An Industry 4.0 Research Review For The Pulp And Paper Industry

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Abstract

Industry 4.0 defines the intelligent network and inter-relationship amongst components of production systems, providing digital feedback across the industrial value chain. The pulp and paper production organization execute flexible advanced manufacturing processes i.e. mechanical pulping, chemical pulping, re-pulping of waste paper, rolling and milling, to produce paper products. In this paper, research output of Industry 4.0 in the pulp and paper industry 4.0 is appraised. A systematic literature review of publications from 2007 to 2017, pertaining to key practices of Cyber Physical System (CPS) is conducted. The authors reviewed ninety three publications, utilizing coupled search engines such as open and internet based research search.

Keywords:
Internet of Things, Cyber Physical System, Security, Industry 4.0

1. Introduction

Industry 4.0 describes the digital transformation of information across the horizontal and vertical chains of an enterprise. Industry 4.0 escalates automation in manufacturing processes by utilizing the artificial intelligence network and the micro level sensors. Industry 4.0 is tangible and intended to include technologies and embedded processes. Industry 4.0 integrates various business subsets i.e. Enterprise Resource Planning (ERP), Manufacturing Execution Systems (MES) and Plant Control (PC). Industry 4.0 is being applied in several industrial sectors i.e. steel, oil, gas, energy, pulp and paper.

The pulp and paper industry manufactures a range of paper grades and paper-based packaging by utilizing wood traded globally. Contemporary challenges for producing higher volumes of products with minimum lead-time and higher quality actuate the pulp and paper industry to drive production systems further. Improvement in the production rate of the pulp and paper industry is possible with the application of industry 4.0.

2. Literature Survey

A literature review is conducted to identify Industry 4.0 practices in the pulp and paper. A brief summary of the focus areas of some of the current research themes are described. The themes include, water, mass and energy balances, systems, IoT, statistical process control and other optimisation techniques.

The paper first describes an optimization technique, using information gathered from an expert's panel, applied for assessing a new design process of a pulp and paper firm, with a case study depicting the results [1]. The fresh water treatment and recycling process of an Indian pulp and paper mill is investigated. Few initiatives are applied to save freshwater, with the results illustrated in a case study [2]. Mass and energy balances and mixed integer linear programming tools are utilised for determining the optimum energy generation capability by automation of the paper mills power plant. The results show that automation reduces the production cost by minimization of fuel consumption [3]. The unproductive practices are identified and investigated by calculating the energy efficiency of the various production units of concern. Moreover, the authors investigated the gaps between the pulp and paper industries of China and foreign countries via a horizontal comparison [4].

Enterprise Resource Planning (ERP) integrates business processes, activities and systems of a pulp and paper enterprise to meet the customers' demand. It is perceived that improved synchronization of ERP is expected amongst executives' within the pulp and paper industries [5]. The authors discuss the extent of application of Manufacturing Execution Systems (MES) in the pulp and paper industry i.e. storing process data and exploring data for process trouble shooting, enterprise asset management for maintenance activities and streamlining of manufacturing and distribution operations and business processes [6].

Electronic-Business includes IoT, which provides supply chain revolution and creates a bridge amongst business-trade-commerce under the scope of Industrial Information Technology (IIT). IoT makes the business of the pulp and paper industry faster and less expensive [7]. Mercangoz and Doyle (2006) presents an outline to control the pulp and paper production rate and provides models to control the process units of pulp and paper production. The current and future research areas in the pulp and paper industry are also discussed [8]. A technique and framework model to bring together two important ideas in pulp and paper industries is presented; Engineering Process Control (EPC), which assists in achieving short term control, and Statistical Process Control (SPC) to attain medium and long term control. The integration of both enhances the final product performance [9]. The potential interactions between water and heat networks in pulp and paper mills is described. Water is utilized for dilution, washing, cooling and heating, while heat transporters and dissipaters are used for rolling processes. Techniques to augment energy efficiency in current pulp and paper mills are presented, with results illustrating heat-savings about 15–30% [10].

