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Adaptive decision support for shop-floor operators in automotive industry

Magnus Holm[a,*], Aimar Cordero Garcia[a], Göran Adamson[a] and Lihui Wang[b]

[a]*University of Skövde, PO Box 408, 541 28, Skövde, Sweden*
[b]*KTH Royal Institute of Technology, 100 44, Stockholm, Sweden*

* Corresponding author. Tel.: +46-500-448551; fax: +46-500-448 599. *E-mail address:* magnus.holm@his.se

Abstract

Today's operators on factory shop-floors are often not stationed, dealing with a single or few tasks but have increasing responsibilities demanding enhanced skills and knowledge in a production environment where any disturbance must be settled with adequate actions without delay to keep optimum output. To be able to respond to these demands, the operators need dynamic, distributed and adaptive decision support in real-time, helping them to distinguish decision options and maximizing productivity despite incoming stochastic events. The minimum of time and option for operators to consider appropriate action both during normal production and when facing unexpected or unscheduled events point out the need of adaptive decision support for operators. When initiating this research project the question from the industry partner was the following: *In what ways is it possible to support operators in making decisions for optimal productivity?* By targeting this problem this paper introduces a novel framework for an adaptive decision-support system enabled by event-driven function blocks and based on decision logics. The proposed decision support systems' ability to adapt to the actual conditions on the shop-floor is validated through a case study, and its capability is compared to the voice message system installed on-site.

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Keywords: Decision support; Adaptability; Shop-floor operators

1. Introduction

To stay competitive on today´s global market, manufacturers are forced to adapt to constantly changing market demands, updated or new product variants and the need of decreasing costs. The shop-floor operators who yesterday were stationary, serving one or a group of machines, has today received increased responsibility and scope demanding extensive skills, being one of the company's keys to future competitiveness and sound production.

External production variables set by demands from the market in combination with internal stochastic variables, for instance, missing or broken tools, machine break downs, fixture shortage, changes in the number of available operators form the working environment for the shop-floor operators. These stochastically changing conditions raise the bar demanding production operators be able to handle and act in an information intensive environment with an increased degree of uncertainty. Traditional planning and control systems usually do not have the capability of handling such events negatively affecting the production efficiency [1]. To manage and handle counterproductive situations, adaptability must be a significant variable of the production system. Using real-time production data in combination with a distributed control system facilitates adaptive decision-making and dynamic control capability enabling the production system's vital and valuable capacity to handle uncertainty [2, 3]. The minimum of time and option for operators to consider appropriate action both during normal production and when facing unexpected or unscheduled events points out the need of adaptive decision support for operators. This paper introduces a novel architecture for an adaptive and distributed

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decision support system for operators in a demanding production environment. It is tested in an industrial case study together with our research partner from the automotive industry.

The remainder of the paper is organized as follows. Section 2 presents a literature review focusing on previous research done on decision support for shop-floor operators. Section 3 presents interviews with shop-floor operators at Volvo Cars in Skövde, Sweden about their need of decision support systems, discusses adaptive decision support and also describes the architecture of the proposed decision support system. In Section 4, two case studies are given, focusing on the proposed adaptive decision logic and user satisfaction together with perceived clearness of the proposed decision support system. Section 5 concludes the paper.

2. Literature review

Decision support systems for industry are not an immature academic topic. Already in 1971 Gorry and Scott Morton [4] used the concept "decision support system" in their work. More than 30 years later, in two extensive literature reviews, Arnott and Pervan [5][6] analysed previous research concerning decision support systems (DSS) defining seven major DSS sub-fields but also pointing out the severe and significant lack of case studies widening a gap between research and practice. Their definition of DSS "the area of information systems (IS) discipline that is focused on supporting and improving managerial decision-making" indirectly signals a general absence of DSS-research focusing on the needs of the operators in production industry, an indication which was strengthened by the performed literature review when writing this article. Though there is some light in the cloudy sky, some research together with industrial production case studies has been performed.

