Industry 4.0 Adoption and 10R Advance Manufacturing Capabilities for Sustainable Development

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Abstract

Industry 4.0 technologies provide digital solutions for the automation of manufacturing. In circular economy-based models, the resources stay in the system as it experiences one of the 10R (Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Recover) processes. These 10R processes require the development of advanced manufacturing capabilities; however, 10R processes suffer from various challenges and can be effectively overcome through Industry 4.0 technological applications. Although literature has indicated the use of various Industry 4.0 technologies, little information is available about firms' views on the degree of Industry 4.0 application in the 10R based advanced manufacturing area and its ability to achieve sustainable development. The current study aspires to examine how great an effect Industry 4.0 adoption has on 10R advanced manufacturing capabilities and its outcome on sustainable development under the moderating effect of an Industry 4.0 delivery system. Practice-based view and Dynamic capability view theories are used to conceptualise the theoretical model. The research team statistically validated the theoretical model considering 124 data points that were collected using an online survey with a structured questionnaire. The findings point out that the path degree of Industry 4.0 adoption and 10R advanced manufacturing capabilities are statistically significant. 10R advanced manufacturing capability is found to have a positive influence on sustainable development outcomes. The Industry 4.0 delivery system has a moderating effect on the path degree of I4.0 implementation and 10R advanced manufacturing capabilities. This paper explores an emerging phenomenon and establishes new links which serve to enrich and advance literature in this area.

1. Introduction

Globally, manufacturers are facing a scarcity of resources due to unsustainable manufacturing and resource utilization practices (Bell et al., 2013; Gould and Colwill, 2015). In recent times, manufacturers engaged in international markets are adopting various green initiatives for sustainability outcomes which can attract more customers (Kawai et al., 2018). Through corporate social responsibility programs, manufacturers are trying to return something useful to society (Kolk and Van Tulder, 2010). However, most companies are failing to achieve sustainable development goals due to their failure of sustainable remanufacturing, recycling, and reusing operations. These failures are due to their lack of flexibility, visibility and poor resilience (Kouedeu et al., 2014; Jiang et al., 2016).

Industry 4.0 (I4.0) technologies can be used to effectively aid digital transformations of an organisation to achieve sustainable development goals (de Sousa Jabbour, 2018b). It is worth examining how I4.0 adoption can help manufacturers enhance advanced manufacturing capabilities and further meet their sustainable development goals. The current study focuses on a contemporary research area, I4.0, which has become a popular topic within the research community. The fourth industrial revolution has brought an advancement in digital technologies, which will completely change traditional manufacturing architecture (Telukdarie et al., 2018). However, I4.0 technologies pose a challenge because they are relatively new and manufacturing companies face difficulties such as skill gaps, financial constraints and operational complexities in I4.0 projects (Sung, 2018; Raj et al., 2019). To overcome these challenges, a proper I4.0 delivery system needs to be developed (Bag et al., 2018b). I4.0 provides firms with increased visibility. Managers can access supply-and-demand-related real-time data from a supply chain network through the I4.0 system dashboards. This could provide a great opportunity for organization learning (Tortorella et al., 2020) and the ability to run production lines using recycled, refurbished and remanufactured components. Operations can easily be optimised with the implementation of I4.0 systems and a standard operating process aligned with I4.0, which provide several options to optimise business processes and significantly reduce resources and lead times (Chuks and Telukdarie, 2018; Bag et al., 2020 a,b).

In volatile business environments, companies practicing remanufacturing and recycling face problems such as high levels of uncertainty, supply-related bottlenecks, production losses, excess inventory, and delayed sales order dispatch, which affect the overall

operations performance (Inderfurth, 2005). Uncertainties largely influence the decision-making quality of managers. This also leads to an increase in spending levels, thus reducing profit margins. A supply crisis majorly impacts manufacturing schedules and increases backlogs, leading to production loss and lower customer satisfaction levels. A lack of visibility causes difficulty in performing accurate sales forecasting of remanufactured/recycled products. To avoid losing customer orders, firms maintain slack resources, i.e. stocking all high lead time related inputs/raw material. The disadvantage to stocking these items is a blockage of working capital. Further, with increasing technological changes, an increased chance of stock becoming obsolete at some point of time can also result in huge financial losses. A delay in sales order dispatch and the inability to meet customers' requested dates can result in customer dissatisfaction. Such delays that impact customer business can lead to an opportunity loss and can also result in the loss of customers (Bag et al., 2018a). However, manufacturing companies that successfully adopt I4.0-enabled technologies can improve both their top and bottom line simultaneously. As per the PWC report (2016), after adopting I4.0, companies can expect a betterment of more than 10% in terms of efficiency. These companies can also expect an operations cost reduction of more than 10% when they adopt smart manufacturing technologies, which can integrate planning and scheduling activities. Predictive maintenance also helps to significantly lower machine downtime and avoid production delays. Manufacturing companies with a high degree of I4.0 adoption when applying front-end and base technologies will attain operational flexibility, operational efficiency and operational effectiveness (Karimi et al., 2007; Frank et al., 2019).

Manufacturing companies play a big role in sustainable developments; however, it is also a big concern for high technology-oriented manufacturing firms (Law and Gunasekaran, 2012). The proper selection of product design, services and transportation can lower global warming while allowing firms to become competitive in the international market (Gunasekaran and Gallear, 2012). This is possible through the development of advanced manufacturing capabilities using 10R-based manufacturing approaches such as refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle and recover options that can provide opportunities for cleaner production in the circular economy based business model and help firms to achieve a competitive edge over their competitors (Kirchherr et al., 2017). A positive relationship exists between competitive strategies and manufacturing strategies (Amoako-Gyampah and Acquaah, 2008). I4.0 creates value by allowing better flexibility and visibility (Rymaszewska and Gunasekaran, 2017), but a low level of infrastructure and information is generally available to detail the expectations from

firms that belong to different emerging economies with regards to the potential for I4.0 technologies to cause performance improvements (Dalenogare et al., 2018). Small and medium sized firms lack understanding of I4.0 technological applications (Frank et al., 2019). Focus is required on these micro and medium sized firms as they are the backbone of economic development for any country (de Sousa Jabbour et al., 2019). Small and medium sized firms are consuming larger portions of resources and generating higher volume of wastes, therefore research focus is required to analyse different aspects of sustainability (de Sousa Jabbour et al., 2019).