3. RESEARCH OBJECTIVES AND GAPS

There is a need to recognize the Industry 4.0 research opportunities for the pulp and paper industry specific to water management, energy management, ERP, MES, plant control, integration, internet of things and cyber physical systems.

3.1 Research objectives

The research gaps are transformed into the research objectives detailed below:

- The recognition and advisement of the Industry 4.0 research opportunities in the pulp and paper industry by researchers.
- To determine the research output of CPS and IoT in the pulp and paper industry.
- To identify practices to quantify the performance of pulp and paper production systems applying Industry 4.0.

3.2 The research framework

The framework of this research explicates the objective of a research and this enables researchers to apply this structure in solving problems of other disciplines. Figure 1 depicts the research framework.

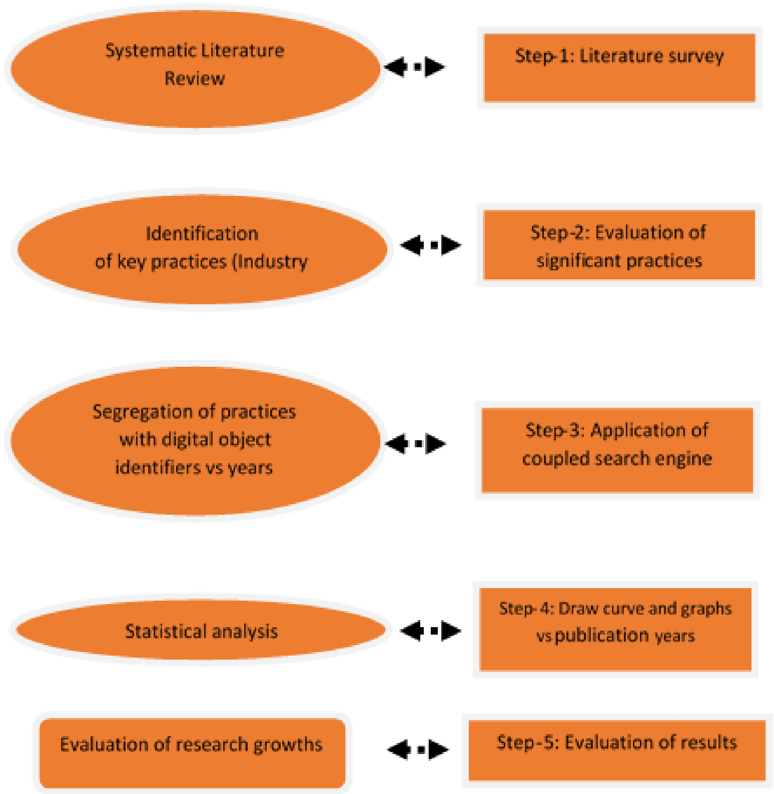

Figure 1. The structure of conducted research work

4. RESEARCH TECHNIQUE

In order to conduct the research, the authors adopted a Systematic Literature Review(SLR) engine as proposed by Kitchenham and Stuart (2002) [11]. The authors utilized the search mechanism of Internet-Based Research Search Engines (IBRSEs), to focus upon the output of research work vs key performance practices of industry 4.0 i.e., Water Management (WM), Energy Management (EM), Optimization (O), ERP, MES, PC, Integration (I), IoT and CPS for pulp and paper Industry 4.0.

Ninety three publications are reviewed considering the protocol of the aforementioned practices of pulp and paper Industry 4.0. The publications are sourced by utilizing the following Internet Based Search [11] and Open search (Google search) engines.