Gertosio and Dussauchoy [7] developed a DSS for operators at an engine manufacturing unit using a distributed environment. Their DSS communicates with each operator giving a list of next executable actions in order to increase effectiveness. Swanepol [8] developed a DSS integrated in a tube mill. It assists the operator to, when needed, manually change operating settings of the weld process to return it to stable conditions. The welding process is continuously monitored acknowledging the operator when an alarm occurs, also indicating appropriate action to be taken. A simulation-based intelligent decision support system (IDSS) for a Canadian milling plant manufacturing doors and windows is presented by Elghoniemy et al. [9]. The IDSS aids operators in decision-making by presenting recommended actions. By using a simulator of the rough mill, the operators are able to examine the effects of the recommendations before choosing the one to implement. The continued research about IDSS at the rough mill was presented five years later by Elghoniemy and Gruver [10], an agent ontology was developed, and a prototype system was implemented. Their continued research demonstrates both architecture and inter-agent communication within the IDSS. The IDSS offers the production benefits, such as helping operators to make consistent and standardized decisions, the ability to run the production using less experienced personnel, the possibility to train new operators, as well as knowledge acquisition and transfer when experienced operators update the IDSS recommendations. A DSS using knowledge acquisition at an electronic assembly line is presented by Gebus and Leiviskä [11]. They state that "an effective decision support system is essential to provide workers with information necessary to identify the causes of a problem and take appropriate action to solve it". The aim of their proposed DSS is to improve product quality by providing understanding and formalization, to the operators, of the parameters influencing it. A support system for decision-making using a simulation-based scheduling system for on-line optimization (OPTIMIST) is presented by Frantzén et al. [12]. The OPTIMIST system is implemented at an automotive manufacturer giving the operators continuously updated and near-optimum scheduling solutions at a manufacturing shop floor. Another decision support approach using simulation technique is presented by de Ugarte et al. [13]. The approach supports the rescheduling process in an enterprise resource planning (ERP) controlled system at an aluminium industry. In [14], Thorvald et al. focuses on the information context in a DSS for assembly workers. They discuss and investigate in what way the performance of operators is affected by how the needed assembly information is presented.

An operator has great potential to adapt to different situations [15]. However, during production with dynamically changing demands and stochastic events, it is not possible for an operator to make the correct decisions and prioritizations at all times since one possesses neither all the production information in real-time nor the ability to process or evaluate it. It would be good if the operators could act as rational decision makers, defined by Lee [16]. A rational decision maker should be completely informed, infinitely sensitive and rational, knowing exactly what to do. No human can hold and process all information in real-time being a rational decision maker, but a well-designed DSS will help the operator to come closer. A decision is not an isolated event in time. It is affected by previous production situations and impacts the succeeding. This is the situation for the shop floor operators. It is therefore essential that the DSS used at the shop floor is developed with the operator in focus. Despite the obvious importance of the narrow time window and connectedness to the whole, it is seldom modelled in research [17].

There has been much research done focusing on DSS, supported by several journals [5][6], but as found in the literature survey the major approach has been from the IS point of view. The main focus of performed research is at the management level. Few researchers have published work from the industrial shop-floor operators' perspective of decision support and their need of adaptive support in real-time.

3. Enhancing adaptive decision support

Running a modern production line using the automatic, semi-automatic and manual stations optimally is a tough task even if every machine and operation is up and running according to plan. When reality kicks in with tool/machine breakdowns, operators having different skills, quality control, variance in material and cycle-times, and on top of that various alarms, the optimum is easily buried under harsh circumstances. The operator facing several options and choices during changing production demands will strongly impact the production outcome through made action prioritization. To meet these changing conditions the supporting systems must be able to adapt to current production status and respond in real-time.

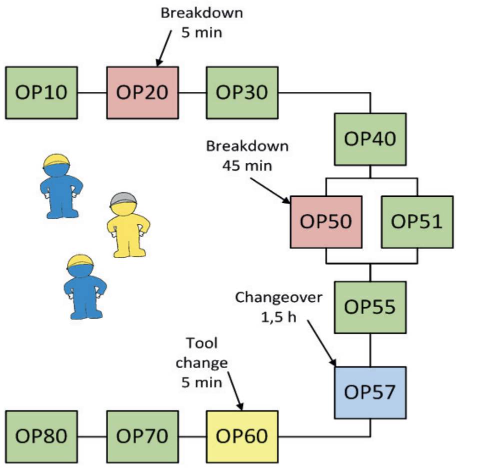

Figure 1. Question initiating project: *In what ways is it possible to support operators in making decisions for optimal productivity?*?

3.1. Interviews with operators

The question from the projects industrial partner, described in Figure 1, initiating the project was: *In what ways is it possible to support operators in making decisions for optimal productivity when facing several events claiming action?* The present installed voice message system on the shop floor polls machine status using beacon signals of every station. This system announces occurring events to the operators, alarm status of a machine or that it is time to do a periodic measuring verification. The events are announced through a voice message to the operators using handheld receivers. This system is compared to the proposed decision support system in the first test case described in section 4.

