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Towards intelligent and sustainable production systems with a zero-defect manufacturing approach in an Industry4.0 context

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Abstract

The paper addresses intelligent and sustainable production achieved through combination and integration of online predictive maintenance, monitoring of process parameters and continuous quality control of both input materials and output from the process. This enables production systems, within both manufacturing and process industries, to move towards zero-defect manufacturing. Such a zero-defect manufacturing approach allows for earlier identification of problems or issues, which will or already negatively affect the output. The paper outlines the first part of the second cycle of an action research effort at Gestamp HardTech AB in Sweden, whose objective is to keep its position as a world-leading provider of press-hardened vehicle parts. In order to fully implement the zero-defect manufacturing approach, 4-6 action research cycles are expected to be needed in order to iteratively refine the approach. During the first cycle, various methods and solutions for some of the individual issues/problems have been conceptualized, realized and initially tested. The selected design criteria for the action research efforts were: simplicity, low cost, robustness, high-quality output and future-proofing. The result from the research in the second cycle so far is an action plan for the technical change and a set of challenges/problems which need additional investigation.

Keywords: continuous quality control; Industry4.0; intelligent; online predictive maintenance; production; sustainable, zero-defect manufacturing

1. Introduction

The paper concerns the first phase and part of the second phase, i.e., diagnosing and planning action, of the second cycle of an action research effort at a manufacturing company, Gestamp HardTech AB (GHAB). GHAB produces lightweight, advanced and complex press-hardened components mainly for the automotive industry. Parts of the first cycle results and efforts have previously been reported in [1-2]. Further, additional research efforts such as [3-4], which were initially conducted at other vehicle manufacturers, are continued at GHAB as well. The research effort described in this paper builds on [1-4], striving towards intelligent and sustainable production systems aligned with the Industry4.0 concept where relevant information can flow up and down within an organization as well as be shared in between partners in the same value-chain.

Most manufacturing and process industry companies want to achieve intelligent and sustainable production systems, and thus move towards **zero-defect manufacturing (or production)** (ZDM) with related benefits such as: lower costs, lower energy consumption, less scrapped output and material waste, faster lead times and deliveries, increased production status overview and planning ability, production system resilience against problems and issues, and confidence in availability and output quality, etc. This is a way to stay competitive and profitable as

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well as reliable or trustworthy in the eyes of customers, as they in turn have pressed production processes and just-in-time schedules.

In order to move towards ZDM, a number of smaller and drastic changes may be needed in terms of technology, organization, finance, investments, partnerships, and research and development activities. However, this paper will focus on the technology aspects and, to some extent, research and development challenges/problems.

The ZDM objective requires a combination and integration of areas, teams, skills, competencies, information systems, data from many sources as well as data analytics. The problem addressed is that if the output from a production process is outside of specifications and there is no indication of issues found (except that it is out of specifications) – the established methods are insufficient to detect them and need to be improved to be able to identify the underlying issue(s) by combining and integrating various data from monitoring systems and a number of analytic methods. The paper will (see section 4) address the combination and integration of the following into a **ZDM approach**:

- Monitoring of process parameters
- Collaborative manufacturing
  - Sharing of manufacturing data without media breaks along the supply chain
- Continuous quality control
  - Measurement of input to the process
  - Measurement of output from the process with automatic sorting
- On-line predictive maintenance
- Data storage and analytics
- Re-configuration and re-organization of production
- Re-scheduling of production

The rationale for combining and integrating the above is that they together can provide a better result. Of course, sometimes a combination and integration may not find the issues, due to the fact that all possible parameters and activities are not measured or monitored, as it is a question of time, money and value (i.e., to get return-on-investment).

The purpose of the paper is to provide ideas and guidance to manufacturing and process industry companies concerning how to move towards ZDM with intelligent and sustainable production systems by combining and integrating what they already have together with what is deemed missing.

The paper is organized such that the research approach follows the introduction and related work. This is followed by the result section including an analysis and, finally, the discussion and conclusions section.