- Science Direct - http://www.sciencedirect.com/
- IEEE Xplore - http://www.ieee.org/
- Springer Link - https://link.springer.com/
- ACM Digital Library - http://dl.acm.org/
- Emerald Insights - http://www.emeraldinsight.com/

5. KEY SETS OF INDUSTRY 4.0, CONSIDERING PROTOCOL OF PULP AND PAPER INDUSTRY

- Optimization

Optimization helps to find the best option, considering cost or highest attainable performance under given constraints, by maximizing beneficial factors and minimizing non-beneficial factors. In the pulp and paper industry, experimental based models, decision support systems, and decision making tools assist top management executives to resolve problems related to production

- Water Management

Is an activity associated with planning, developing, executing, distributing and optimizing utilization of water resources in the pulp and paper industry.

- Energy Management

Deals with planning the operations of production units in achieving maximum energy efficiency. The energy management focuses on resource conservation, environment protection, best energy utilization alternative and energy savings for pulp and paper industry.

- Enterprise Resource Planning (ERP)

ERP integrates the planning, purchasing, in process inventory, sale, marketing, finance and human resource departments via digital transformation.

- Manufacturing Execution Systems (MES)

MES tracks and documents the transformation of raw materials into finished product. MES maintains the multiple input data of the production process i.e. workers, machines and services.

- Plant Control(PC)

The plant control controls the input and output signals and multiple variables of production units by utilizing digital feedback systems.

- Integration (I)

It is an extension and enhancement in the value of production systems of pulp and paper enterprises by using methods, techniques, routings etc.

- Internet of Things (IoT)

TIoT deals with computing devices and mechanical and digital machines, which transfers data via networking for connecting human to human, machine to machine and human to machine.

- Cyber Physical System (CPS)

CPS is an advanced engineering system, which integrates computational algorithms with physical components i.e. robot, CNC, etc. It is also considered as a potential synchronization between physical and software components enabling production system reliability.

6. RESULTS AND DISCUSSION

The authors conducted a detailed literature review from 2007 to 2017 by using coupled search engine, considering eight key performances practices i.e. WM, EM, ERP, O, MES, PC, I, IoT and CPS in the pulp and paper industry. The authors reviewed ninety three publications. The authors also arranged the publication per digital object identifiers vs publication years. The results are discussed in the following sections:

6.1 Results of five internet based research search engines

Tables 1 and 2 (merged) in the Appendix depict the digital object identifiers and number of publications for the eight key performance practices for the years 2007 to 2017. The results are computed as per the scoring of publications vs practices from 2007-2017, as illustrated in Figure 2.

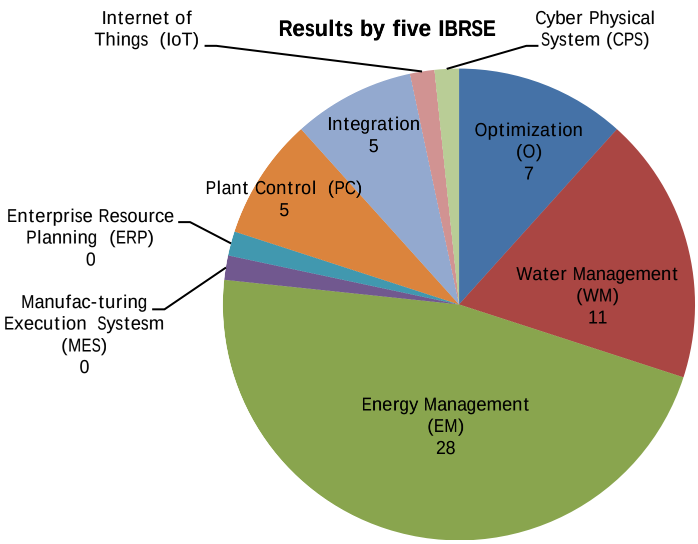

Figure 2. Statistics of research output of key performance practices from 2007-2017

6.2 Results by open internet based research search engines

Tables 3 and 4 in the Appendix detail the digital object identifiers of publications from 2007-2017. The results are confirmed by using an open (Google) internet based research search engine. The results calculated as per the scoring of Table 4, is illustrated in Figure 3.

