamic reconfiguration of enterprises, including manufacturing systems, implying real-time alignment with the market, which is of special importance in nowadays conditions of market turbulence and uncertainty. Further, special topics of interest are related to the sustainability, referring to the "triple bottom line", that is to the environmental, economic and social sustainability.

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References

Avesani, P., Perini, A., & Ricci, F. (2000). Interactive case-based planning for forest fire management. Applied Intelligence, 13(1), 41-57.

Badell, M., Nougues, J. M., & Puigjaner, L. (1998). Integrated on line production and financial scheduling with intelligent autonomous agent based information system. Computers & chemical engineering, 22, S271-S277.

Beldona, S., & Ismail, J. A. (2002). Locus of control and its role in determining student performance in food service management. Journal of Human Resources in Hospitality & Tourism, 1(2), 27-39.

Borovits, I., & Segev, E. (1977). Real-Time Management—An Analogy. Academy of Management Review, 2(2), 311-316.

Bouet, M., & Pujolle, G. (2010). RFID in eHealth systems: applications, challenges, and perspectives. Annals of telecommunications-annales des télécommunications, 65(9-10), 497-503.

Burck, Gilber and the Editors of Fortune, The Computer Age (New York, Harper & Row, Publishers, 1965), p. 106.

Chen, R. S., Tu, M. A., & Jwo, J. S. (2010). An RFID-based enterprise application integration framework for real-time management of dynamic manufacturing processes. The International Journal of Advanced Manufacturing Technology, 50(9-12), 1217-1234.

Coviello, N., Milley, R., & Marcolin, B. (2001). Understanding IT-enabled interactivity in contemporary marketing. Journal of Interactive Marketing, 15(4), 18-33.

Dearden, J. (1966). Myth of real-time management information. Harvard Business Review, 44(3), 123-132.

Diallo, O., Rodrigues, J. J., & Sene, M. (2012). Real-time data management on wireless sensor networks: A survey. Journal of Network and Computer Applications, 35(3), 1013-1021.

Dror, M. (1997). Large-scale, high-priced applications: An introduction. European journal of operational research, 97(2), 215-219.

EC (2009), Work Programme 2010, Cooperation, Theme 3, ICT – Information and Communications Technologies (European Commission C(2009) 5893 of 29 July 2009), European Commission, Bruxelles.

Fisher, P. R., Heins, R. D., Ehler, N., & Lieth, J. H. (1997). A decision-support system for real-time management of Easter lily (Lilium longiflorumThunb.) scheduling and height—I. System description. Agricultural Systems, 54(1), 23-37.

Flamini, M., & Pacciarelli, D. (2008). Real time management of a metro rail terminus. European Journal of Operational Research, 189(3), 746-761.

Gupta, A., Stahl, D. O., & Whinston, A. B. (1998). Managing computing resources in intranets: an electronic commerce perspective. Decision Support Systems, 24(1), 55-69.

Hallowes, J. S., Pott, A. J., & Döckel, M. (2008). Managing water scarcity to encourage sustainable economic growth and social development in South Africa. Water Resources Development, 24(3), 357-369.

Hughes, D. A., & Mallory, S. J. (2008). Including environmental flow requirements as part of real-time water resource management. River Research and Applications, 24(6), 852-861.

Hwang, Y. D. (2006). The practices of integrating manufacturing execution systems and Six Sigma methodology. The International Journal of Advanced Manufacturing Technology, 31(1-2), 145-154.

Jarugumilli, S., Grasman, S. E., & Ramakrishnan, S. (2006, December). A Simulation framework for real-time management and control of inventory routing decisions. In Simulation Conference, 2006. WSC 06. Proceedings of the Winter (pp. 1485-1492). IEEE.

Kizza, J. M. (2013). Security Threats to Computer Networks. In Guide to Computer Network Security (pp. 63-88). Springer London.

Lau, H. C., Agussurja, L., & Thangarajoo, R. (2008). Real-time supply chain control via multi-agent adjustable autonomy. Computers & Operations Research, 35(11), 3452-3464.

