Analysis of information systems as empowering tools in Circular Manufacturing

Acerbi F.*, Taisch M.*

** Dipartimento di Ingegneria Gestionale, Politecnico di Milano, Via Lambruschini 4/b – Milan – Italy (federica.acerbi@polimi.it - corresponding author -, marco.taisch@polimi.it)*

Abstract: Circular Economy (CE) adoption, especially in manufacturing, is gaining momentum thanks to its potentials in enhancing environmental, social and economic sustainability of this sector. In this context, CE is also named as Circular Manufacturing (CM), and by relying on several strategies it allows to reduce resource consumption and to extend their lifecycle towards lowering the greenhouse gases emissions too. The adoption of CM, among all, requires managerial, organizational, and technological changes and supports. In particular, in the scientific literature, researchers underlined the relevant role that digital technologies, spanning from Industry 4.0-related technologies to software and information systems, have in the implementation of CM with a special attention on data. Although this general awareness is present, in the scientific literature is still scarce research dealing with information systems usage to empower manufacturing companies in embracing CM. Therefore, the present contribution, based on both scientific and grey literature, aims to structure the extant contributions by elucidating which information systems can support CM adoption, by underling their role in respect to the specific CM strategy embraced by the company and the potential benefits obtained. In particular, the present contribution shows which information systems can be used for the advancements of the manufacturing companies' daily activities covering the aspects characterizing CM without being limited to economic benefits only. As a conclusive remark, this research not only aims to cover a research gap, but it empowers practitioners creating awareness about the importance of technological investments to keep high their companies' competitive advantage including CE values in their strategic plans.

Keywords: Circular Economy, Circular Manufacturing; Manufacturing, Information System

1.Introduction

In the last decades, the diffusion of digital technologies in the manufacturing sector has been considered the gear boosting companies' productivity improvement, keeping high their competitive advantage. Among all, Industry 4.0 enabling technologies have seen a wide diffusion worldwide (Erro-Garcés, 2019). Investments in this direction have been supported by policymakers too, understanding the potentialities of these technologies in enhancing enterprises' performances also in terms of sustainability (European Policy Centre, 2019). To report some example on the social sphere, technologies like collaborative robots and exoskeletons can be used to physically support the operators during the productive activities (Romero *et al.*, 2016), and additive manufacturing can be used to develop in a flexible way one-of-a-kind products to improve the alignment between the offer and the market requests (Brischetto, Maggiore and Ferro, 2017). These promising technologies are backed by many others which rely more on the cognitive sphere and data.

Indeed, in most of the cases, the power of digital technologies stands in the possibility to gather huge amount of data and exploit them in a valuable way (Schmidt and Lueder, 2018), by providing positive returns on the economics too. Therefore, starting from the collaborative robots that tend to act as human-beings, other technologies, among which artificial intelligence, big data analytics, and Internet of Things allow data tracking and data analytics, which support the "intelligent" sphere of manufacturing companies. These technologies can be even more powerful if integrated with Information and Communication Systems (Qu *et al.*, 2019).

Actually, information systems (IS), being fed with appropriate data thanks to the support and the integration with Industry 4.0 technologies, can be useful for the fulfilment of sustainable and circular goals (Ferrari *et al.*, 2021; Vidmar, Marolt and Pucihar, 2021). More in detail, circularity is highly promoted by policymakers worldwide, because of its goal to design on purpose regenerative and restorative systems (Ellen MacArthur Foundation, 2015). Circular Economy (CE) can be implemented by manufacturing companies through different strategies, named Circular Manufacturing (CM) strategies, whose introduction is highly reinforced by the usage of specific data (Acerbi *et al.*, 2021). Therefore, the appropriate adoption of IS can be a good mean to reach circularity. Nevertheless, the extant literature is scarce in terms of researches dealing with this issue (Zeiss *et al.*, 2021). Therefore, the research objective of this contribution is to cover this gap by elucidating what are the ISs to be used to support the adoption of the CM strategies in manufacturing companies, investigating IS functionalities and benefits in this context.