- Energy Management = 6.
- Water Management = 3.
- Optimization = 9.
- Plant Control = 3.
- Integration = 14.
- Remaining is stable with research output <2%

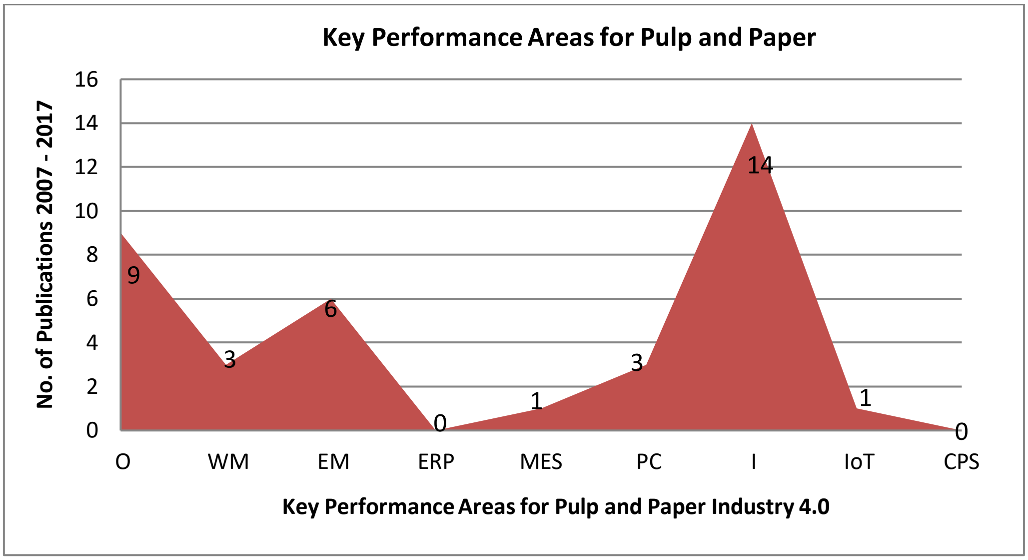

Figure 3. Statistics of number of publications vs practices

6.3 Results of coupled (merged) searching

Table5 in the Appendix exhibits the cumulative publications identified by IBRSE and open search engines from 2007-2017. The results are published as 2D line charts in Figures 4, 5 and 6. The results are as per the scoring of Table5. Aforementioned Figures are sketched for numbers of publications vs key performance practices

- Energy Management = 34.
- Water Management = 14.
- Optimization = 16.
- Plant Control = 8.
- Integration = 19.
- Remaining research is <2%.