Love, T (2000). Philosophy of Design: A Meta-Theoretical Structure for Design Theory. Design Studies 21(3), 293-313

Lusby, R. M., Larsen, J., Ehrgott, M., & Ryan, D. (2011). Railway track allocation: models and methods. OR spectrum, 33(4), 843-883.

Martin, E. Wainright, (1965) Electronic Data Processing (Homewood, Illinois, Richard D. Irwin, Inc., 1965), p. 38 I.

Martin, James (1965), Programming Real-Time Computer Systems (Englewood Cliffs, New Jersey, Prentice-Hall, Inc., 1965), p. 378.

Merlo, C., Vicien, G., & Ducq, Y. (2013). Interoperability Modelling Methodology for Product Design Organisations. International Journal of Production Research, (ahead-of-print), 1-17.

Minis, I., Mamasis, K., & Zeimpekis, V. (2012). Real-time management of vehicle breakdowns in urban freight distribution. Journal of Heuristics, 18(3), 375-400.

Monostori, L., Csáji, B. C., Kádár, B., Pfeiffer, A., Ilie-Zudor, E., Kemény, Z., & Szathmári, M. (2010). Towards adaptive and digital manufacturing. Annual Reviews in Control, 34(1), 118-128.

Monostori, L., Kádár, B., Pfeiffer, A., & Karnok, D. (2007). Solution approaches to real-time control of customized mass production. CIRP Annals-Manufacturing Technology, 56(1), 431-434.

Nageshwaraniyer, S. S., Meng, C., Son, Y. J., & Dessureault, S. (2011b). Simulation-based utility assessment of real-time information for sustainable mining operations. In Proceedings of the Winter Simulation Conference (pp. 871-882). Winter Simulation Conference.

Nageshwaraniyer, S. S., Son, Y. J., and Dessureault, S. (2011a). “Simulation Based Optimal Planning for Material Handling Network in Mining.” In Proceedings of the 2011 IERC. Reno, Nevada, May 21-25.

Nixon, B. (1996). Business-led management development. Industrial and Commercial Training, 28(2), 15-21.

Nixon, B. (1998). Creating the futures we desire-getting the whole system into the room: part I. Industrial and Commercial Training, 30(1), 4-11.

Papageorgiou, L. G. (2009). Supply chain optimisation for the process industries: Advances and opportunities. Computers & Chemical Engineering, 33(12), 1931-1938.

Pfeiffer, A., Kádár, B., Monostori, L., & Karnok, D. (2008). Simulation as one of the core technologies for digital enterprises: assessment of hybrid rescheduling methods. International Journal of Computer Integrated Manufacturing, 21(2), 206-

Qin, L., Miao, L., Ruan, Q., & Zhang, Y. (2014). A local search method for periodic inventory routing problem. Expert Systems with Applications, 41(2), 765-778.

Ridley, A. D., Fu, M. C., & Massey, W. A. (2003). Customer relations management: call center operations: fluid approximations for a priority call center with time-varying arrivals. In Proceedings of the 35th conference on Winter simulation: driving innovation (pp. 1817-1823). Winter Simulation Conference.

Tien, J. M. (2012). The next industrial revolution: Integrated services and goods. Journal of Systems Science and Systems Engineering, 21(3), 257-296.

Tien, J. M., Krishnamurthy, A., & Yasar, A. (2004). Towards real-time customized management of supply and demand chains. Journal of Systems Science and Systems Engineering, 13(3), 257-278.

Van der Vaart, J. T., De Vries, J., & Wijngaard, J. (1996). Complexity and uncertainty of materials procurement in assembly situations. International Journal of Production Economics, 46, 137-152.

Zurita, G., Baloian, N., Baytelman, F., Farias, A., & Antunes, P. (2008). A Platform Supporting the Implementation of Collaborative Learning through Participatory Simulations. In Computer Supported Cooperative Work in Design IV (pp. 523-533). Springer Berlin Heidelberg.