The remainder of the paper is organized as follows. Section 2 elucidates the research background on CE and IS, both in the manufacturing sector. Section 3 outlines the methodology adopted. Section 4 reports the results of the literature review, while Section 5 provides the discussion about these results. Last, Section 6 concludes the article underlining the managerial and the scientific outcomes, delineating future researches.

2. Research background

This chapter aims first to provide the reader with the basic knowledge about CE in manufacturing, thus CM, and second to elucidate what are the most diffused IS in manufacturing companies. This creates the ground to investigate their interaction and integration.

2.1. Circular Economy in manufacturing

Even though the concept behind "circular economy" is quite old, this term was coined quite recently and even more recently was defined as an industrial economy designed on purpose to be regenerative and restorative by the Ellen MacArthur Foundation (Ellen MacArthur Foundation, 2015). It is based on the idea to extend as much as possible the resources lifecycles retaining the maximum value from them, to make recirculate resources in sub-sequent cycles and to put efforts in reducing the consumption of natural resources in all the industrial activities. More specifically, these values are applicable to the manufacturing sector through different strategies (i.e. reuse, recycling, remanufacturing, disassembly, circular design, resource efficiency, cleaner production, servitization, industrial symbiosis, closed-loop supply chain), which have been detected and elucidated in the systematic literature review proposed in (Acerbi and Taisch, 2020). These strategies, named Circular Manufacturing (CM) strategies, require the sharing of information among the actors involved, about for instance product characteristics and conditions, to facilitate the resources circulation (Acerbi *et al.*, 2021).

2.2 Information systems in manufacturing

The diffusion of researches dealing with IS can be dated back in the 1970s in alignment with the introduction worldwide of computers in industries (Gorry and Morton, 1971). Although the potentialities are quite known, their usage in daily business activities must be not taken for granted since often, especially small and medium companies, consider these systems as costs and use them only for administrative tasks (Ramdani, Lorenzo and Kawalek, 2009). In particular, looking at the manufacturing sector, this can be considered a later adopter in respect to the service one, and the systems being initial diffused were mainly the Enterprise Resource Planning (ERP), the Customer Relationships Management (CRM) (Ramdani, Lorenzo and Kawalek, 2009), the Material Requirement Planning (MRP), and the Computer Aided Design (CAD) (Kling *et al.*, 1992). More recently the Product Lifecycle Management (PLM) has started its diffusion in manufacturing companies (Terzi *et al.*, 2010).

Below their key characteristics and functionalities are described:

- CAD: supports the engineering department in the product design and allows the firm to be aligned with the external changes and demand from consumers about technical requirements and consumers preferences in product design characteristics (Kling *et al.*, 1992).
- MRP: helps the monitoring of the material consumption, and the inventory level to schedule production and the purchase of materials in alignment to the requests from the market. This system improves the firm flexibility, since the firm's scheduling of the production activities depends on the changes in consumers' demand (Kling *et al.*, 1992; Singh, Singh and Singh, 2013).
- ERP: (an evolution of the MRP, more complex but broader, with less granular data) helps to have a complete view over firms' resources (e.g. human, material, finance etc.) analysing data about for instance business performance, production, spare parts, maintenance, etc. It supports different functions, such as the distribution and sales respectively with order fulfilment and billing, and to be more effective and efficient it can be integrated with the other systems (Singh, Singh and Singh, 2013; Haddara and Elragal, 2015). The Supply Chain Management (SCM) information system might be embedded in the ERP too (McLaren, Head and Yuan, 2004).
- CRM: helps the marketing department in monitoring consumers' behaviours. It supports the tailored advertisement of the products and services sold, by targeting consumers in a customised way (Rajendiran, Sekar and Manikandan, 2017).
- PLM: integrated with the Product Data Management (PDM) system, extends its view over the entire product lifecycle. This is possible since PLM supports the collaboration among different functions stimulating a concurrent engineering approach. It allows internal coordination of the several activities impacting on the product development and on the product entire lifecycle (Terzi *et al.*, 2010).