Interviews with ten operators at three production lines at Volvo Cars in Skövde were made during 2012 with the objective to have their view of the everyday situation and possible needs and requirements of a DSS for operators. One of the production lines had only machining jobs, the second machining jobs in combination with some assembly, and the third one only assembly, stretching from fully automatic over semi-automatic to manual stations. The most important capacity of a DSS mentioned by the interviewed operators was that it should be customizable so that each group and in some cases each individual are able to customize the settings.

3.2. An adaptive Decision Support System

By using a DSS the organization can benefit in several areas depending on the focus of the system. No DSS in the literature survey claims to perform in all five focus categories listed by Power [18]: Improve productivity, Improve decision quality, Support interpersonal communication, Improve skills in decision-making and Increase organizational control. To meet the demands from the project partner and the shop-floor operators, architecture for an Adaptive Decision Support System (ADSS) is proposed. The proposed ADSS focuses the first three categories in Power's list and aims to facilitate operators to achieve an overall optimal production performance. The ADSS as depicted in Figure 2 has four main modules: Production status evaluation, Adaptive decision logic, Dynamic resource position detection and the Operator device. It also uses some supporting functionalities, real-time monitoring of the production line together with process plans and the production status from the production management system (PMS). The status of the production is evaluated and function block based decision logic is used in combination with resource positioning to enable decision support to the shop-floor operators in real-time both during normal production and when incoming events call for actions. Supporting modules are marked with dashed lines in Figure 2.

The ADSS' main modules can be divided into two layers, one joint level, placed in the decision support server platform, which holds the three outer modules (marked with * in Figure 2) and one individual level, each operator's device, which can be individually configured to some extent. The objective of the ADSS is to provide the right operator with the right information at the right time in a dynamic production environment with stochastic events calling for actions.

3.2.1. Process monitoring and production information

Updated and accurate information from the production system is vital for the operators' ability to correctly understand and interpret the current status. The ADSS uses real-time monitoring technology as described by Wang et al. in [19]. It is a web based solution significantly reducing network traffic while increasing the controllability of the production system, not only from the shop-floor but also from remote locations. The PMS collects and saves information from the production system displaying, for instance, the actual production rate and status, as well as machine availability to both the management and the shop-floor operators.

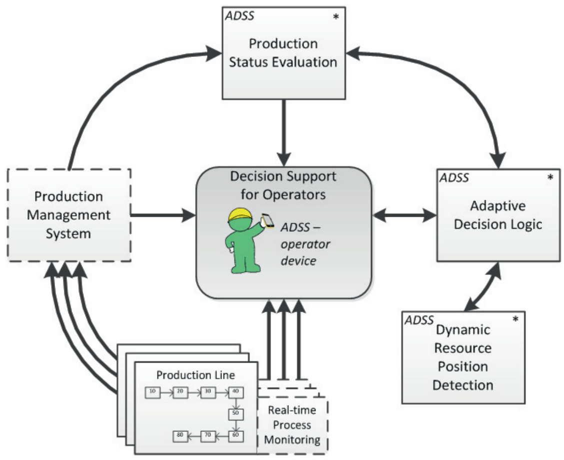

Figure 2. Architecture of proposed DSS

3.2.2. Production evaluation and decision logic

Production data from the PMS together with output from the decision logic are used to evaluate the current production status both in an overall perspective and for the different sectors of the production. It can calculate bottleneck location and optimize production plans as well as resource scheduling both at run time and for scheduled events like planned maintenance. The optimization can be performed at the operator level (production cell) or at the manager level (whole production line). The evaluation outputs are used as inputs to the decision logic and are also visible in the operator's device.

The decision logic and parts of the production status evaluation are built using event-driven function blocks (FB). These FBs are reusable functional modules based on the event-driven models defined in the international standard IEC 61499. The behaviour of the FB is internally controlled by a state machine. Different internal algorithms are executed by the state machine depending on arriving events and the current state. In our earlier papers [20] and [21] the functionality and test cases using FBs are thoroughly described.

Managers and the operator teams are able to set the characteristics of the Adaptive Decision Logic through the internal algorithms of the FBs. This possibility meets the requirements, the ability to steer the system, as earlier stated by the operators during the interviews. Output from the three other ADSS-modules are in run-time used to steer the behaviour of the FBs enabling adaptive decision support in real-time to the shop floor operators. System adaptability is enabled through the encapsulated algorithms and state driven design. The algorithms in the FBs can be updated when, for example, a new optimum, due to changing production status, is found. The modules Production status evaluation and Adaptive decision logic are based in the Decision support server platform (Figure 3).