2. Related work

There is a lot of existing work pertaining to intelligent and sustainable manufacturing/production systems, zero-defect manufacturing/production, circular economy, predictive maintenance and quality control, etc. The review of related work will thus be narrowed down to the most interesting and referenced papers since 2010. Further, we consider that ZDM is part of striving toward Industry4.0, and in particular through the combination and integration of many types of systems where information and knowledge flows from top- to low-level systems and vice versa. The benefits from ZDM are also aligned with the ones in an ideal Industry4.0 scenario. Ideally, there should also be a strive, to move from ISA-95-based to RAMI4.0-based architecture of the manufacturing or production environments, in order to get the full benefits from the Industry4.0 concept and increase flexibility and costs.

Concerning zero-defect manufacturing or production, Wang [5] provides ideas about how to use product, equipment and process data in a data mining framework used to improve knowledge finding and quality of products. Further, Myklebust [6] outlines a product and plant-oriented approach with use of real-time data and knowledge feedback loops to achieve near zero defect level. In addition, Teti [7] brings up signal processing and decision-making, Di Foggia and D'Addona [8] consider the need to identify critical key parameters and Ferretti et al. [9] discuss use of monitoring systems for raw materials/input, in-process and output measurements. The research in [5-9] brings up relevant aspects of ZDM, which according to above have been brought together into a comprehensive approach (see Figure 2).

In terms of more general ZDM and Industry 4.0 challenges, for instance, Lee et al. [10] assert for Industry 4.0 with service innovation/smart analytics that there are five areas not yet adequately resolved: manager and operator interaction (health condition of machine components is missing in decisions made), machine fleet (gathering information and knowledge about common design issues and errors for various contexts of use in order to find any systematic or context specific issues), product and process quality (feedback loops to the system are needed), Big Data and Cloud (cloud capabilities needed for self-awareness and self-learning machines with adaptive prognostics and health management), and, finally, sensor and controller networks (where, for instance, sensor failure and degradation can provide wrong input to prognostics and, subsequently, incorrect outcome and decisions). This paper aims to address all five of these problems. The problems are addressed by outlining a scalable and generalizable ZDM approach for production processes, equipment and input/output by collecting, modeling and analysing data originating from sensors or other data extractors with cloud solutions to support decision-making. Additional research of interest also includes: Cassady et al.'s [11] concept on predictive maintenance and quality control, Lee et al.'s [12] conceptual work on e-Maintenance (proactive maintenance and prognostic tools), Deloux et al.'s [13] concept of a predictive maintenance policy based on combining statistical process control and condition-based maintenance, as well as Duffuaa et al.'s [14] suggested conceptual simulation model for maintenance systems. The majority of the research listed above is conceptual and only some of it has been tested and verified in industrial contexts. Finally, additional research of interest includes Koc et al.'s [15] introduction to e-Manufacturing (intelligent maintenance systems and e-Maintenance), Choudhary et al.'s [16] work on data mining in manufacturing (maintenance and quality), and Löfstrand et al.'s [17-18] and Reed et al.'s [19-20] simulations of maintenance, service and availability. This set of research brings in other important aspects of ZDM.

3. Research approach

The research approach employed in this study has been based on an in-depth qualitative study using action research with a manufacturing company, GHAB, located in northern Sweden. It would have been possible to use other iterative or spiral models having iterated refinement of the research results. However, action research was deemed as a good fit due to its flexibility and the possibility to use various data collection and analytic methods. GHAB, part of the global Gestamp Group, produces body-in-white parts for vehicles. The Gestamp Group is active in more than 21 countries with 13 R&D centers, approximately 105 production plants and 40,000 employees. GHAB has an R&D center, press-hardening tool development and manufacturing, as well as a production plant. The research targeted in this paper is the second cycle's first and second phases, i.e., diagnosing and planning action, of an action research [21] effort where the researchers have had the roles of external expert/consultant and internal expert.

The research effort required to reach "full" ZDM is estimated to be 4-6 cycles (each including 4 phases as outlined later in this section).