3. Methodology

Once outlined the characteristics of CE in manufacturing, thus CM, and the most diffused ISs in manufacturing companies, the present contribution operated a review of the extant scientific literature to investigate what has been so far proposed in terms of researches dealing with IS exploitation for CM purposes, to clarify how the usage of

IS can support the adoption of CM strategies. This allows to cover a research gap by grouping and structuring the scattered knowledge already available, and to help manufacturers in this domain in understanding how the single IS can contribute in empowering the adoption of the distinctive CM strategies.

Therefore, an initial research has been performed on Scopus with the following keywords: TITLE-ABS-KEY (“remanufactur*” OR recycl* OR reus* OR dis assembl* OR "cleaner production" OR "industrial symbiosis" OR "closed-loop supply chain" OR "circular design" OR "servitization" OR "circular economy" OR "resource efficiency" AND ("information system" AND manufacturing)) to explore, for each CM strategy taken from (Acerbi and Taisch, 2020), the IS to be adopted according to the scientific literature. The initial output was 250. Only English written documents were selected reducing the sample to 236 (the most meaningful contributions are summarised hereinafter while the remaining part are not reported due to space constraints). In addition, the grey literature (e.g., software companies web-sites, consultant companies reports etc.) has been investigated as well, to evaluate what has been so far developed in an industrial domain observing the experience from the market.

4. Review on information systems supporting CM

The use of IS for CM purposes has been recognised as a powerful mean by scholars, even though very few studies have been so far developed (Zeiss *et al.*, 2021).

Looking at the remanufacturing strategy, to be put in place it is first necessary to have information about product characteristics, and to encounter this need the CAD has been considered essential for the correct implementation of this strategy. CAD is especially useful to encounter the possible reverse engineering issues in giving the initial quality to the restored products (Dekhtiar *et al.*, 2016). In addition, it is relevant to have under control the inventory level of the remanufacturing parts (Turki, Hajej and Rezg, 2015) to obtain also an economic favourable condition in remanufacturing the returned products, which can be done through the appropriate usage of specific ISs. Moreover, new ISs have been proposed, as the case for example of the one by Tateno and Kondoh, (2010) that have introduced the eco-agents systems as new IS to search for instance for new users while the product is in use. This would allow to reduce the lead time to remanufacturing and perform in advance an inspection of product modules to reuse or recycle them. In addition, remanufacturing requires also the correct alignment with the other actors in the supply chain entailing marketing activities too (Li *et al.*, 2009) which require ad hoc systems pursuing their engagement.

Actually, remanufacturing strategy as well as the recycling and the reuse ones require to have under control the product return flows to try to reduce the uncertainty with the final aim to schedule accordingly the internal activities (Aydin *et al.*, 2018). In line with that, for the recycling strategy is fundamental to encounter the consumption pattern of consumers to obtain positive outcomes from the selling of recycled products, and of products containing recycled materials. In addition, ERP systems can be used to support the extend producer responsibility strategy by tracking business resources and commitments to finally evaluate the convenience in recycling products (Singh and Saha, 2018) and it can also allow the producer to have under control the recycling content of each item (Syspro, 2019). Moreover, PLM system can be used to track information along the entire product lifecycle, until the material recycling, by integrating different views and requirements coming from the company’s functions (Zhang *et al.*, 2012).