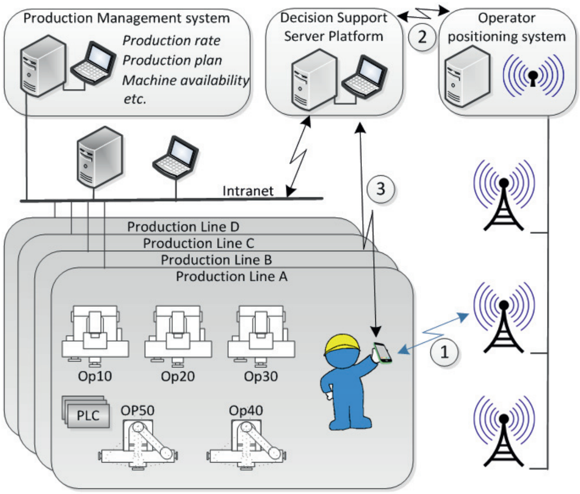

Figure 3. Operator positioning system

3.2.3. Dynamic resource location detection

On today's shop-floor operators are not stationed at a single location but must be ready to engage in the whole production premises. Operators, trucks and other resources move in the premises, and their position is an important variable when giving information and assigning tasks. The positioning system tracks, for example, the position of the operator device ① and trucks. It is sent as input ② to the decision support server and the decision logic, affecting the support output ③ to the operators (Figure 3). The module Dynamic resource location detection is based in the Decision support server platform.

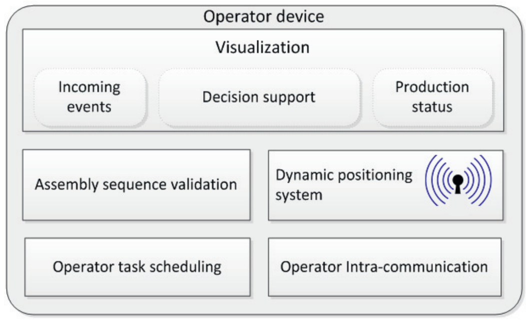

Figure 4. Architecture of Operators device

3.2.4. Operators' device

A modular architecture has also been used in the design of the operator's device. It has five modules: Visualization is the basic module displaying information from the other four that are Sequence validation, Positioning system, Task scheduling and Intra-communication (Figure 4). When an event in the production system occurs, decision support to the operators is generated mainly by the decision logic. When the decision support is displayed to the operator, the response (chosen action) from the operator is sent back to the decision support server.

The device is part of the localization system transmitting its location back to the server. This functionality can be set to stand-by mode manually by the operator if needed (leaving the area etc.). The position of the operator is used by the ADSS to filter what information and decision support to send to which operator. Only production data, event information and assigned tasks relevant to each individual operator are shown.

The operator task scheduling module is used by the operator and also by the PMS to book time for meetings etc. If for example an alarm occurs 5 minutes before operator A has a booked meeting, operator B should be assigned to deal with it even though operator A might be more skilled than operator B. The last module is for interactive communication and information. It can also be used to send and receive both voice and text messages. A tablet, smartphone or other portable programmable device can be used as an operator's ADSS-device.

4. Case studies

The two modules Adaptive decision logic and Visualization (in the operator's device) were chosen for two case studies. The first study compares the production throughput when using the at site installed voice message system with the suggested ADSS, and the second study focuses on user satisfaction and perceived clearness. The experiments for the case studies were set up in the laboratory at the University of Skövde. Online production data in real-time was not available for the test case; instead a model was built simulating the production line and its operators.

The event flow through the voice message system used in the first test case is depicted in Figure 5. The simulation system sends events (alarms, tool changes etc.) to the voice message system (described in section 3.1). In the case study the operator accepting the task is the one working in the specific section of the production line. If that operator is occupied, another operator in the next section is chosen. During working hours the operators change the sections in which they work.