A literature review, concerning finding new ideas and research since the first cycle ended, was part of the first phase and its result was used as input to the diagnosis. Action research has been defined as "*a participatory, democratic process concerned with developing practical knowing in the pursuit of worthwhile human purposes, grounded in a participatory worldview which we believe is emerging at this historical moment. It seeks to bring together action and reflection, theory and practice, in participation with others, in the pursuit of practical solutions to issues of pressing concern to people, and more generally the flourishing of individual persons and their communities*" [21]. The characteristics of action research are: (1) that action researchers act in the studied situations, and (2) that action research involves two goals. The goals pertain to solving the problem (the role of the consultant) and making a contribution to knowledge (the role of the researcher); further, that action research requires interaction and cooperation between researchers and the client personnel and, finally, that action research can include all types of data gathering methods [22]. In accordance with [23], the action research approach encompasses 4 phases: diagnosing, planning action, taking action and evaluating the action in relation to a certain context and specific purpose.

The second cycle's first and second phases were completed with an iterative and reflective case management methodology. The data pertaining to the first phase, i.e., technical and organizational needs for change, were collected during 4 workshops [24] (involving 4-6 key respondents from the R&D, production and maintenance departments at each workshop) and 3 semi-structured open-ended interviews [25-26] with key respondents (i.e., R&D manager, manager tool design and development and senior researcher/development engineer). The workshops and interviews were conducted from late 2016 until 2018. The respondents were well aware of and knowledgeable regarding production systems/equipment, predictive maintenance, quality control, and input/output measurements.

GHAB has its roots in hardware and material development and production, and its set of special competencies comprises: press-hardening techniques and technology (creator of original patent SE 7315058-3), simulation-driven design and just-in-time logistics. However, additional complimentary components have been added to its customer offerings. Further, GHAB aims to increase its global revenue from soft parts such as: services, knowledge or know-how.

To collect data after the workshops semi-structured interviews with open-ended questions [25-26] were used, allowing the respondents to give detailed answers and the possibility to add extra information where deemed necessary [27]. The duration of the interviews was between one and three hours. In order to reduce response bias, the respondents came from various parts of the organization as well as different levels i.e., strategic, tactical and operational units. In order to strengthen the validity of the study, data were continuously displayed using a projector during the interviews, allowing the respondents to immediately read and accept the collected data. After that, the collected data were displayed and analyzed using matrices (cf. [28]) and the outcome of the planning action efforts summarized into causal relational graphs (cf. [28]). The analyzed data were finally summarized into two matrices comprising the diagnosis in terms of technical needs and additional challenges/problems (see Tables 1 and 2) as well as a high-level plan for action.

The design criteria for the action research were decided by GHAB as: simplicity, low cost, robustness, high-quality output and future-proofing. The design criteria will not be formally evaluated (as the action in the second cycle has not yet been taken) in this paper but discussed in the last section of the paper in order to judge if the outcome will lead "towards intelligent and sustainable production systems" and "zero-defect manufacturing".

4. Towards an intelligent and sustainable production system with a ZDM approach

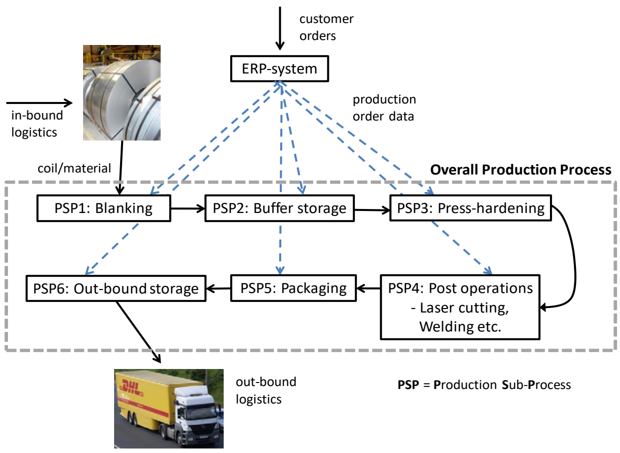

Fig. 1. Overall production process and its sub-processes (based on [1]).

As previously described in [1], the overall production process at GHAB is depicted in Figure 1 and comprises a number of sub-processes, e.g., blanking, buffer storage, press-hardening, post operations, packaging and out-bound storage prior to outbound logistics.