Products can be recycled only if they have been disassembled first. Therefore, to support this issue, so far in the extant literature examples of recycling information systems are proposed to provide useful information about the product to be disassembled for recycling purposes (Naito and Kashima, 1999). Actually, these systems rely on product characteristics data and can be also integrated with the Product Data Management systems (PDM) to have retrieved information about the disassembling process required for a specific product (David *et al.*, 1999). Moreover, the disassembling strategy requires the usage of CAD to allow the gathering of information about the parts to be disassembled of the product (Yamada, Igarashi and Inoue, 2013). In addition, the information about the disassembling process need to be integrated with the other ISs present in the company to support an improved product end-of-life management and product design based on the product Bill of Material (BOM) (Zhuang *et al.*, 2006) available in the MRP.

ISs cover a relevant role for the correct management of product recovery (Toyasaki, Wakolbinger and Kettinger, 2013), but also for the monitoring and management of production activities. In particular, cleaner production adoption is supported by the gathering of data through cyber-physical production systems which are then stored and used through several ISs enabling the internal sharing of information (Leiden, Herrmann and Thiede, 2021). Moreover, to monitor the environmental impacts of the company’s production activities, environmental management systems are suggested to be introduced based also on the ISO 14001 (Nikolic *et al.*, 2013). These are useful for both resource efficiency and cleaner production, and can be also backed by PLM systems allowing to integrate during product development process, an extended and comprehensive view coming from the different functions (Zhao *et al.*, 2012). MRP is useful too, to balance the production and reduce avoidable waste generation (Dassault Systems, 2017).

The introduction of circular design strategy is supported by the CAD, that can be integrated with the PLM system. Therefore, the PLM allows to integrate environmental product attributes to support the decision-making process enhancing sustainable performances of products along their lifecycle (Diakun, Dostatni and Talarczyk, 2018). The servitization strategy can be enhanced by the adoption of ISs since they sustain innovation in this field (Chen *et al.*, 2020) allowing also to deploy tailored services based on reliable data. It's indeed, important to establish strong relationships with customers (Ellen MacArthur Foundation, 2018).

Industrial Symbiosis networks creation can benefit from the adoption of information-sharing tools which can be based on integrated ISs allowing the correct exchange of resources flows (Fraccascia *et al.*, 2019). The sharing of information aids also the establishment of closed-loop supply chains. In this case, the exchange is performed among actors belonging to the same supply chain which might be consumers (Hong *et al.*, 2021) or suppliers (Golinska, 2009). Therefore, ERP system, which might embed SCM too, can benefit the sharing of information both internally and externally to the company, especially in the discrete manufacturing sector, to allow manufacturers to make coherent decisions about production planning, procurement etc. (Venkatesh *et al.*, 2008). In particular, in this context IS must consider also the return of products and materials to make decisions about the planning of the activities (Karacapilidis, Adamides and Pappis, 2004).

Wrapping up, the type of IS required by manufacturing companies can be different according to the strategy to be adopted. Nevertheless, in most of the cases, their integration can facilitate the adoption of more than one strategy per time enhancing the CM benefits. Indeed, each system has specific functionalities which can better encounter different strategies, and vice versa the data required for the adoption of a specific strategy might be collected through different systems (Acerbi *et al.*, 2021).

5. Discussion

As just stated in the extant literature, CM requires the concurrent adoption of more than one CM strategy per time to fully address the circular values. This need can be highly empowered by the appropriate usage of data relying on the simultaneous usage of several IS (as reported in Table 1). In particular, on the left side of Table 1 are reported the traditional ISs already adopted by manufacturers for other purposes (e.g. ERP for efficiency and effectiveness improvement, and CRM for consumers' engagement). On the right side instead are reported the new-born ISs developed on purpose with the goal to support companies in undertaking a sustainable and circular path (e.g. the recycling information system developed to ensure the gathering of data on the disassembling of products).

Table 1: IS and CM strategies

CM strategies	**Traditional manufacturing IS**					**New-born sustainable and circular - oriented IS**		
	CAD	**PLM (PDM)**	**CRM**	**MRP**	**ERP (SCM)**	**Eco-Agents information system**	**Recycling information system**	**Environmental information system**
Remanufacturing	x				x	x		
Recycling		x		x	x	x	x	
Reuse			x		x	x		
Disassembling	x	x		x			x	
Circular Design	x	x		x				x
Servitization		x	x					
Cleaner Production				x	x			x
Resource Efficiency				x	x			x
Industrial Symbiosis					x			x
Close-loop supply chain			x		x			

Each system has specific characteristics exploitable in CM.