Firms apply various technologies to justify their investments in processes and novel technological applications (Raafat, 2002). Although literature has indicated use of various basic and advanced level I4.0 technologies, little is known about how firms see the degree of I4.0 application in the 10R based advanced manufacturing area to exploit sustainable development outcomes. To remove the void in the literature, the current study aspires to examine how great an effect Industry 4.0 adoption has on 10R advanced manufacturing capabilities and its final outcome for sustainable development.

Based on the preceding discussions the research team aims to answer the question below.

RQ1: How great an effect I4.0 adoption has on 10R advanced manufacturing capability and sustainable development?

Literature indicates that the stronger the delivery system, the better the degree of implementation and the more positive the outcome in manufacturing operations (Bag et al., 2018b). The I4.0 delivery system involves top management support, training and project resources, support of research institutes, and universities facilitating adoption of I4.0 technologies (Bag et al., 2018b). The literature also indicates that a large demand exists for information and communication technology adaptation among the segment of small and medium enterprises in South Africa (Cant and Wiid, 2016). This gap can be bridged using I4.0 technologies (Frank et al., 2019), which can easily connect the shop floor to the top floor (Telukdarie et al., 2018). However, there is a lack of awareness around I4.0 and its related terms such as internet of things (IoT), industrial internet of things (IIoT), and supply chain 4.0. To many in the business world, the interaction between these terms remains unknown (Glas and Kleemann, 2016). Moreover, small and medium enterprises consider themselves inefficient when it comes to implementing new technology with respect to manufacturing scheduling and control areas (Moeuf et al., 2018). Large manufacturing firms face various

challenges, from sustainable development policies for final products to the real-time production scheduling of manufacturing resources (Zhang et al., 2018a). Few studies have been completed that are related to the sustainability of the 10R advanced manufacturing capability while also considering Industry 4.0 (Prause and Atari, 2017). The potential of I4.0 to aid in developing sustainability-related research is in an early stage of its existence and requires more attention from future researchers (Bag, 2018b). The current study attempts to answer the second question as under.

RQ2: Does I4.0 delivery system play a moderating role on the relationship between degree of I4.0 adoption and 10R advanced manufacturing capability?

The theoretical relevance of the current study is its focus on three interesting concepts, one in the domain of information technology (I4.0); the second in that of operations management (10R advanced manufacturing), and the third in environmental management (sustainable development). Practice Based View (PBV) and Dynamic Capability View (DCV) theories are used as theoretical support to explain the links, which the research team believes is the unique contribution in this study.

Section two detailed the main constructs that are central to this study, such as I4.0 adoption, 10R advanced manufacturing capability, and sustainable development. Further, the research team presents the two key theories (Practice-based view and Dynamic capability view) used to develop the research framework. In section three, the research team presents the hypotheses followed by research methodology applied in this study. The data analysis and findings are in section five is followed by the discussion of the results; and the final sections present the theoretical and practical usefulness of the study.

2. Review of Literature
In this section, the research team describes the key constructs and theories used to develop the research framework.
2.1 Industry 4.0
Industry 4.0 (I4.0) research in operations management is gaining momentum as digitalization is considered a priority among manufacturing companies (PWC report, 2018). A report by Deloitte published in 2014 indicated that enabling Industry 4.0 technology would lead to global supply chain operations becoming more competitive (za-Africa-industry-4.0-report). Industry 4.0 tools can be used to integrate all of the key functions in order to share

common data, information, and knowledge throughout the supply chain (Dalenogare et al., 2018; Dev et al., 2019). They can also be applied to automate critical operations activities. However, the key impact of Industry 4.0 is its ability to produce and access real-time information to allow increased visibility and to mitigate risks in the supply chain network (Telukdarie et al., 2018). The unstructured data generated from various sources, such as intelligent digital sensors (temperature, pressure, flow, weight, density and power utilisation in a manufacturing environment) connected via wireless networks and mobile devices (from sales, procurement, planning and control, stores team) with special applications, can generate a high volume of data which can then be analysed in a central control room to further extract key information for quality decision making. This can improve the accuracy of forecasts, supplying a greater degree of visibility, higher resource efficiency, asset utilisation, and improved throughput times (Telukdarie et al., 2018).

Smart manufacturing uses systems based in Internet of Things (IoT) and artificial intelligence (AI) to plan machine loadings and vehicle routing, control production flows, and schedule deliveries and vehicle movements. According to Čolaković and Hadžialić (2018), IoT-based applications enable a seamless integration of the virtual world with the physical world. IoT uses a combination of devices to produce data, send it to other devices and then further send it to the cloud. This data is useful when it comes to management decisions and data mining completed by business analysts who extract key information from data.

Decision making is one function of data quality and stakeholder commitment that is important for data quality and analytics (Hazen et al., 2017). This is why big-data-based research is gaining importance as supply chains see an increasing complexity (Hazen et al., 2016). Hazen et al. (2014) suggested a method for scrutinizing and managing data quality in supply chain management, while Dubey et al. (2016) investigated the role of big data and analytics in enhancing sustainable manufacturing. In a recent study, Dubey et al. (2017b) stated that there was a positive relationship between big data and predictive analytics and social/environmental performance. Huge volumes of data are constantly being generated by business logistics operations (Wang et al., 2016). The critical information and knowledge gained from the shop floor/inbound logistics/outbound logistics can be used for new services and applications (Dev et al., 2019). Machine-to-machine communication systems are an advanced technology, which enables the exchange of wireless data between IoT equipment and the gateway. Further, with the use of the internet, data flows from the gateway to a remote repository in the control room (Montori et al., 2018). However, machine-to-machine communications in smart manufacturing have different traffic features and cause distinctive

problems. Smart technologies such as advanced manufacturing systems (additive manufacturing), advanced process control, and advanced machine control are used to monitor and control smart production lines. The main focus of I4.0 technological enablement in manufacturing is the improvement of operational flexibility, operational efficiency and operational effectiveness in order to enhance operational performance (Karimi et al., 2007).

Delic and Eyers (2020) suggested that additive manufacturing can improve supply chain flexibility and supply chain performance. Further, Lucianetti et al. (2018) suggested the prerequisites of application of advanced manufacturing tools. Raj et al. (2019) mentioned that coordinated national level policy on I4.0 is essential for the diffusion of technological innovation. Without these policies, restricted applications may deprive firms from availing full benefits. It is clear that digital strategy and resources are essential for I4.0 applications.