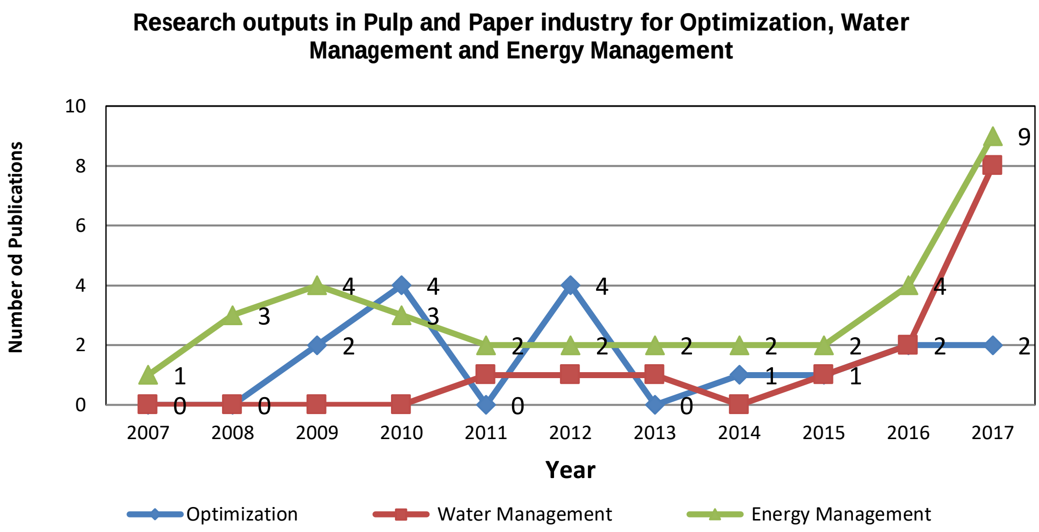

Figure 4. Statistics of publications vs O, WM and EM practices

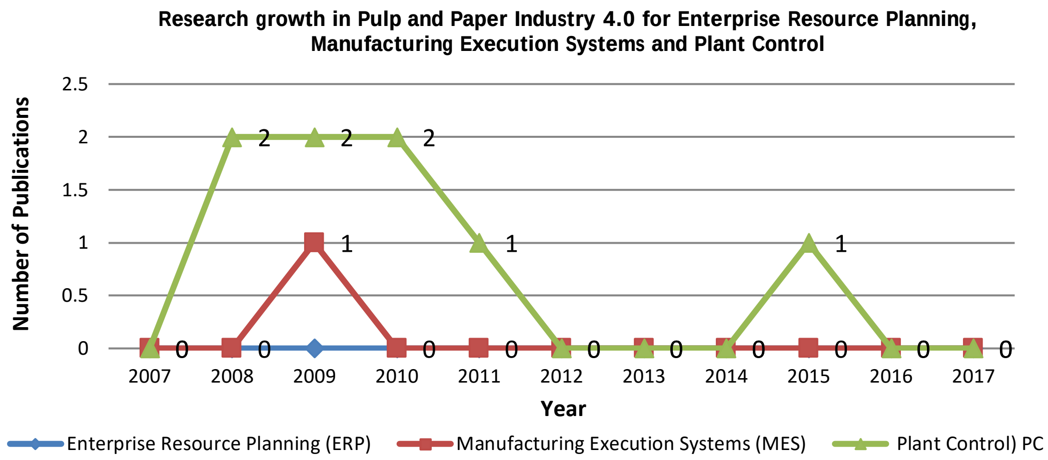

Figure 5. Statistics of publications vs ERP, MES and PC practices

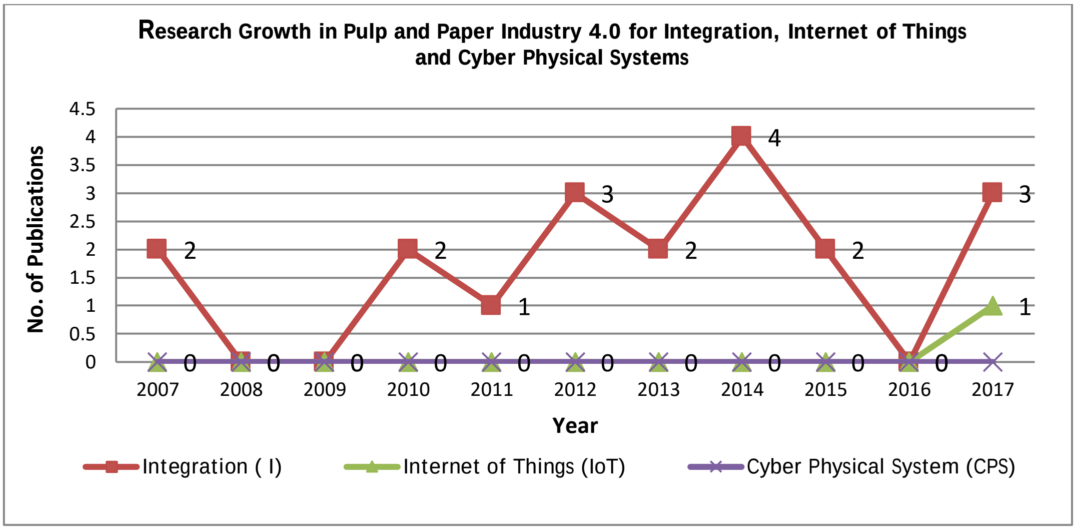

Figure 6. Statistics of publications for I, IoT and CPS practices

7. RESULTS AND DISCUSSION

- **Applications**

This research facilitates researchers to quantify the research output of key performance practices of each sector applying Industry 4.0. The research provides performance measurement practices to aid professionals in the pulp and paper industry in appraising the performance under Industry 4.0, undertaking the subjective information of expert's panel or numeric data.