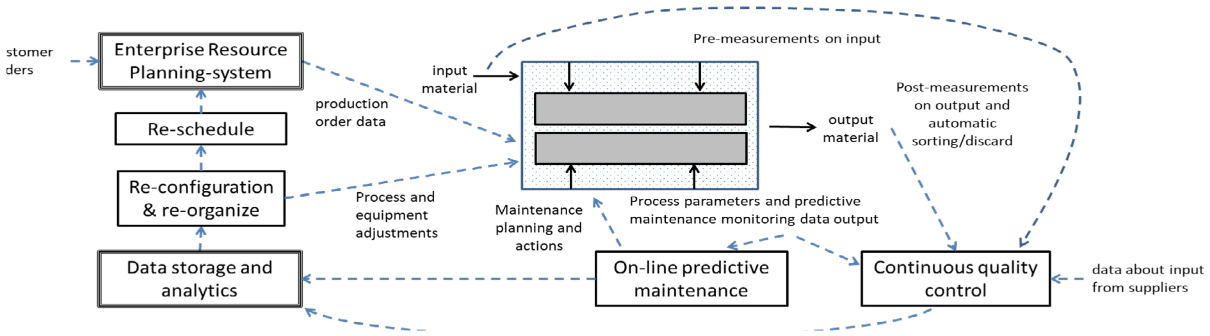

Fig. 2. ZDM approach starting to be applied at press-hardening.

In Figure 1 the ERP-system sends production order data to all sub-processes based on customer orders. During the second cycle, the focus has been on the press-hardening sub-process and how it can be improved further. The output from the first cycle, and thus the input to this cycle was, after a number of research efforts targeting various parts of the press-hardening sub-process, an improved understanding of what is required to move towards ZDM. Thus, the following ZDM approach was developed (see Figure 2) based on those first cycle findings.

The approach, which is applied in a manufacturing context at the press-hardening production sub-process, will be further described here below.

The approach has the following main pillars:

- Monitoring of process parameters
- Collaborative manufacturing
- Continuous quality control
  - o Measurement of input (materials) to the process (with potential discard)
  - o Measurement of output (part or product) from the process with automatic sorting and discard
- On-line predictive maintenance
- Data storage and analytics
- Re-configuration and re-organization of production
- Re-scheduling of production

The ultimate objective is to manufacture only output that is within the wanted specifications, i.e., what can be delivered to customers. Commonly, only one quality is delivered, i.e., within specifications, but there could also be two or more (in case there a multiple customers with different specifications requirements for the same output). Producing output without defects is very hard or not feasible, but what is more important is to not produce more than one or two faulty products in a row and to not ship any faulty ones to customers. If more than one faulty (out-of-spec) product is produced consecutively, the production process could be re-configured or re-organized to be able to continue manufacturing output within specifications. If there are obvious problems that can easily be detected, such as problems with input, wrong process parameters, indications of maintenance need, these can commonly be rectified without a lot of analytics and root-cause analysis. However, if faulty output is manufactured and there are no indications apart from the output measurement, the problem becomes additionally intricate. The idea and rationale for combining and integrating the pillars concerning monitoring of process parameters, continuous quality control and on-line predictive maintenance [cf. 1] is that they complement and support each other and provide information to be analyzed for decision-making. For instance, if the output is faulty and there are no indications from the monitoring of process parameters or on-line predictive maintenance, something that is not monitored may have caused the problem or the sensors may not be working properly. Thus, if the quality of the output is outside of specification – even if no indication of problems is flagged by predictive maintenance or process parameter monitoring – it is a sign that something else is wrong and needs to be identified, analyzed and rectified in order to get back on track again. This is an integrated way to combine different methods and analytics in order to learn more than would be possible by applying the individual methods separately.

Below, each of the pillars is outlined in greater detail.

Monitoring of process parameters – the process is monitored using sensors and other data extracted from the production equipment and process control in order to ensure the process quality level. Examples of parameters in the GHAB context are: pressure/force, time in press, press temperature, cooling temperature/time, etc. If the input is outside of normal tolerances, it can be possible to change the process parameters so that the output still complies with the desired specifications. However, this requires information from the supplier about the input as well as input measurements. Furthermore, if the output from the process is outside of wanted specifications, a change in parameters can rectify the problem and allow manufacturing to continue uninterrupted.

Collaborative manufacturing – sharing of manufacturing data without media breaks along the supply chain. Information provided by the input material (i.e., coils) suppliers regarding the coils and any potential variations or issues within the coils should also be factored in during the manufacturing, as slight variations can be adjusted for by re-configuring process parameters such as pressure, temperature, time in the press and time for cooling.