2.2 10R advanced manufacturing capability

The foundation of a circular economy is built on extending both manufacturer responsibility and the accountability of end users. In a circular economy, the resources stay in the system for a long time and provide maximum value, and then at the end of its life cycle, components are recovered (Bag et al., 2020a). Developing advanced manufacturing capabilities requires research and developments (Ren et al., 2015; Chan et al., 2018). Advanced manufacturing using 10R-based approaches such as refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle and recover can provide options for cleaner production and can help firms achieve a competitive edge over their competitors (Kirchherr et al., 2017). Digital technologies can be used to allay uncertainties in 10R manufacturing operations. Durach et al. (2017) discussed contemporary 3D printing based production steps and presented fifteen challenges. The advanced manufacturing technology of additive manufacturing and prototyping can help immensely in 10R manufacturing operations (Hannibal and Knight, 2018). Mativenga et al. (2017) declared cost reduction to be an influential driver and sustainer for composite waste recycling in South Africa. Cost control can be enhanced by adopting Industry 4.0 and vertical and horizontal integration of the firm to allow a flow of information. 10R manufacturing is a relatively new concept, thus further research is required to shed light into this important area. The basic concept of 10R principles is presented in Figure 1.

1	Refuse means making product redundant by discarding its function or by offering the same function with a completely dissimilar product
2	Rethink means making product use more intensive
3	Reduce means use of lesser natural resources in manufacturing
4	Reuse means use of discarded product by another user which is still in working condition and the original functionalities are present
5	Repair means repairing and maintenance of defective product so that it can be used with original function
6	Refurbish means restoring an old product to bring it up to date
7	Remanufacture means use parts of discarded product in a new product with the same function
8	Repurpose means use discarded product or its parts in a new product with a different function
9	Recycle applies recycling for processing materials to obtain the same or lower quality of product
10	Recovering use incineration of material for energy recovery

Figure 1. 10R principles (Source: Kirchherr et al., 2017; Potting et al., 2017)

2.3 Sustainable development

In September 2015, the member states of United Nations (UN) adopted the 2030 agenda for Sustainable Development (SD). SD focuses primarily on people, planet and prosperity. The 2030 agenda includes 17 goals, 169 targets, and 231 indicators. Based on these global SD targets, each country is establishing their own targets on a national level. The vision for African Union is "Africa We Want", which includes 8 principles, later transformed into 7 goals of Agenda 2063 which is considered a vision-cum-action plan (Dlamini, 2015). South African manufacturers are aligning these 7 goals with business operational goals to enhance ecology, economy, and social equity (Mativenga et al., 2017).

Markley and Davis (2007) stated that, as the current sources of competitive advantages deplete, firms must focus increasingly on new sources of competitive advantage for sustainability. Carter and Rogers (2008) introduced the concept of sustainability, which is basically the integration of social and economic parameters to allow a firm's long-term economic viability. Winter and Knemeyer (2013) stated that current literature lacks sustainability-related studies focusing on an integrated approach. Cultural and economic factors also greatly influence sustainability developments in any country (Roy and Goll, 2014).

Therefore, identifying key sustainable supply chain drivers and understanding the inter-relationships among those drivers can be helpful for managers to use as a simple guide (Gimenez et al., 2012; Dubey et al., 2017b; Dubey et al., 2015) for integrating sustainability

aspects in business operations. Supply chain transparency was found to enhance social and environmental parameters (Dubey et al., 2017c). Literature indicates that lean practices can help both directly and indirectly in achieving supply chain sustainability (Ruiz-Benitez et al., 2019). Firms are gradually moving to a circular economy by applying recycling and remanufacturing based principles (Bag et al., 2018a). Trust building is important to operate business in a sharing economy (Govindan et al., 2020). It is clear that without complying to SD goals, firms are likely to perish in this planet. Next, we present the theories used to conceptualise the research framework.

2.4 Underpinning theories

Conceptual research methodologies provide momentous enhancements to a researcher's ability to develop solid theories on operations management. The proposed theory may be a simple framework, but it must meet the Dubin's five basic needs for a theory nonetheless, in that it: offers an improved understanding; is interesting; consists of variables and their relations; contains no composite variables; and contains the boundary criteria (Meredith, 1993).

2.4.1 Practice Based View (PBV)

The PBV perspective was proposed by Bromiley and Rau (2016). Having reviewed top Resource-Based View (RBV) papers, they contend that applying RBV in operations management research does not always help researchers align with their research objectives. RBV works on certain assumptions, such as those firms that are aiming to maximize profit margins and managers in firms that are strictly rational. Resource heterogeneity and resource immobility are two further assumptions in RBV (Barney and Arikan, 2001).

Bromiley and Rau (2016) proposed that PBV was a better choice for operations management scholars to elucidate the total set of firm and unit performance on the basis of exchangeable practices. In PBV, the dependent variables are adoption or usage of particular practices and analysing midway or end performance results at a firm or a plant level or other business units. The explanatory variable in PBV is what creates the difference at a firm, plant level or other business unit. The underlying assumption in PBV is that firms demonstrate a large deviation in performance within an industry; moreover, not every firm adopts every practice that may prove beneficial to them. As a result, the utilisation of practices can clarify performance deviation. The payback of individual practices may vary across an organisation as various moderators' impact each and every practice. Thus, PBV can remove a number of problems linked with RBV. Similar to RBV, PBV is an umbrella concept under which a researcher may use alternate theories to present the primary concept that can clarify the

specific impact on competitive advantage or performance, and which is triggered by individual firm characteristics.

In the present research study, authors argue that I4.0 is an individual practice that may be used by individual firms to enhance 10R advanced manufacturing capabilities. Furthermore, the research team considers the I4.0 delivery system a moderator that impacts the I4.0 practice and its outcome on the firm's 10R advanced manufacturing operations. Enhanced operational excellence means improved operational flexibility, efficiency, and operational effectiveness which further determine the development of 10R advanced manufacturing capability to be able to run remanufacturing- and recycling-based production operations. I4.0 practices lead to the development of 10R advanced manufacturing capabilities, which is further supported using Dynamic capability view theory.

2.4.2 Dynamic Capability View (DCV)

Dynamic capability theory is used by previous researchers in operations management research, specifically for performing strategic choices under different business scenarios (Teece and Pisano, 1994; Teece et al., 1997; Barreto, 2010).