- **Limitations**

The research is not solely limited to quantify the research output of Industry 4.0 practices in the pulp and paper. The research progress of Industry 4.0 practices of other sectors can be quantified as per the framework detailed in this paper.

- **Novelties**

The research introduces the concept of coupled search engine (open plus five internet based research search engines) to quantify the research progress of key practices of Industry 4.0 for any sector.

8. CONCLUSION

The authors identified ninety three publications on the key Industry 4.0 practices of the pulp and paper industry from 2007-2017 by utilising coupled search engines. The quantity of publications corresponding to EM and WM is thirty four and fourteen, respectively. While I, O and PC have nineteen, sixteen and eighteen publications, respectively. Only two publications are identified for the remaining practices of MES, IoT, ERPand CPS. The obtained results illustrate the following arguments:

- In the case of EM, the research output is 37%. The research output is observed to increase from 2007-2010, however it declines slightly in 2009. The research output is constant from 2011-2015. The likely trends of 2009 and unexpected increases in 2016 and 2017 in comparing the trend of 2011-2015.
- In the case of I, the research output is 20%. The research fluctuates during the observed time period of 2007-2017.
- In the case of O, the research output is 17%. It is zero in 2007. It escalates slightly in 2008 and increases further in 2009, 2010 and 2012. Research output increases from 2014 to 2017, but never breaks the research trends of 2009, 2010 and 2012.
- In case of WM, the research output is 15%. It is zero from 2007-2010. A constant trend is observed from 2011-2013, however it is zero in 2014. Research output increases from 2015-2017, with the highest output achieved in 2017.
- In case of PC, the research output is 9% and is strong in years 2008-2011 and 2015. It is zero in remaining years i.e. 20012,2013,2014,2016 and 2017.
- The research output is less than 2% for MES, IoT, ERP and CPS. In MES, the research output is zero from 2007-2017, with the exception being 2009. The research output is zero from 2007-2017 for IoT, ERP, CPS. The researchers conclude that there is indeed a gap on the fundamental building blocks (ERP/MES/PC) in the pulp and paper industry.

The presented work provides evidence for the need of current/forthcoming researchers to focus upon CPS, IoT, ERP and MES, to further enhance the performance of pulp and paper by application of Industry 4.0. The proposed key performance practices enable managers to evaluate the performance of the enterprise

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APPENDIX

Table 1 and 2. Digital object identifiers against eight key practices of pulp and paper industry 4.0 (five IBRSE results)

Years	O	WM	EM	ERP
2007	-		DOI:https://doi.org/10.1016/j.apenergy.2006.07.003	
2008			DOI:https://doi.org/10.1016/j.enpol.2008.07.017	
2009			DOI:https://doi.org/10.1016/j.jclepro.2009.07.003 DOI:https://doi.org/10.1016/j.enpol.2008.09.097 DOI:https://doi.org/10.1016/j.biortech.2009.02.041	
2010	DOI:https://doi.org/10.1108/14777831011067917 DOI:https://doi.org/10.1016/j.apenergy.2010.04.023		DOI:10.1109/ACC.2010.5531037	
2011	-	DOI:https://doi.org/10.1016/B978-0-444-53199-5.00100-7	DOI:https://doi.org/10.1016/j.forpol.2011.06.003 DOI:https://doi.org/10.1016/j.energy.2011.02.0 DOI:51	
2012	DOI:https://doi.org/10.1016/j.apenergy.2012.01.014 DOI:https://doi.org/10.1016/j.apenergy.2012.01.014		DOI:https://doi.org/10.1016/j.enpol.2012.01.037	
2013			DOI:https://doi.org/10.1016/j.applthermaleng.2011.12.038 DOI:10.1007/s12053-012-9163-9	
2014			DOI:https://doi.org/10.1016/j.bej.2013.11.019 DOI:https://doi.org/10.1016/j.energy.2014.06.070	
2015		DOI:https://doi.org/10.1016/j.jenvman.2015.05.010	DOI:https://doi.org/10.1016/j.enpol.2015.01.028 DOI:https://doi.org/10.1016/j.enpol.2015.01.028	
2016	DOI:https://doi.org/10.1016/j.cie.2016.05.024	DOI:https://doi.org/10.1016/j.jenvman.2015.11.061	DOI:https://doi.org/10.1016/B978-0-12-803411-8.00002-0	