- CAD allows to have under control the product design characteristics. It is important during the design phase to facilitate the disassembling, recycling, remanufacturing and reuse of the product at the end of its useful life;
- MRP allows to keep track of data about the materials and components for each product type which enables to verify the material recyclability, materials consumption and waste. It also encounters the requirements of cleaner production and resource efficiency;
- PLM allows to have a broader view covering different functions requirements. This enables to have a long-term perspective facilitating the resource cycling starting from the product beginning of life and selecting the most appropriate materials and components;

- CRM allows to engage consumers. This facilitates the deployment of tailored services needed for the product lifecycle extension, and supports a reduction of uncertainty about returned products;
- ERP allows to keep track about the resources needed and consumed within the company boundaries supporting the implementation of different CM strategies. It enables to align internal activities with those of the suppliers and the consumers creating a value chain perspective, with the SCM, by facilitating the extension of resources lifecycle.

In most of the cases, more than one system can be used for a certain strategy, but the integration of different ISs, starting at least from those internal to the company, would allow to create internal cohesiveness towards circularity. More in detail, their integration allows to have under control all the resources of the enterprise making firms more flexible and reactive against the market needs, and against the requests from the society in terms of moderate and optimised usage of resources. This indeed allows to obtain benefits from environmental and social point of views, which directly impact on economic positive outcomes. Therefore, considering that each strategy can be supported by the usage of different ISs, the integrated usage of these systems also facilitates the concurrent adoption of the several CM strategies requiring sometimes similar data. In addition, the internal cohesiveness is important and needs to be extended also to the external stakeholders as the case of the establishment of an industrial symbiosis network or a closed-loop supply chain, the integration of systems should be also external. Therefore, the ERP, and in most of the cases also the SCM, are adopted and the integrations among systems belonging to different companies are required to be established. This external integration allows to always have the necessary information without replicating data avoiding possible non-alignment among enterprises. Actually, some traditional manufacturing IS have not been mentioned in the literature as supporting tools for CM, even though what is required for circularity can be found in all of them. It is usually spoken about IS in general without entering in detail about the specific system. To report an example, CRM often is not mentioned as a relevant IS, although its potentialities in engaging consumers are many. This characteristic is extremely important in CM, since there is the need to involve consumers in this transition ensuring their acceptance of the undertaking of this path by companies and stimulating their willingness to purchase the innovative circular products developed by manufacturing companies. Moreover, CRM might be adopted also to reduce the uncertainties related to the return products having under control consumers' behaviours.

Beyond the traditional manufacturing ISs, others are mentioned to support CM adoption, such as the Eco-Agent to track data about product usage to evaluate possible future reuse or recycling instead of remanufacturing, but also the recycling information system which can be integrated with the traditional ones, such as the PLM, to exploit the information about product disassembling, facilitating materials recycling. The development of specific systems might be reflected into the raising awareness about the need to use data to successfully enable the extension of the resources lifecycle. These new proposed ISs are reported below:

- Environmental Information System has been developed ad hoc to keep track about sustainable performances of the company covering in particular the environmental sphere;
- Recycling Information System enables to keep track about disassembling process requirements of the single products to be recycled;
- Eco-Agents allows to keep track of product use to evaluate in advance requests for reuse, recycling or remanufacturing.