Teece (2007) defined dynamic capabilities, stating that they "*can be used firstly, to anticipate and mould opportunities and threats, secondly, to grab opportunities, and thirdly, to sustain competitiveness through improving, integrating, defending, and, fourthly, when required, reconfiguring the tangible and intangible assets of the firm*".

Here, researchers argue that 10R advanced manufacturing capability is required to anticipate threats and to be able to make a strategic move before competitors, and also to be able to penetrate newer markets with remanufactured/recycled products at competitive pricing. The firm can reconfigure both tangible and intangible assets in 10R advanced manufacturing activities as per business requirements.

3. Research Hypotheses

The three research hypotheses are developed from the preceding discussion.

3.1 Degree of I4.0 adoption and 10R advanced manufacturing capability

International businesses practicing smart manufacturing focus mainly on three aspects to measure operational excellence: operational flexibility, operational efficiency, and operational effectiveness (Karimi et al., 2007). Smart production lines apply principles of flexible manufacturing systems that aid easy changeovers without having to wait a long time for an input (raw material/returned goods) and continue production of other products with available resources. This can save time and resources (energy, air, water), improve equipment

and manpower utilisation, and significantly save costs. However, the main contribution of implementing such a flexible system is in regard to resource efficiency and resource savings (Kumar et al., 2015; Malik et al., 2016).

I4.0 implementation improves the process and product efficiency. I4.0-enabled technologies help to reuse the waste generated during the manufacturing stages. They can also help recover energy from scraps/rejects and production wastages. These advanced technologies also optimise business processes and result in a lower percentage of scarce resource usage required in unit product manufacturing (Kolber and Zuklke, 2015).

Data integration in I4.0 systems provides increased visibility in the supply chain network (Xu et al., 2018). As technology advances, stock can become obsolete, thus smarter companies utilise I4.0 systems to avoid overstocking/understocking resources. I4.0 technological enablement can be used to provide accurate sales forecasts and companies can then plan and schedule accordingly to meet customer requirements (Saucedo-Martínez et al., 2018). I4.0 automation can improve the quality of business operations in a volatile environment and thus allows smart manufacturing firms to develop their ability to successfully apply the 10R manufacturing principles. This will provide a competitive edge to a manufacturer over its competitors (Chen et al., 2015; de Sousa Jabbour et al., 2018b). Therefore, we hypothesise:

H1: Manufacturing companies which adopt I4.0 to a greater extent to apply front end and base technologies will demonstrate higher levels of 10R manufacturing capabilities.

3.2 Moderating effect of I4.0 delivery system on the path degree of I4.0 implementation and 10R advanced manufacturing capabilities

The I4.0 delivery system involves top management support, training resources, project resources, and the support of research institutes and universities (Bag et al., 2018b). Top management support in I4.0 projects ensures the success of projects. The interest of top management in the I4.0 project motivates juniors to participate more actively in projects and to manage it efficiently. Management reviews of I4.0 projects' progress greatly help in achieving project goals (de Sousa Jabbour et al., 2018a). Training resources are an integral part of the I4.0 delivery system. In-house and external training for employees are necessary to keep them abreast of the technological advancements and process changes in order to easily fit into the I4.0 structure.

Similarly, project resources are important to drive the I4.0 delivery system. In successful projects, the I4.0 project team is headed by an experienced and capable project manager (Lasi et al., 2014). Secondly, a logical and realistic schedule for I4.0 implementation

will generate better outcomes. Lastly, the application of appropriate project management tools and techniques while adopting I4.0 projects will provide a better operational output (Albers et al., 2016) which indicates that the level of I4.0 delivery systems influences their implementation. If the I4.0 delivery system is not properly developed within the company, the full extent of I4.0 activation cannot be achieved, which will lower the capabilities of 10R advanced manufacturing. Therefore, we hypothesise:

H2: Manufacturing companies with a stronger (weaker) I4.0 delivery system have a greater (lower) level of operational excellence for a given level of I4.0 adoption.

3.3 10R advanced manufacturing capability and sustainable development

The changeover to a circular economy needs advanced technological applications (Cecconet et al., 2017). I4.0 architecture can fit the technical requirements necessary to set up a sustainable smart manufacturing unit to run production lines using 10R principles. The ability to build 10R advanced manufacturing capabilities can transform the traditional operations into a circular economy system. Globally every multi-national company is currently aiming for cleaner methods of production to achieve sustainable development goals (Fahy, 2002). Adopting 10R principles in the production line will help to develop a closed loop supply chain and enhance the longevity of resources. This will help engineering companies to improve environmental quality and increase economic prosperity and social equity, thus aligning with sustainable development goals (Zhang et al., 2018b). Therefore, we hypothesise:

H3: 10R advanced manufacturing capability has a positive influence on sustainable development.

4. Research Methods

The proposed method is based on empirical research design. Empirical is defined as knowledge gathered from real world observations or experiments (Flynn et al., 1990). Empirical research is field based research designed to collect data from naturally occurring events. Field data can be useful when building a baseline for a longitudinal study and for developing parameters and distributions for mathematical modelling and simulation studies. Empirical data is very useful for theory building and theory verification in the field of operations management. Empirical study in operations management research consists of five key steps (Flynn et al., 1990). The steps followed are depicted in Figure 2.
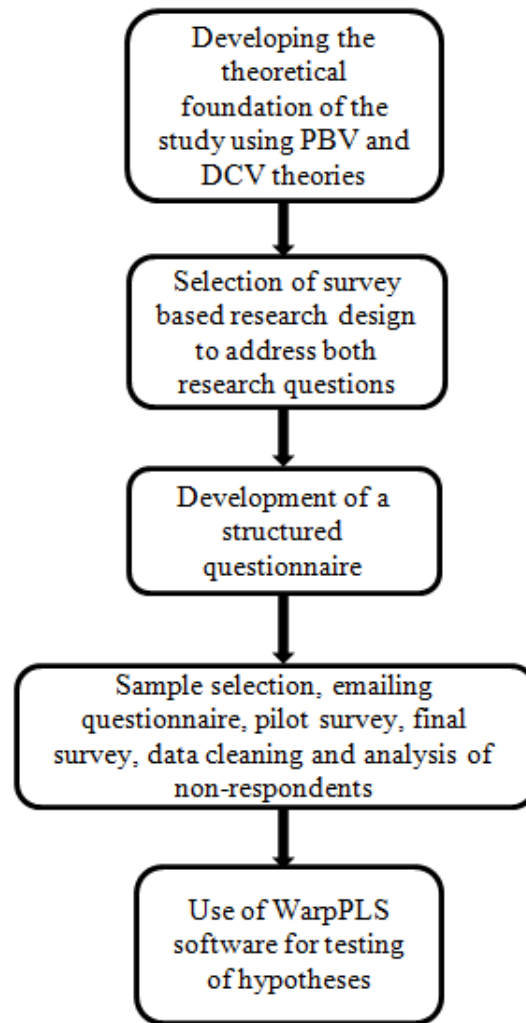
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┌─────────────────────┐
│   Developing the    │
│    theoretical      │
│ foundation of the   │
│ study using PBV and │
│    DCV theories     │
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│  Selection of survey│
│ based research design│
│   to address both   │
│  research questions │
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┌─────────────────────┐
│  Development of a   │
│     structured      │
│   questionnaire     │
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│ Sample selection,   │
│ emailing            │
│ questionnaire, pilot│
│ survey, final       │
│ survey, data cleaning│
│ and analysis of     │
│ non-respondents     │
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│  Use of WarpPLS     │
│ software for testing│
│   of hypotheses     │
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Figure 2. Research steps (Source: Flynn et al., 1990)