	DOI:https://doi.org/10.1016/j.applthermaleng.2015.10.136		DOI:https://doi.org/10.1016/B978-0-12-803411-8.00004-4 DOI:https://doi.org/10.1016/j.jclepro.2015.12.116 DOI:https://doi.org/10.1016/j.jclepro.2015.12.116	
2017	DOI:https://doi.org/10.1016/j.psep.2017.07.014	DOI:https://doi.org/10.1016/B978-0-12-811099-7.00002 DOI:https://doi.org/10.1016/B978-0-12-811099-7.00004-6 DOI:https://doi.org/10.1016/B978-0-12-811099-7.00005-8 DOI:https://doi.org/10.1016/B978-0-12-811099-7.00007-1 DOI:https://doi.org/10.1016/B978-0-12-8110997.00006-X DOI:https://doi.org/10.1016/B978-0-12-811099-7.00003-4 DOI:https://doi.org/10.1016/B978-0-12-811099-7.00009-5 DOI:https://doi.org/10.1016/j.indcrop.2017.09.006	DOI:https://doi.org/10.1016/j.egypro.2017.03.1766 DOI:https://doi.org/10.1016/j.rser.2017.05.021 DOI:https://doi.org/10.1016/j.egypro.2017.10.210 DOI:https://doi.org/10.1016/j.egypro.2017.10.208 DOI:https://doi.org/10.1016/j.rser.2017.05.021 DOI:https://doi.org/10.1016/j.ijggc.2017.09.010 DOI:https://doi.org/10.1016/j.resconrec.2015.05.001 DOI:https://doi.org/10.1016/j.jclepro.2017.02.090 DOI:https://doi.org/10.1016/B978-0-12-811099-7.00004-6	

Years	MES	PC	I	IoT	CPS
2007		DOI:https://doi.org/10.1108/02635570810847581			
2008		DOI:https://doi.org/10.1108/14636680911004966			
2010		DOI:https://doi.org/10.1016/j.promfg.2017.07.175 DOI:https://doi.org/10.1108/14502191011080836	DOI:https://doi.org/10.1016/j.enconman.2015.06.063		
2011		DOI:https://doi.org/10.1016/j.jclepro.2016.10.166			
2012			DOI:10.1016/jcie.2012.01.008		
2013			DOI:https://doi.org/10.1533/9780857097255.5.765		
2014			DOI:https://doi.org/10.1016/j.jclepro.2014.03.014		
2015					
2016					
2017			DOI:https://doi.org/10.1016/j.apenergy.2017.05.146		

Table 3. Digital object identifiers and URL link of publications vs eight key practices of pulp and paper industry 4.0 (Open research results)