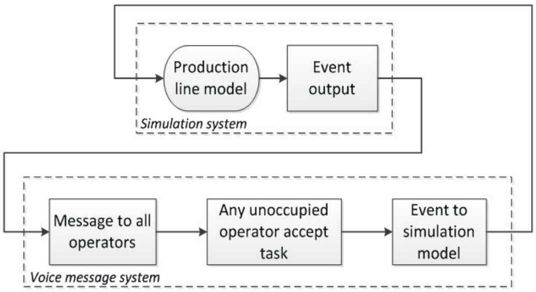

Figure 5. Event flow through the voice message system

The event flow through the ADSS-framework used in the first test case is depicted in Figure 6. The simulation system sends events (alarms, tool changes etc.) to the ADSS-server which processes and visualizes incoming events. Available operators are detected by the server and the selected decision rule is used by the adaptive decision logic to assign an operator to the task. A message is sent to the allocated operator's device which visualizes the assigned task, and the operator has to either accept or refuse the task. If accepted the ADSS-server sets the operator's state to *occupied*. When the task is finished, the simulated system sends an event back to the ADSS-server, and the operator state is set to *unoccupied*. If the operator denies the task or if the respond time limit is exceeded, the ADSS-server assigns the task to another operator.

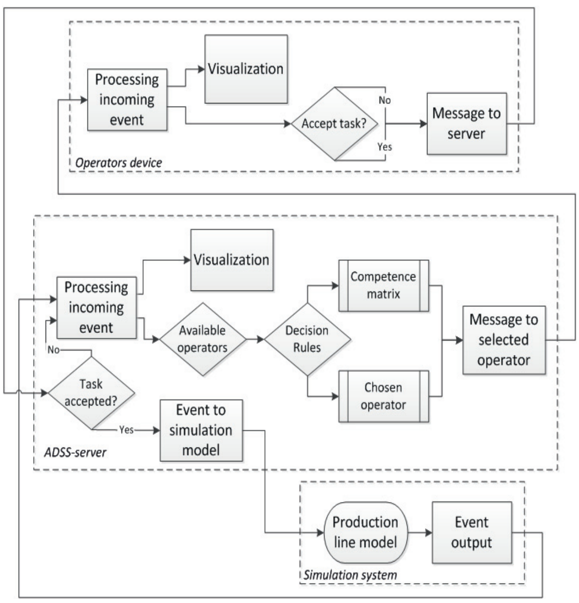

Figure 6. Event flow through the ADSS framework.

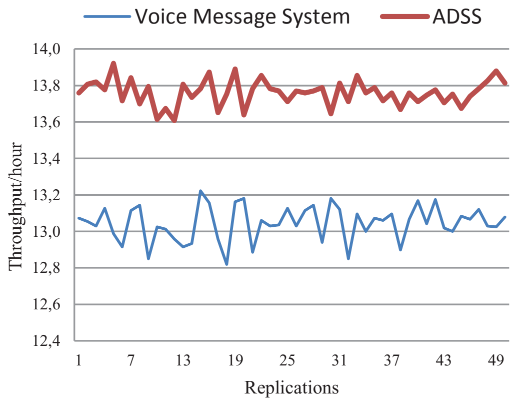

Figure 7. Average throughput/hour for the two systems in the first test case

During the first test case the ADSS uses an FB-algorithm called "Competence matrix" for the adaptive decision logic. It evaluates the available operators and assigns the one with the highest competence depending on the task.

In the first case study, it is evaluated how different approaches of assigning operators (ADSS and the voice message system) to incoming stochastic events affect the throughput per hour. The production line used in the test case has 12 stations with conveyers in-between each having a capacity of holding three products. Four operators are working at the production line.

Each of the two systems, the voice message system and the ADSS, together with the simulation model was run for 168 hours (seven days) with 49 replications. The voice message system reached an average throughput per hour of 13,045 with a standard deviation of 0,096. For the second run using the ADSS the average throughput per hour was increased with more than 5%, reaching 13,761 with a standard deviation of 0,071. The proposed ADSS using the FB-algorithm "Competence matrix" showed a significant better result than the installed voice message system (Figure 7 and Table 1).

For the second test case, in which fifteen persons participated, user satisfaction and perceived clearness was the focus. The participants were introduced to both the installed voice announcing system and the novel ADSS. Each of the two systems presented information on incoming events from the production line model. In the first setup the participants used the voice announcing system, and during the second setup they used the ADSS. During the concluding evaluation all of the participants ranked the ADSS higher than the voice announcing system in perceived satisfaction and comfort. The ADSS was also considered to offer a higher level of clarity and confidence.