The first step deals with developing the theoretical foundation of the study. In this study PBV and DCV are used to develop the theoretical foundation of the research. The current study examines a research problem that involves theoretical verification.

The second step involves the selection of a research design appropriate for both the research problem and the theoretical foundation of the study. The current study focuses on survey-based research design which is a commonly used method in operations management research.

The third step is the selection of data collection methods which can involve one or more than one method. In the current study, a structured questionnaire is considered for the purpose of data collection. A large number of factors may bias survey-based research using questionnaires. Therefore, prior to commencing the survey it is important that the researcher design a reliable questionnaire consisting of valid constructs.

The fourth step is the collection of data. Sample selection, questionnaire emailing, pilot survey, final survey, data cleaning and analysis of non-respondents are part of this step.

The fifth step consists of the selection of an appropriate statistical tool for data analysis. The key focus in theory verification research is hypothesis testing that is within a specified level of confidence. In the current study WarpPLS software is used to perform hypothesis testing.

4.1 Survey questionnaire

South Africa is an emerging economy and is currently witnessing an increase in consumer demands and spending levels. This country has rich mineral resource reserves which attract foreign investors. South Africa has world-class facilities with an increased number of research and development activities taking place in the advancement of manufacturing and digitalisation related areas (DTI report-Why invest in South Africa).

The scales are adapted from previous studies such as the degree of I4.0 implementation consisting of three items which is adapted from Frank et al. (2019); I4.0 delivery systems consisting of four items are adapted from Karimi et al. (2007) and Sung (2018); 10R advanced manufacturing capability consisting of ten items is adapted from Kirchherr et al. (2017); and Sustainable development consisting of three items is adapted from Kirchherr et al. (2017) (refer Table 1). Two control variables including age of the organization and size of the organization are considered in this study. Firm age indicates the operating years since the firm's establishment. The firm age is controlled, bearing in mind the ability of old firms to develop capabilities and process information more easily than new firms. Old firms are equipped with better information-collection and processing capability, therefore old firms achieve increased productivity performance in the dynamic business environment (Yu et al., 2018). Firm size can be measured by considering the number of workers employed at the firm. More workers are employed in larger firms. In large enterprises there is a larger availability of resource levels and capabilities (Gunasekaran et al., 2017).

4.2 Sample selection and data quality checking

The sample is selected using the convenience sampling method from the Chartered Institute of Purchasing and Supply (CIPS), South Africa database. For the measurement of the items, the research team used a Likert scale (5-point) and initially a pilot run was performed among forty executives to see the appropriateness of the scale. Four items related to sustainable development construct were dropped from the initial scale as they were indicated to be redundant and could create multicollinearity issues. The final survey was conducted by

sending the Google form based questionnaire link online to 500 potential respondents. CIPS database is considered for selecting the samples. In the end, 124 questionnaires are returned, indicating a reply rate of 24.80 percent. In Table 2, the respondent details are presented which indicates that the highest responses were received from two sectors (Manufacturing/manufacturing-related services and automotive parts and associated producers) and, secondly, a large percentage of responses were received from persons working over thirty years in the industry.

Further, an analysis is performed to discern the role of the respondent in the organisation as well as the size (small, medium or large) of the organisation. In Table 3, the results of the analysis are presented, wherein it is shown that the greatest number of responses are received from Senior Vice President/Vice President level and, secondly, that the maximum responses are received from medium-sized organisations with 300-500 employees. For this study, the research team gathered primary data which poses the risk of common method bias (CMB) (Podaskoff and Oragn, 1986). However, a robust method of designing the instrument using multiple scales was used to minimize the effect across each type of construct. Further, the research team used a conservative version of Harman's one factor test (Podaskoff et al., 2003) which depicted that one of the factors explained 35.93% of the variance and was below the suggested limit. This concludes that the data is free from CMB.

Non-response bias (NRB) test is also performed. The first wave and the second wave are compared using SPSS software. The survey was started in the second week of Jan 2019 and the research team received forty responses during early February 2019. After performing one round of follow up; the research team received another eighty-four responses before the end of June 2019. The results of the comparison indicate there is statistically no significant difference between early and late respondents. It was also observed that there exists no significant difference between the profile of respondents and non-respondents. This confirms that the study is free from non-response bias (Armstrong and Overton, 1977).

Table 4 provides the details related to model fit and quality indices such as APC, ARS, AARS and results indicate that they are statistically significant. AVIF and AFVIF values are satisfactory and indicate no threats related to multicollinearity (Kock, 2016). Finally, the research team checked the Tenenhaus GoF result which indicated large fit and that the model can be used for further analysis.

5. Data Analysis and Findings

Structural equation modelling is a group of multivariate data analysis that can be used to assess the complex relationship between latent variables and indicators. SEM using partial least squares method is used extensively in the field of operations management. Leading researchers in this area such as Wamba et al. (2017); Dubey et al. (2019 a, b) have used this PLS-SEM technique in their research work. In PLS-SEM analysis any latent variable can be measured through many indicators. Researchers need to look at the path coefficients and corresponding P values for assessing the links. PLS-SEM is used in this study because it has the ability to estimate hierarchical models by eliminating the vagueness of prohibited solutions through means of its flexible assumptions (Hair et al., 2011).