6. Conclusions

The present contribution outlined the importance of ISs in managing and sharing, both internally to the company and externally along the value chain, the data required for the implementation of the different CM strategies. More precisely, traditional ISs, already known by manufacturers, have been analysed for their promising role in this direction. In addition, other new-born ISs, developed on purpose to encounter the needs of manufacturers to improve their sustainable and circular performances, have been detected as empowering tools in embracing the CM strategies. Actually, relying on the findings from the extant scientific and grey literature, it has been shown for each strategy the most coherent IS to be adopted grounding on their characteristics. Therefore, this contribution has two-fold implications: managerial and scientific. From a managerial perspective, this research elucidated the main ISs usable to adopt the different CM strategies. It can be used as a reference for manufacturers interested in exploiting the potentialities of the IS to encounter circular values. This opens new opportunities for manufacturing firms towards circularity, empowering their competitive advantage. From a scientific perspective, this contribution covers the scientific gap detected referring to the lack of studies dealing with the exploitation of IS potentialities for CM embracement. Therefore, this research enabled to structure and analyse the scattered knowledge already available in this domain, clarifying the exploitable ISs, both traditional and new-born, supporting the transition.

Last, to reinforce the findings and concretely evaluate the benefits in using ISs for CM, empirical investigations will be developed in future works. Moreover, the specific system functionalities required in CM, independently from the single IS, will be analysed in future research allowing to explore the potentials of other software applications.

References

Acerbi, F. et al. (2021) 'A Systematic Literature Review on Data and Information Required for Circular Manufacturing Strategies Adoption', Sustainability

2021, Vol. 13, Page 2047, 13(4), p. 2047. doi: 10.3390/su13042047.

Acerbi, F. and Taisch, M. (2020) 'A literature review on circular economy adoption in the manufacturing sector', Journal of Cleaner Production, p. 123086. doi: 10.1016/j.jclepro.2020.123086.

Aydin, R. et al. (2018) 'Quantifying impacts of product return uncertainty on economic and environmental performances of product configuration design', Journal of Manufacturing Systems, 48, pp. 3–11. doi: 10.1016/j.jmsy.2018.04.009.

Brischetto, S., Maggiore, P. and Ferro, C. G. (2017) Additive Manufacturing Technologies and Applications. MDPI AG - Multidisciplinary Digital Publishing Institute.

Chen, M. et al. (2020) 'Influence of information technology capability on service innovation in manufacturing firms', Industrial Management and Data Systems. doi: 10.1108/IMDS-04-2020-0218.

Dassault Systems (2017) Material Requirements Planning (MRP): Why Choose a Unified ERP System? Available at: https://erpblog.iqms.com/material-requirements-planning-mrp-erp/ (Accessed: 18 February 2021).

David, B. T. et al. (1999) 'Automation of disassembly processes and its information systems', in Proceedings - 1st International Symposium on Environmentally Conscious Design and Inverse Manufacturing, EcoDesign 1999. Institute of Electrical and Electronics Engineers Inc., pp. 564–569. doi: 10.1109/ECODIM.1999.747675.

Dekhtiar, J. et al. (2016) 'Toward an extensive data integration to address reverse engineering issues', in IFIP Advances in Information and Communication Technology. Springer New York LLC, pp. 478–487. doi: 10.1007/978-3-319-54660-5_43.

Diakun, J., Dostatni, E. and Talarczyk, M. (2018) 'Decision support on product using environmental attributes implemented in PLM system', in Advances in Intelligent Systems and Computing. Springer Verlag, pp. 275–284. doi: 10.1007/978-3-319-77700-9_28.

Ellen MacArthur Foundation (2015) 'Growth within: a circular economy vision for a competitive europe', Ellen MacArthur Foundation, p. 100.

Ellen MacArthur Foundation (2018) KEEPING CUSTOMER CONNECTIONS Why customer relationships don't have to end at the point of sale-lessons from the circular economy COLLABORATIVE PROJECT.

Erro-Garcés, A. (2019) 'Industry 4.0: defining the research agenda', Benchmarking. Emerald Group Publishing Ltd. doi: 10.1108/BIJ-12-2018-0444.

European Policy Centre (2019) Creating a digital roadmap for a circular economy.

