Guest editorial

1. From linear to circular manufacturing business models

1.1 Background and motivation

Since the industrial revolution, manufacturing organisations have been developing better business models and strategies to enhance what it has traditionally been considered their primary objectives of increasing economic profit and resources throughput. However, the last two decades have seen a rise in the awareness of the impact that current manufacturing models have on the environment and society in general (Garbie, 2014). Thus, the traditional manufacturing paradigm, which has been dominated by a linear business model, has now been increasingly challenged by governments and societies. In this linear model, raw materials are extracted, transported to manufacturing sites and processed into a diverse range of products. These products are then shipped to retailers, sold to customers, used, and ultimately discharged and replaced by other products. This business model, however, represents an unsustainable approach to manufacturing and consumption of goods as it is argued it treats nature as an industry, which leads to global negative impacts such as CO_2 emissions, global warming, scarcity of and permanent damage of natural and non-renewable resources, pollution of soil and water, etc. (Geissdoerfer *et al.*, 2017). These negative environmental effects, derived from the linearity of current manufacturing business models, have made organisations in this industry to face pressures related not only to the compliance with environmental regulations but also to challenges of price volatility and supply risks due to increasing resource scarcity (Lieder and Rashid, 2016).

To address the environmental, and other social and economic challenges posed by linear manufacturing business models, the concept of circular economy (CE) has been gaining importance and increasingly drawing attention worldwide (Ghisellini *et al.*, 2016). CE, as opposed to linear models, advocates a closed loop, i.e. circular, flow of materials, raw materials and energy in the entire economic system (Masi *et al.*, 2018; Geng and Doberstein, 2008; Yuan *et al.*, 2006). In this line, Stahel (2010) argues that circular-based models can potentially minimise material, energy and environmental deterioration without restricting economic, social and technical progress. Within the context of manufacturing activities, circular business models (CBMs) are based on keeping resources in the economy for as long as possible. This is possible through the prolonged use of products as well as through restorative processes that take products, by-products and waste materials back into the economy through reusing, remanufacturing and recycling processes (Lacy and Rutqvist, 2015; Lovins and Braungart, 2014). CE therefore advocates manufacturing business models that are restorative by intention, purpose and design, and that shift production value chains from linear to circular manufacturing business models.

However, despite the fact that CE business models are considered as a potential and viable solution for harmonising ambitions for economic growth and environmental protection (Lieder and Rashid, 2016), research in this field has been mainly concentrated at a national, regional and industrial levels, whereas very little attention has been paid to the operationalisation of CE principles and practices at manufacturing systems and processes levels. Therefore, the circular capability of manufacturing systems, processes and operations in general has not yet been comprehensively understood in the light of CE principles. Rigorous research was, for this reason, needed to investigate the operationalisation of CE principles and practices within the context of manufacturing

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systems, operations and processes. This needed research included, but was not limited to, the investigation of the following research questions:

RQ1. What characterises a circular manufacturing business model?

RQ2. Which core capabilities are required in manufacturing processes, systems, supply chains, services, managerial practices and/or technologies to enable a transition from linear to circular manufacturing business models and how can these be developed?

RQ3. How can digital technologies and logistics and supply chain systems contribute to enabling the circular capability of manufacturing processes and systems?

RQ4. How can the degree of circularity and/or circularity readiness of manufacturing business models and/or practices be measured?

RQ5. What are the key benefits, challenges, opportunities and trade-offs for manufacturing organisations to initiate a transition from linear to more CBMs?

RQ6. What are the main experiences, outcomes and lessons learnt from manufacturing organisations which have implemented or transformed the linearity of their manufacturing business models into those with circular characteristics?

RQ7. How can industrial symbiosis configurations connecting organisations from diverse sectors into cascading and feedback loop processes enable the circular capabilities in the manufacturing industry? How can these wider organisational linkages be identified and/or developed?

2. Features and areas of the special issue contributions

This special issue of the *Journal of Manufacturing Technology Management* intends to explore how manufacturing organisations can design, redesign or adapt linear manufacturing processes, systems, supply chains, services, managerial practices and technologies with principles and functionalities that align with the sustainability imperatives of the CE. In a broader context, this special issue aimed at instigating a critical and constructive discussion regarding the role that CE can play on helping manufacturing companies to go beyond the consideration of only economic imperatives to also consider and act upon the effect and impact that their manufacturing operations may have on the environment and society in general. Real-world applications and business models including company case studies dealing with the application of circular manufacturing business models were welcome. Theoretical papers, review papers and methodological papers were also encouraged if CE was explored within the context of manufacturing organisations and their operations. In particular, practical, novel and original contributions investigating the development, application or potential implementation of CBMs in the manufacturing industry were sought, with particular interest on articles that addressed the following research themes:

- restorative manufacturing systems and processes;
- life cycle analysis for CE decision making;
- identification of intra- and inter-connections and feedback loops within the manufacturing industry and their supply chains and production systems;
- traceability of resource streams;
- issues in the segregation of waste streams and its value;
- manufacturing systems improvements as enablers of circularity;
- innovations in technology and resource management practices to enable a transition towards more circular manufacturing business models;

- case studies within the manufacturing sector based on the application of CE models and principles;
- assessment of CE models with focus on investigating their potential, barriers, challenges and trade-offs in the manufacturing sector;
- definition of benchmarking models to support comparative analysis, assessment and simulation of circular capabilities in manufacturing systems and processes;
- definition of suitable measures for manufacturing organisations to assess their level of progress towards more circular operations or to evaluate their readiness to embark on such transition; and
- integration and relationship of the CE approach with other approaches such as industrial sustainability, sustainable/green manufacturing, industrial symbiosis, cleaner production, green lean, etc., within the context of the manufacturing sector.