WarpPLS version 6.0 software is used to perform the path modelling. To verify the connections of the model, causality assessment indices are estimated, and the values are provided in Table 5. All values are above the acceptable level of 0.70. The reliability of the instrument is analysed using composite reliability as well as Cronbach's alpha and Nunnally and Bernstein (1994) showcased that its value should be 0.70 or higher. The analysis in Table 6 showcases that the composite reliability and Cronbach's alpha for all variables are above 0.70 and thus reflect a high level of instrument reliability.

As per the suggestion of Fornell and Larcker (1981), the discriminant validity is checked, and no abnormality related to association of construct with an incorrect variable was found. The results are presented in Table 7. The combined loadings and cross loadings are presented in Table 8. All of the standardised factor loadings were above a level of 0.50 and significant at P <0.001.

In Figure 3, the model after statistical testing is presented.
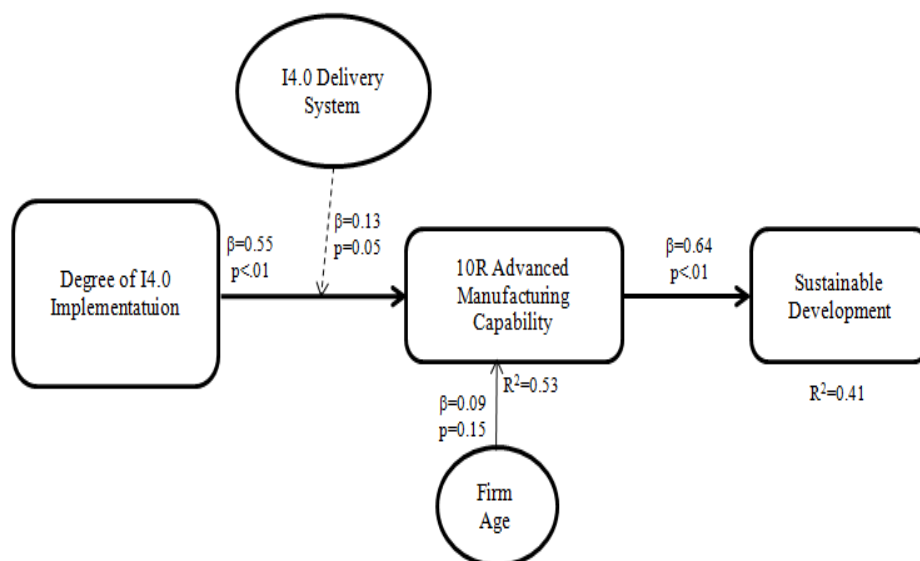
Notes: Significance at the 5% level

Figure 3. Model obtained post statistical testing (Source: WarpPLS output)

The hypothesis testing results are provided in Table 9. All research hypotheses are supported based on the p values (all are below 0.05). This supports, firstly, the relationship between I4.0 and 10R advance manufacturing capability and secondly, the direct relationships between 10R advance manufacturing capability and sustainable development. The moderating effect of I4.0 delivery system on the path I4.0 and 10R advance manufacturing capability is shown to be significant. Firm size and firm age are the control variables used in this study and neither of them showed any significant influence on 10R advanced manufacturing capability. Firm size is controlled during the data sorting stage (no response is obtained from firms having less than 100 employees).

6. Discussion

Globally, firms are focusing on developing sustainable production and consumption strategies to reduce their negative environmental and social impact. 10R-based advanced manufacturing capabilities can be developed to manufacture products in an environmentally friendly manner. However, a lack of visibility increases uncertainty and eventually results in low supply chain responsiveness. This is one of the main setbacks for any 10R-based advanced production line. Failing to accurately estimate demand due to a poor sales forecast and lack of visibility in the supply lines impacts the production scheduling and machine loading parameters. This impacts the sales order dispatches and ultimately increases customer dissatisfaction levels. A poor visibility of inventory levels throughout the supply chain means it is difficult to estimate the volume of old goods/non-functional goods/components-related stock that may arrive at the focal firm's warehouse at any point in time. Moreover, poor demand visibility leads to stock remaining stagnant for an extended period of time, thus blocking the working capital. Technology is changing rapidly and may even lead to obsolescence of such stocks, which leads to a financial loss for the firm. The fourth industrial revolution has brought a digital revolution to the operations management world. I4.0 technology enablement is used to apply front end technologies (smart supply chain, smart working, smart manufacturing and smart product) and base technologies (IoT, Cloud, Big data and Analytics) can provide a greater degree of visibility and enhance operational performance. The current study examined the extent of the effect I4.0 adoption has on 10R advanced manufacturing capabilities and sustainable development and, secondly, to study the

moderating role of the I4.0 delivery system on the relationship between the degree of I4.0 implementation and 10R advanced manufacturing capability. The research findings are summarized in a framework which indicates that firms with a high degree of I4.0 implementation lead to a positive development of 10R advanced manufacturing capabilities. Secondly, 10R advanced manufacturing capabilities are found to have a positive influence on sustainable development outcomes. Lastly, I4.0 delivery system is found to have a moderating effect on the relationship degree of I4.0 adoption and 10R advanced manufacturing capabilities. This suggests that firms should focus on the degree of I4.0 adoption and 10R advanced manufacturing capabilities to enhance sustainable development outcomes and achieve their goals. However, serious focus on the development of infrastructure for I4.0 delivery systems is essential. This paper explores an emerging phenomenon and establishes new links which serve to enrich and advance literature in this area.

6.1 Theoretical contributions

The theoretical framework draws upon PBV and DCV Theory. The model is statistically tested considering samples from South African firms. WarpPLS software is used to perform PLS based structural equation modelling. The three research hypotheses are tested and found to be accepted in South African context. It is found that, firstly, firms with a high degree of I4.0 adoption that apply front end and base technologies will demonstrate a higher level of 10R advanced manufacturing capabilities; secondly, it can be seen that firms with more (less) I4.0 delivery systems have a greater (lower) level of 10R advanced manufacturing capabilities for a given level of I4.0 adoption; thirdly, it is found that 10R advanced manufacturing capabilities have a positive influence on sustainable development. Therefore, I4.0 can enhance the operational performance in 10R advanced manufacturing and improve the circular economy performance by achieving sustainable development goals. Firms must focus on PBV, implementing I4.0, and using DCV theory to build dynamic capabilities for running 10R-based advanced manufacturing operations effectively. The data generated from wireless sensor networks must be collected, processed, and stored to ensure high quality decision making.