Years	O	WM	EM	ERP	
2007					
2008			DOI: oai:DiVA.org:liu-11673 DOI: 10.1007/s12053-007-9001-7		
2009	DOI:https://doi.org/10.1080/13873950903375387 DOI:https://doi.org/10.1063/1.3183565		URL:https://www.energystar.gov/ia/business/industry/downloads/Pulp_and_Paper_Energy_Guide.pdf		
2010	DOI:2099.1/14785 URL: http://www.dcsc.tudelft.nl/~bdeschutter/private_20100705_acc_2010/data/papers/1674.pdf		DOI: 10.1080/01998591009595081 URL: http://www.cellulosechemtechnol.ro/pdf/CCT10(2010)/p.521-529.pdf		
2011					
2012	DOI:10/2012/1/7/optimization DOI:10.13189/eer.2016.040505	DOI:10.1021/ie2024504	DOI:10.3390/en5093550		
2013		DOI: http://dx.doi.org/10.1155/2013/536721			
2014	DOI:10.5277/epe140110				
2015	DOI: 10.2166/wst.2015.081				
2016		DOI:V3/i8/IRJET-V3I8340			
2017	URL:http://www.ijtsrd.com/papers/ijtsrd7161.pdf				
Years	MES	PC	I	IoT	CPS
2007			DOI:https://doi.org/10.1504/IJEP.2007.012807 DOI:https://doi.org/10.1080/00207729608929332		
2008		DOI:https://doi.org/10.2202/1934-2659.1087			
2009	DOI:10.5539/mas.v3n5p136	DOI:10.18725/OPARU-1788 DOI:10.4236/jwarp.2009.12016			
2010			DOI:10.1016/j.biortech.2010.05.013		
2011			Url:https://search.informit.com.au/documentSummary;dn=313699999526941;res=IELHSS		
2012			DOI:10.1080/01919512.2012.710139 Url:https://researchcommons.waikato.ac.nz/bitstream/handle/10289/11510/Appita%202012.pdf?sequence=2&isAllowed=y		
2013			DOI:https://doi.org/10.1186/1754-6834-6-13		
2014			DOI:10.1021/ie404002r DOI:10.4236/nr.2014.59039		

			DOI:https://doi.org/10.2478/eko-2014-0007		
2015		DOI:10.15662/ijareeie.2015.0403054	DOI:https://doi.org/10.1371/journal.pone.0120954 DOI:10.1111/jiec.12348		
2016					
2017			Url:https://doi.org/10.23719/1390779 file:///C:/Users/ATUL%20KUMAR%20SAHU/Downloads/103-512-1-PB.pdf DOI:10.3183/NPPRJ-2017-32-03-p375-385	DOI: https://doi.org/10.1139/cjfr-2017-0014	

Table 4. Statistic of eight key practices of pulp and paper industry 4.0 by using open search research engine

Years	**O**	**WM**	**EM**	**ERP**	
2007					
2008			2		
2009	2		1		
2010	2		2		
2011					
2012	2	1	1		
2013		1			
2014	1				
2015	1				
2016		1			
2017	1				
Total	9	3	6	0	
Years	MES	PC	I	IoT	CPS
2007			2		
2008		1			
2009	1	1			
2010			1		
2011			1		
2012			2		
2013			1		
2014			3		
2015		1	2		
2016					
2017			2	1	
Total	1	3	14	1	0

Table 5. Sum of publications vs eight key practices of pulp and paper industry 4.0 by using coupled search (five IBRSE+open search research) engine

Years	**O**	**WM**	**EM**	**ERP**	
2007	0	0	1	0	
2008	0	0	3	0	
2009	2	0	4	0	
2010	4	0	3	0	
2011	0	1	2	0	
2012	4	1	2	0	
2013	0	1	2	0	
2014	1	0	2	0	
2015	1	1	2	0	
2016	2	2	4	0	
2017	2	8	9	0	
Total	16	14	34	0	
Years	MES	PC	(I)	IoT	CPS
2007	0	0	2	0	0
2008	0	2	0	0	0
2009	1	2	0	0	0
2010	0	2	2	0	0
2011	0	1	1	0	0
2012	0	0	3	0	0
2013	0	0	2	0	0
2014	0	0	4	0	0
2015	0	1	2	0	0
2016	0	0	0	0	0
2017	0	0	3	1	0
Total	1	8	19	1	0