Continuous quality control – firstly, the **input should be measured** in order to verify that it meets specifications; otherwise, it should directly be discarded and taken off the manufacturing line to avoid costs without any revenue. The parameters of interest for GHAB are, for instance, material thickness and homogeneity, geometries, trim edges and holes, and weight. Lastly, the output should be measured in order to determine if it is within specification and can be directly sent to packaging, if any post operations such as laser cutting are required, or if the output is out of specification without any possibility to rectify it and it should thus be directly sorted out and discarded so that it is not inadvertently shipped to customers. Alternatively, the output can be sorted automatically at the end of the production line, prior to the packaging, into discarded products and products that are approved for shipment to customers – but that requires that the production system can keep track of the individual output from start to end. Parameters of interest for GHAB are: trim edges, holes, surface geometry, welds, etc. The relevant output measurements should be sent to the next sub-process to automatically program/require any post operations needed. Continuous quality control thus offers monitoring of quality in order to make fast decisions in case the output quality is outside of specification – compared to quality testing of a few in a batch at the end. Batch-oriented testing may miss faulty items in a batch and also cause entire batches to be discarded, as the quality issues were not discovered in time.

On-line predictive maintenance – data is collected by monitoring the production equipment using sensors and other types of data extractors. The aim is to find early signs of maintenance needs or the need for replacements, etc. The use of prediction allows for planning of most maintenance actions and purchase of spares or larger components in a timely manner, thus avoiding unplanned stops, as maintenance should be done during planned maintenance stops to keep the production pace up and avoid delivery problems.

Data storage and analytics – in order to get control of the data (and long-term management/preservation of the data selected to be stored) and common analytics, storage and analytics need to be crafted and kept updated. Some of the data storage and analytics will be done within, for instance, the on-line predictive maintenance and continuous quality control parts, but an aggregated view and central point for distribution of the decision-making information is desirable. This also makes it easier to assess or calculate the confidence levels, etc. pertaining to the decision-making information due to the knowledge and meta-data about the collected data and which analytic methods are applied.

Re-configuration and re-organization of production – as mentioned above, re-configuration of the process could solve issues related to, for instance, input variations or certain output issues. Further, if there are issues with the equipment, some of these problems can also be temporarily managed by re-configuring process parameters until a scheduled maintenance occurs (avoiding an unplanned stop). In some cases, if problems are detected, a re-organizing of the process and equipment can help to temporarily solve the problem until it can be properly fixed.

Re-scheduling of production – in case problems arise and it is not possible to continue with the current output/schedule, it is essential to know whether other output can still be manufactured without a maintenance stop or simply by retooling, etc. If so, a re-scheduling of the production order flow can be decided and the manufacturing can continue after some changes. This requires that the lead times for change of order and tools, etc. are not too long. This, in combination with re-configuration and re-scheduling, will enhance the robustness of production processes with input uncertainty as well as dynamic manufacturing steps (i.e., with process parameters varying) involving, e.g., high pressures and temperatures as well as advanced geometries.

During the diagnosis phase the needs for technical and additional changes were revealed and collected. These are listed below in Tables 1 and 2 and prioritized according to 10 (high) and 1 (low) need.

Table 1. Diagnosis - need for technical change.

Technical issue or need	Priority
1.) Use data analytics to create value from production data.	10
2.) Triangulation of methods and data. Using mixed methods and data from as many sources as possible to get higher confidence/reliability regarding the output – i.e., the decision-making information.	8
3.) High deployment efficiency, self-configuration and scalability.	9
4.) Advanced modeling of process data and simulation…to support re-configuration of process parameters.	7
5.) Know and keep the order of input/output materials within the production line – enables automatic sorting and keeping track of any necessary post operations.	8
6.) Go from six sigma methods towards ZDM through individual quality control.	10

The technical issues/needs with a prioritization exceeding 6, i.e., all, were passed on to the next phase action planning.

Table 2. Diagnosis – additional challenges/problems to investigate.