PBV theory supports I4.0 as a unique method that may be used by individual firms to facilitate technological applications. Secondly, DCV theory supports the notion that 10R advanced manufacturing capability is required to anticipate threats and be able to make a strategic move before competitors, as well as being able to penetrate newer markets with remanufactured/recycled products at competitive pricing. The firm can also reconfigure both

tangible and intangible assets for 10R advanced manufacturing processes in line with business requirements.

6.2 Practical implications

There are four key messages for managers. Firstly, managers should focus on implementing the I4.0 technologies all the way from the shop floor to the top floor level. Within a company, managers must apply I4.0 technologies across the plant, divisional, and functional level. Secondly, careful attention must be paid to strengthening the I4.0 delivery systems. I4.0 delivery systems such as top management commitment, training resources, project resources and support of research institutes and universities play an instrumental role in I4.0 adoption. It is important that appropriate project management tools and techniques are applied while undertaking I4.0 projects. This is made possible when experienced and capable project managers are leading the I4.0 project team. Such experienced team leaders need to design the I4.0 implementation schedule, which is logical and realistic. Skills development is required to fit the I4.0 system in the firm, which is made possible through collaborations between research institutes and universities in I4.0 projects generally facilitating skills development.

The I4.0 delivery system must not be neglected by companies and must be embraced for strengthening the effect of the I4.0 delivery system on 10R manufacturing capabilities. Thirdly, managers must focus on using I4.0 technological enablement in building capabilities for 10R advance manufacturing operations. I4.0 enablement will provide visibility, flexibility and agility to enhance operational excellence in 10R manufacturing. Finally, 10R advanced manufacturing capabilities must be used to efficiently utilise resources and to achieve a firm's sustainable development targets. The resources will remain in the closed loop; thus, the life of the resources will be increased which is key to running circular economy operations.

6.3 Policy implications

I4.0 is like a great tectonic movement in the African continent. Disruptive I4.0 technologies such as artificial intelligence, big data, IoT and cloud computing have the potential to drive economic, societal and environmental changes. Africa's education, health care and businesses have suffered tremendously in the past which has retarded the economic development to a great extent. Like South Africa, other African countries can equally exploit I4.0 to overcome developmental challenges. South Africa has aimed to fully harness the potential of advanced information and communication technologies by the year 2030 for economic growth. To create a holistic country level response strategy, South Africa has established a Presidential

Commission on I4.0. This commission is working on resources, capabilities, policy and legislation among other areas related to I4.0. The focus is towards the creation of adaptive culture to this technological shift. The target is also the development of competitiveness at an international level relating to key sectors. The study provides insight which can be helpful when framing new policies in the era of the fourth industrial revolution. A clear policy is required to manage the ethical, legal, and safety issues surrounding the use of robotic/automatic systems in parallel with human labours in 10R based smart manufacturing environments. Policy must also be framed for the authorisation and control of robots/automatic systems in such smart factories. A policy on sustainability must be available to be able to target specific sustainable development goals.

6.4 Research limitations and future research directions

The sample size is small (124) and most responses are received from the manufacturing and automotive sectors. Secondly, samples for an empirical study are collected from an emerging economy, namely South Africa. Therefore, the results can only be generalised in context to emerging economies but cannot be generalised for developed nations. From an operations perspective, managing human resources to fit in the I4.0 setup is a large challenge for top management. Research studies must attempt to find solutions to such problems. Moreover, the role of AI in managing 10R advanced manufacturing can also be studied for advancement of I4.0 and sustainability literature.

Appendices

Table 1. Operationalization of Constructs

Construct	Factors	Items	Adapted from
Degree of I4.0 Implementation (DII)	Global Scope	All our plants located across different geographical regions have the capability to apply I4.0 front end technologies and base technologies	Frank et al. (2019)
	Organization Scope	All divisions in our organisation have the capability to apply I4.0 front end technologies and base technologies	Frank et al. (2019)

	Functional Scope	Our organization has capability to apply I4.0 front end technologies and base technologies at the functional level	Frank et al. (2019)
I4.0 Delivery System (IDS)	Top Management Commitment	Top management support in the I4.0 project is high	Karimi et al. (2007)
		Top management shows a lot of interest in the I4.0 project	
		Top management reviews I4.0 project progress on a regular basis	
	Training Resources	Time and resources are invested in training manpower for using I4.0 techniques	Karimi et al. (2007)
		Internal users are provided with proper on the job training to apply I4.0 systems	
		Training on I4.0 technology and processes are provided to employees	
	Project Resources	Appropriate project management tools and techniques are applied while adopting I4.0 project	Karimi et al. (2007)
		Experienced and capable project managers are in-charge of the I4.0 project team	
		The I4.0 implementation schedule is logical and realistic	
	Support of Research Institutes & Universities	Local research institutes and universities provide sufficient support for developing I4.0 infrastructure development	Sung, (2017)
		Collaboration between research institutes and universities in I4.0 projects generally facilitate skills development	
		Collaboration between research institutes and universities for I4.0 projects will be useful for developing social relationships	
10R Advanced Manufacturing Capability (10R)	Refuse	Our firm focuses on making product redundant by abandoning its function or by offering the same function with a radically different product	Kirchherr et al. (2017)
	Rethink	Our firm focuses on making product use more intensive	Kirchherr et al. (2017)
	Reduce	Our firm focuses on lower resource consumption and improving manufacturing efficiency	Kirchherr et al. (2017)

	Reuse	Our firm promotes reuse by another consumer of discarded product which is still in good condition and fulfills its original function	Kirchherr et al. (2017)
	Repair	Our firm does repair and maintenance of defective products, so it can be used with its original function	Kirchherr et al. (2017)
	Refurbish	Our firm restores an old product and brings it up to date	Kirchherr et al. (2017)
	Remanufacture	Our firm uses parts of discarded product in a new product with the same function	Kirchherr et al. (2017)
	Repurpose	Our firm uses discarded product or its parts in a new product with a different function	Kirchherr et al. (2017)
	Recycle	Our firm recycles for processing materials to obtain the same or lower quality	Kirchherr et al. (2017)
	Recover	Our firm uses incineration of material for energy recovery	Kirchherr et al. (2017)
Sustainable Development (SD)	Environmental Quality	CE capability enable the transition towards a low carbon economy	Kirchherr et al. (2017)
		CE capability protect and/or restore the environment by focusing on environmental quality aspects and improving resource efficiency	Kirchherr et al. (2017)
	Economic Prosperity	CE capability help to maintain, protect, transform and/or strengthen the economy	Kirchherr et al. (2017)
	Social Equity	CE capability protect, transform, strengthen and/or develop the society, human well-being and/or jobs	Kirchherr et al. (2017)