From the submissions of papers considered for this special issue, four articles that characterise excellent and state-of-the-art research work that spans from a variety of leading edge research in the area of CE, with particular application in the design, management and improvement of manufacturing operations, processes and technology were selected. These papers are summarised in the following section.

3. Contributing articles to the special issue on from linear to circular manufacturing business models

The articles selected for publication in this special issue echo the increasing and contemporary relevance of the special issue themes for academics and practitioners. The articles thus offer a broad multiplicity of research lines, research methods and valuable practical and theoretical insights in the field of manufacturing technology management. Research methods were not limited in scope in order to achieve an overall and complete profile of the latest research perspectives in the field. Therefore, the nominated papers mainly included the development of methodologies, frameworks, models and/or tools that, in some cases, were later applied in real industrial cases, and exploratory researches. Particularly, the selected papers included.

3.1 Managerial practices for designing circular economy business models: the case of an Italian SME in the office supply industry

This paper investigates the managerial practices that companies can implement in order to design a CE business model and how companies can create and capture value from a CE business model. Ünal, Urbinati and Chiaroni adopt a single case study methodology with semi-structured interviews and company, supplier and manufacturing site visits. The visits were conducted in a small- to medium-sized Italian company operating in the office supply industry. With this, the theoretical setting maps a set of managerial practices for a CE business model and sets the research gaps and question in a research framework designed along three main dimensions, namely: value network, customer value proposition and interface, and managerial commitment. The empirical analysis conducted by the authors revealed that the proposed dimensions are interdependent and reinforce each other. Additionally, the managerial commitment as moderating factor between the value network and the customer value proposition and interface dimensions is identified as essential for reaching the intended goals of CE business models. The authors comment that the defined set of relevant managerial practices for CE business models can be used by managers who have the will to embrace in practice CE principles to support the design, change or upgrade of the business model of companies within which they operate.

3.2 Investigating "circular business models" in the manufacturing and service sectors

In this paper, the authors investigate the role of the different CBMs in the manufacturing and service sectors, and apply this in the context of the food industry. Upadhyay, Akter, Adams, Kumar and Varma followed a systematic literature review approach, where the relevant CBMs were explored in the context of the manufacturing and service sectors. By following this research method, the authors shortlisted 40 articles. The shortlisted papers revealed that CE is better than linear economy both in the context of the manufacturing and service sectors. Circular business operations generate value at various stages, starting from raw material sourcing to the disposal of the final goods. The research also found that CBMs promote eco-friendly business and insignificantly contribute to innovation in this environment. The authors argue that the findings derived from the research are relevant and applicable to the food industry.

3.3 Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context: a business model proposal

In this paper, Nascimento, Alencastro, Quelhas, Caiado, Garza-Reyes, Rocha-Lona and Tortorella explore how rising Industry 4.0 technologies can be integrated with CE practices to establish a business model that reuses and recycles wasted material such as scrap metal or e-waste. To carry out the research, the authors follow a qualitative research based on three stages. Stage 1 consisted of a literature review on concepts, success factors and barriers related to the transition towards a CE along with sustainable supply chain management, smart production systems and additive manufacturing. Stage 2 comprised the development of a conceptual framework to integrate and evaluate the synergistic potential among these concepts. Finally, stage 3 validated the proposed model by collecting rich qualitative data based on semi-structured interviews with managers, researchers and professors of operations management. The research outcome consists in the provision of a circular model to reuse scrap electronic devices, integrating web technologies, reverse logistics and additive manufacturing to support CE practices. Results also suggest a positive influence from improving business sustainability by reinserting waste into the supply chain to manufacture products on demand. The proposed model can help industrialists to make their operations and processes more sustainable.

3.4 Analysis of network design for a circular production system using multi-objective mixed integer linear programming model

In this paper, KEK, Rajak and Kandasamy propose a mathematical model for the design of a circular production system for an Indian manufacturing organisation participating in a symbiotic network. To do this, the authors used a multi-objective mixed integer linear programming to model the network for quantifying the economic benefits and then they employed the GAMS optimisation package to simulate the model. As a result, the model is able to compute the economic benefit achieved through circular operations in the case organisation and obtain the flow of different items through the network. KEK, Rajak and Kandasamy suggest that the article can contribute in better understanding the role of sustainable supply chains in a CE model, especially in energy and materials intensive industries.

The guest editors would like to explicit their thankfulness to all those who participated and contributed to this special issue. These included the anonymous reviewers; without their expert guidance, advice and constructive feedback for the improvement of articles, the guest editors would have not been able to complete this special issue successfully. Likewise, the guest editors would like to sincerely thank the Editor-in-Chief of the *Journal of Manufacturing Technology Management*, Professor Harm-Jan Steenhuis, the editorial office

and Emerald Group Publishing for their continuous support and dedication for this endeavour. Finally, the guest editors would also like to acknowledge the effort of all the authors who considered this special issue as a relevant platform to disseminate their research work. The authors and the editorial office of the *Journal of Manufacturing Technology Management* hope that this special issue will make a good reference material and be of great interest and use to the academic and industrial communities that wish to better understand how CE can intervene, support and contribute to deliver more economic, social and environmentally sustainable manufacturing operations and processes, and this way help to address some of the most critical challenges the authors are currently confronting as humankind, i.e. environmental degradation and scarcity of natural resources.

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