Challenges/problems	Priority
1.) Integrating data from different sources and precision. Analogue and digital data. Time series and frequency variations – can data be integrated with enough time and precision accuracy?	9
2.) Confidence level in decision-making information.	10
3.) Too many solutions possible – which one is the best for a problem situation?	6
4.) Sensor loses accuracy, loses calibration and slowly deteriorates due to age.	7
6.) Measurements and calculations are too slow or costly.	8

The additional challenges/problems with a prioritization exceeding 6, i.e., all, were also passed on to the next phase.

The high-level plan for action, regarding technical change as well as additional challenges/problems to investigate, concerning the press-hardening sub-process and its equipment is to continue the system level development and methodology development in smaller pieces/units until a larger R&D-project enables it all to be executed together. The plan is to firstly focus on the data quality/reliability and how to manage and use it in an adequate way, as well as data measurement techniques and analytic methods, in order to get solid input for the rest of the process and decision-making.

4.1 Analysis

Concerning Table 1 and the prioritization level exceeding 6, all entries were selected and will be dealt with. The prioritization related to Table 2 is similar and all entries will be dealt with as well. All this presents a great challenge and will require considerable effort, knowledge, funding and time.

5. Discussion and conclusions

The paper makes a contribution to the literature by outlining a ZDM approach which combines and integrates: monitoring of process parameters, collaborative manufacturing, continuous quality control (input and output), on-line predictive maintenance, data storage and analytics, and re-configuration/re-organization/re-scheduling of manufacturing/production. Further, the paper contributes to practice by providing sets of technical changes and additional challenges/problems that need to be addressed in order to achieve ZDM. The managerial contributions of the paper are the approach and high-level map of ZDM (see Figure 2) and the description of what this entails, and that the individual pieces need to be combined and integrated in order to reach the full potential of the approach. The design criteria, i.e., simplicity, low cost, robustness, high-quality output and future-proofing, stay the same when entering into the action phase and the next action research cycle. The idea of the approach outlined in the paper is highly generalizable and usable in both manufacturing and process industries, and can be used to map where an organization is today compared to where it wants to be and, thus, generate a change/action plan. The production process at GHAB is not extremely fast and does not require real-time control and responses (i.e., on micro- or millisecond level), and it is possible to conduct analytics and simulations if problems arise without halting or slowing down the process (a normal press-hardening process step is about 10 seconds depending on the output's functionality). If the process steps are a lot faster or real-time control and response are required, the analytics and simulations need to be speeded up and decisions may have to be taken in an automated manner.

Finally, the ideas and results from efforts like those presented in this paper are necessary for many manufacturing and process industry companies to reach intelligent and sustainable manufacturing/production and stay competitive, profitable and able to attract new young talent.