Ferrari, A. M. et al. (2021) 'Dynamic life cycle assessment (LCA) integrating life cycle inventory (LCI) and Enterprise resource planning (ERP) in an industry 4.0 environment', Journal of Cleaner Production, 286. doi: 10.1016/j.jclepro.2020.125314.

Fraccascia, L. et al. (2019) 'A framework for industrial symbiosis systems for agent-based simulation', 2019 IEEE 21st Conference on Business Informatics (CBI). doi: 10.1109/CBI.2019.00055.

Golinska, P. (2009) 'The concept of an agent-based system for planning of closed loop supplies in manufacturing system', in Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), pp. 382–389. doi: 10.1007/978-3-642-02481-8_54.

Gorry, G. A. and Morton, M. S. S. (1971) A framework for management information systems. Boston: Sloan Management Review. Available at: https://dspace.mit.edu/bitstream/handle/1721.1/47936/frameworkformana00gorr.pdf (Accessed: 9 February 2021).

Haddara, M. and Elragal, A. (2015) 'The Readiness of ERP Systems for the Factory of the Future', in Procedia Computer Science. Elsevier B.V., pp. 721–728. doi: 10.1016/j.procs.2015.08.598.

Hong, X. et al. (2021) 'Quality information acquisition and disclosure with green manufacturing in a closed-loop supply chain', International Journal of Production Economics, 232. doi: 10.1016/j.ijpe.2020.107997.

Karacapilidis, N., Adamides, E. and Pappis, C. P. (2004) 'An IS framework to support the collaborative design of supply chains', Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 3214, pp. 62–70. doi: 10.1007/978-3-540-30133-2_8.

Kling, R. et al. (1992) 'Information Systems in Manufacturing coordination: Economic and Social Perspectives', in International Conference on Information System.

Leiden, A., Herrmann, C. and Thiede, S. (2021) 'Cyber-physical production system approach for energy and resource efficient planning and operation of plating process chains', Journal of Cleaner Production, 280. doi: 10.1016/j.jclepro.2020.125160.

Li, C. B. et al. (2009) 'Operation model for green manufacturing in the electronic industry', Key Engineering Materials, 392–394, pp. 13–17. doi: 10.4028/www.scientific.net/kem.392-394.13.

McLaren, T. S., Head, M. M. and Yuan, Y. (2004) 'Supply chain management information systems capabilities. An exploratory study of electronics manufacturers', Information Systems and e-Business Management, 2(2–3), pp. 207–222. doi: 10.1007/s10257-004-0035-5.

Naito, T. and Kashima, T. (1999) 'A recycling information system for television sets', in Proceedings - 1st International Symposium on Environmentally Conscious Design and Inverse Manufacturing, EcoDesign 1999. Institute of Electrical and Electronics Engineers Inc., pp. 154–157. doi: 10.1109/ECODIM.1999.747600.

Nikolic, V. et al. (2013) 'Environmental management system, green manufacturing and corporate learning from the discourse of sustainable development', Metalurgia International, 18(3), pp. 214–220.

Qu, Y. et al. (2019) 'An integrated framework of enterprise information systems in smart manufacturing system via business process reengineering', Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 233(11), pp. 2210–2224. doi: 10.1177/0954405418816846.

Rajendiran, P., Sekar, K. R. and Manikandan, R. (2017) 'Customer relationship management in the manufacturing industry, using data mining techniques', International Journal of Educational Science and Research, 7(6). Available at: www.tjprc.org (Accessed: 10 February 2021).

Ramdani, B., Lorenzo, O. and Kawalek, P. (2009) 'Information Systems Innovations Adoption and Diffusion Among SMEs: Current Status and Future Prospects', International Journal of E-Adoption (IJEA), 1(1), pp. 33–45. doi: 10.4018/jea.2009010103.

Romero, D. et al. (2016) 'Towards an operator 4.0 typology: A human-centric perspective on the fourth industrial revolution technologies', in CIE 2016: 46th International Conferences on Computers and Industrial Engineering. Computers and Industrial Engineering.