Table 1. Statistics from the two experiments in the first case study

Experiment	Tp/h average	Standard Deviation	Minimum	Maximum
Exp 1	13,045	0,096	12,819	13,223
Exp 2	13,761	0,071	13,608	13,922

5. Conclusions

Decision support systems have been used in industry for a long time, and as found in the literature survey the focus has been on the managerial level. These systems focus on decisions that are to be made in some hours or more. A time window of that size does not meet the requirements from the shop floor, which include decisions that are to be made within some seconds in a dynamic environment with stochastic events.

Our contribution against the reported literature can be summarized as follows. 1) The proposed ADSS-framework focuses the needs of the shop floor operator. It is a system giving decision support in real-time compared to managerial systems having a time window of several hours or more. 2) The ADSS uses event driven function blocks enabling system adaptability through the encapsulated algorithms. 3) The proposed novel framework supports the operator to get closer to being a rational decision maker.

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References

[1] Xu X, Wang L, Newman ST. Computer-Aided Process Planning − A Critical Review of Recent Developments and Future Trends. International Journal of Computer Integrated Manufacturing 2011;24(1):1-31.

[2] Monostori L, Csáji BCs, Kádár B, Pfeiffer A, Ilie-Zudor E, Kemény Zs, Szathmári M. Towards adaptive and digital manufacturing. Annual Reviews in Control 2010;34:118-128.

[3] Wang L, Givehchi M, Schmidt B. Adamson G. A Function Block Enabled Robotic Assembly Planning and Control System with Enhanced Adaptability. Proceedings of the 45th CIRP Conference on Manufacturing Systems 2012. p. 194-201.

[4] Gorry GA, Scott Morgan MS. A framework for management information systems. Sloan Management Review 1971;13(1):1-22.

[5] Arnott D, Pervan G. A critical analysis of decision support systems research. Journal of Information Technology 2005;20(2):67-87.

[6] Arnott D, Pervan G. Eight key issues for the decision support systems dicipline. Decision Support Systems 2008;44:657-672.

[7] Gertosio C, Dussauchoy A. A distributed decision support system for operational units, application to a manufacturing unit. Proceedings of IEEE conference on Emerging Technologies and Factory Automation 2003;2:575-581.

[8] Swanepol K. Decision support systems: real-time control of manufacturing processes. Journal of Manufacturing Technology Management 2004;15(1):68-75.

[9] Elghoniemy E, Uncu Ö, Gruver WA, Kotak DB, Fleetwood M. An intelligent decision-support system for rough mills. International Journal Manufacturing Technology and Management 2006;8:203-225.

[10] Elghoniemy E, Gruver WA. Agent-based decision support and simulation for wood products manufacturing. IEEE Transactions on Systems, Man, and Cybernetics – Part C: Applications and reviews. 2012;42:No 6.

[11] Gebus S. Leiviskä K. Knowledge acquisition for decision support systems on an electronic assembly line. Expert Systems with Applications 2009;36: 93-101.

[12] Frantzén M, Ng AHC, Moore P. A simulation-based scheduling system for real-time optimization and decision making support. Robotics and Computer-Integrated Manufacturing 2011;27:696-705.

[13] Saenz de Ugarte B, Hajji A, Pellerin R, Artiba A. Development and integration of a reactive real-time decision support system in the aluminium industry. Engineering Applications of Artificial Intelligence 2008;22:897-905.

[14] Thorvald P, Högberg D, Case K. The effect of information mobility on production quality. International Journal of Computer Integrated Manufacturing 2014;27(2):120-8

[15] Payne JW, Bettman JR, Johnson EJ. The adaptive decision maker. Cambridge University Press; 1993 ISBN 0-521-41505-5

[16] Lee W. Decision theory and human behavior.. New York: John Wiley & Sons; 1971.

[17] Hollnagel E. Time and time again. Theoretical Issues in Ergonomics Science 2002;3:143-158.

[18] Power DJ. Decision support systems: Concepts and resources for managers. Westport, Connecticut: Quorum Books; 2002

[19] Wang L, Givehchi M, Adamson G, Holm M. A sensor-driven 3D model-based approach to remote real-time monitoring. CIRP Annals – Manufacturing Technology 2011;60:493-6.

[20] Wang L. Wise-ShopFloor: An Integrated Approach for Web-Based Collaborative Manufacturing. IEEE Transactions on Systems, Man, and Cybernetics – Part C: Applications and reviews 2008;38(4).

[21] Holm M, Adamson G, Wang L. Enhancing Adaptive Production using IEC 61499 Event-Driven Function Blocks. Proceedings of NAMRI/SME 2013;41.