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References

[1] Lindström, J., Jonsson, M., Larsson, H., and Lejon, E. (2017). Towards intelligent and sustainable production : combining and integrating online predictive maintenance and continuous quality control. Procedia CIRP, 63, pp443–448.
[2] Lejon, E., Kyösti, P., and Lindström, J. (2018). Machine learning for detection of anomalies in press-hardening : Selection of efficient methods. Procedia CIRP, 72, pp1079–1083.
[3] Bergström, P., Michael, F., and Sjödahl, M. (2018). Virtual projective shape matching in targetless CAD-based close-range photogrammetry for efficient estimation of specific deviations. Optical Engineering, 57(5).
[4] Bergström, P., Fergusson, M., Folkesson, P., Runnemalm, A., Ottosson, M., Andersson, A., and Sjödahl, M. (2016). Automatic in-line inspection of shape based on photogrammetry, proceedings of the Swedish Production Symposium, 25th-27th of October, Lund, Sweden.
[5] Wang, K-S. (2013). Towards zero-defect manufacturing (ZDM) – a data mining approach, Advances in Manufacturing, Vol 1, Issue 1, pp62-74.
[6] Myklebust, O. (2013). Zero defect manufacturing: a product and plant oriented lifecycle approach, Procedia CIRP, 12, pp246-251.
[7] Teti, R. (2015). Advanced IT methods of signal processing and decision making for zero defect manufacturing in machining. Procedia CIRP, 28, pp3-15.
[8] Di Foggia, M. and D'Addona, D. M. (2013). Identification of critical key parameters and their impact to zero-defect manufacturing in the investment casting process. Procedia CIRP, 12, pp264-269.
[9] Ferretti, S., Caputo, D., Penza, M., and D'Addona, D. M. (2013). Monitoring systems for zero defect manufacturing. Procedia CIRP, 12, pp258-263.
[10] Lee, J., Kao, H-A. and Yang, S. (2014). Service innovation and smart analytics for Industry 4.0 and big data environment. Procedia CIRP, 16, pp3-8.
[11] Cassady, R., Bowden, R. O., Liew, L. and Pohl, E. A. (2000). Combining preventive maintenance and statistical process control: a preliminary investigation, IIE Transactions, Vol. 32, Iss. 6, pp471-478.
[12] Lee, J., Ni, J., Djurdjanivic, D., Qiu, H. and Liao, H. (2006). Intelligent prognostic tools and e-maintenance, Computers in Industry, 57, pp476-489.
[13] Deloux, E., Castanier, B. and Bérenguer, C. (2009). Predctive maintenance policy for a gradually deteriorating system subject to stress, Reliability Engineering and System Safety, 94, pp418-431.
[14] Duffuaa, S. O., Ben-Daya, M., Al-Sultan, K. S. and Andijani, A. A. (2001). A generic conceptual simulation model for maintenance systems, Journal of Quality in Maintennace Engineering, Vol. 7, Iss. 3, pp207-219.
[15] Koc, M., Ni, J., Lee, J. and Bandyopadhyay, P. (2005). Intorduction to e-Manufacturing, chapter 97, in (ed) Zurawski, R., The industrial information technology handbook, CRC Press LLC, USA.
[16] Choudhary, A. K., Harding, J. A. and Tiwari, M. K. (2009). Data mining in manufacturing: a review based on the kind of knowledge, Journal of Intelligent Manufacturing, 20, pp501-521.
[17] Löfstrand, M., Andrews, J., Karlberg, M. and Karlsson, L. (2011). Functional Product system availability: simulation driven design and operation through coupled multi-objective optimization, Int. Jour. of Prod. Dev., Vol. 13, No. 2, pp119-131.
[18] Löfstrand, M., Backe, B., Kyösti, P., Lindström, J. and Reed, S. (2012). A model for predicting and monitoring industrial system availability, International Journal of Product Development, Vol. 16, No. 2, pp140-157.
[19] Reed, S., Andrews, J., Löfstrand, M. and Karlsson, L. (2012). The design and modelling of maintenance during the development of functional products or product service systems, proceedings of 1st International Through-life Engineering Services Conference, 5th-6th of November, Cranfield, UK.
[20] Reed, S., Löfstrand, M., Karlsson, L. and Andrews, J. (2013). Service support system modelling language for simulation driven design of functional products, proceedings of 2nd International Through-life Engineering Services Conference, 5th-6th of Nov, Cranfield, UK. Procedia CIRP.
[21] Reason, P. & Bradbury, H. (Eds.) (2001). Handbook of action research: Participative inquiry and practice, Sage Publications, London, UK.
[22] Gummesson, E., (2000). Qualitative Methods in Management Research, 2nd Ed. Sage Publications, Thousand Oaks, CA, USA.
[23] Coghlan, D., Coughlan, P. and Brennan, L. (2004). Organizing for research and action: Implementing action research networks, Systemic Practice and Action Research, 17(1), pp37–49.
[24] Remenyi, D. (2013). Field methods for academic research: Interviews, focus groups & questionnaires in business and management studies, 3rd edition, Academic Conferences and Publishing International Limited, Reading, UK.
[25] Patton, M. Q. (1990). Qualitative evaluation and research methods, Sage Publ., London, UK.
[26] Kvale, S. and Brinkmann, S. (2009). InterViews: learning the craft of qualitative research interviewing, Sage Publications, LA, USA.
[27] Fontana, A. and Frey, J. (1994). Interviewing, in (eds) Denzin, N. and Lincoln, Y., Handbook of qualitative research, Sage Publications, Thousand Oaks, CA, USA.
[28] Miles, M. and Huberman, M. (1994). An expanded sourcebook – Qualitative Data Analysis, 2nd ed, Sage Publications, Thousand Oaks, CA, USA.