Schmidt, N. and Lueder, A. (2018) 'The Flow and Reuse of Data: Capabilities of AutomationML in the Production System Life Cycle', IEEE Industrial Electronics Magazine, 12(2), pp. 59–63. doi: 10.1109/MIE.2018.2818748.

Singh, C. D., Singh, R. and Singh, M. (2013) Critical appraisal for implementation of ERP in manufacturing industry, Int. J. Mgmt Res. & Bus. Strat. Available at: http://www.ijmrbs.com/currentissue.php (Accessed: 10 February 2021).

Singh, Y. and Saha, I. (2018) 'Implementing extended producer responsibility into the ERP model', in 2018 Emerging Trends in Electronic Devices and Computational Techniques, EDCT 2018. Institute of Electrical and Electronics Engineers Inc., pp. 1–5. doi: 10.1109/EDCT.2018.8405097.

Syspro (2019) Circular Economy | The Future of Manufacturing | ERP Technology. Available at: https://www.syspro.com/blog/erp-for-manufacturing/circular-economy-the-future-of-manufacturing/ (Accessed: 18 February 2021).

Tateno, T. and Kondoh, S. (2010) 'Eco-agent system for promoting reuse of product modules', in Nihon Kikai Gakkai Ronbunshu, C Hen/Transactions of the Japan Society of Mechanical Engineers, Part C. Japan Society of Mechanical Engineers, pp. 3230–3239. doi: 10.1299/kikaic.76.3230.

Terzi, S. et al. (2010) 'Product lifecycle management – from its history to its new role', International Journal of Product Lifecycle Management, 4(4), pp. 360–389.

Toyasaki, F., Wakolbinger, T. and Kettinger, W. J. (2013) 'The value of information systems for product recovery management', International Journal of Production Research, 51(4), pp. 1214–1235. doi: 10.1080/00207543.2012.695090.

Turki, S., Hajej, Z. and Rezg, N. (2015) 'Impact of the corrective maintenance cost on manufacturing remanufacturing system performance', in Advances in Intelligent Systems and Computing. Springer Verlag, pp. 275–281. doi: 10.1007/978-3-319-18167-7_24.

Venkatesh, S. et al. (2008) 'Closed loop CNC manufacturing - Connecting the CNC to the enterprise', in 2007 Proceedings of the ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, DETC2007, pp. 453–460. doi: 10.1115/DETC2007-35760.

Vidmar, D., Marolt, M. and Pucihar, A. (2021) 'sustainability Information Technology for Business Sustainability: A Literature Review with Automated Content Analysis'. doi: 10.3390/su13031192.

Yamada, T., Igarashi, K. and Inoue, M. (2013) 'Disassembly system design with environmental and economic parts selection using the recyclability evaluation method', Journal of Japan Industrial Management Association, 64(2), pp. 293–302. doi: 10.11221/jima.64.293.

Zeiss, R. et al. (2021) 'Mobilising information systems scholarship for a circular economy: Review, synthesis, and directions for future research', Information Systems Journal, 31(1), pp. 148–183. doi: 10.1111/isj.12305.

Zhang, Q. et al. (2012) 'Research on RFID application in home appliance PLM information management', in Advances in Intelligent and Soft Computing, pp. 155–160. doi: 10.1007/978-3-642-28658-2_23.

Zhao, W. Bin et al. (2012) 'Design and implementation of a PLM system for sustainable manufacturing', in IFIP Advances in Information and Communication Technology, pp. 202–212. doi: 10.1007/978-3-642-35758-9_18.

Zhuang, X. C. et al. (2006) 'Disassembly process management based on BOM', Liaoning Gongcheng Jishu Daxue Xuebao (Ziran Kexue Ban)/Journal of Liaoning Technical University (Natural Science Edition), 25(2), pp. 268–271.