(Source: Own compilation)

Table 2. Respondent details

Work Area	Years of Work Experience					
	<5 years	5-10 years	10-20 years	20-30 years	>30 years	Total
Manufacturing/ Manufacturing related services	1	4	7	14	16	42
Automotive Component and Allied Manufacturers	1	3	1	7	22	34
Petrochemical	0	0	0	1	10	11
Mines and Quarries	0	0	0	0	5	5
Mineral processing	0	0	0	0	6	6
Heavy Engineering	0	0	4	19	2	25

Electronic goods	0	1	0	0	0	1
Education/ Research	0	0	0	0	0	0
Others	0	0	0	0	0	0
Total	2	8	12	41	61	124

(Source: Own Compilation)

Table 3. Role in the organisation and employee strength

Role in the Organisation	Number of Employees					
	Less than 100	101- 300	300 - 500	500 - 1000	More than 1000	Total
Board Member	0	0	1	0	1	2
CEO/President/Owner/ Managing Director	0	0	0	1	1	2
CFO/Treasurer/Controller	0	0	0	0	0	0
CIO/Technology Director	0	0	0	0	2	2
Chief Procurement Officer	0	0	2	3	6	11
Senior VP/VP	0	0	75	0	2	77
Head of business unit or department	0	1	0	1	5	7
Manager	0	0	3	2	11	16
Data Analyst	0	0	0	0	3	3
Data Scientist	0	0	0	0	3	3
Consultant	0	0	0	0	0	0
Researcher	0	0	0	0	0	0
Others	0	0	1	0	0	1
Total	0	1	82	7	34	124

(Source: Own Compilation)

Table 4. Model fit and quality indices

Model fit and quality indices	Results
Average path coefficient (APC)	0.400
Average R-squared (ARS)	0.563
Average adjusted R-squared (AARS)	0.555
Average block VIF (AVIF)	5.00
Average full collinearity VIF (AFVIF)	3.98
Tenenhaus GoF (GoF)	0.355

(Source: Own Compilation)

Table 5. Causality assessment indices

Causality assessment indices	Results
Sympson's paradox ratio (SPR)	0.733
R-squared contribution ratio (RSCR)	0.951
Statistical suppression ratio (SSR)	0.700
Nonlinear bivariate causality direction ratio (NLBCDR)	0.700

(Source: Own Compilation)

Table 6. Latent variable coefficients

Latent variable coefficients	DII	IDS	10R	SD	FA	IDS*DII
R-squared			0.753	0.409		
Adj. R-squared			0.751	0.404		
Composite reliability	0.876	0.947	0.923	0.827	1.000	0.999
Cronbach's alpha	0.788	0.939	0.907	0.720	1.000	0.999
Avg. var. extrac.	0.703	0.600	0.546	0.545	1.000	0.975

(Source: Own Compilation)

Table 7. Correlation among latent variable with square root of AVEs

Correlations	DII	IDS	10R	SD	FA	IDS*DII
DII	(0.838)					
IDS	0.891	(0.774)				
10R	0.776	0.799	(0.739)			
SD	0.707	0.750	0.600	(0.738)		
FA	0.503	0.498	0.422	0.370	(1.000)	
IDS*DII	-0.845	-0.919	-0.836	-0.686	-0.454	(0.987)

(Source: Own Compilation)

Table 8. Combined Loadings and Cross Loadings

*: p-value for all the items was <0.001

Loadings*	DII	IDS	10R	SD	FA	IDS*DII
DII1	(0.858)	0.062	0.033	-0.040	-0.145	0.206
DII2	(0.819)	0.109	-0.016	0.118	0.039	-0.010
DII3	(0.837)	-0.170	-0.019	-0.075	0.111	-0.202
IDS1	-0.590	(0.785)	0.018	-0.016	0.150	0.090
IDS2	0.540	(0.763)	-0.045	0.016	-0.098	-0.159

IDS3	-0.505	(0.784)	-0.099	0.123	0.021	0.041
IDS4	0.084	(0.758)	0.105	0.087	0.097	0.164
IDS5	0.158	(0.772)	-0.080	0.276	-0.163	0.073
IDS6	-0.098	(0.766)	-0.055	0.105	-0.036	-0.006
IDS7	-0.039	(0.780)	0.042	-0.077	-0.002	-0.010
IDS8	0.364	(0.745)	-0.147	-0.072	-0.116	0.047
IDS9	-0.355	(0.776)	0.227	0.138	-0.012	0.299
IDS10	0.620	(0.791)	-0.088	-0.283	-0.064	-0.246
IDS11	-0.094	(0.772)	0.055	-0.045	0.167	-0.297
IDS12	-0.058	(0.800)	0.063	-0.240	0.049	0.009
10R1	0.491	-0.453	(0.673)	-0.247	0.073	0.092
10R2	0.153	0.045	(0.703)	-0.310	0.262	0.256
10R3	-0.144	0.508	(0.757)	-0.188	-0.018	0.136
10R4	-0.059	0.049	(0.706)	0.037	0.053	-0.453
10R5	-0.564	0.240	(0.767)	0.155	-0.075	-0.036
10R6	0.385	-0.137	(0.790)	-0.091	-0.056	-0.210
10R7	-0.254	-0.421	(0.774)	0.295	-0.123	0.043
10R8	0.584	-0.513	(0.774)	-0.243	-0.145	-0.128
10R9	-0.113	0.460	(0.757)	0.279	-0.074	0.269
10R10	-0.486	0.226	(0.676)	0.300	0.161	0.046
SD1	-0.129	0.056	0.234	(0.777)	0.088	-0.041
SD2	0.329	-0.469	-0.289	(0.744)	0.119	-0.357
SD3	0.421	-0.128	-0.208	(0.670)	-0.276	-0.049
SD4	-0.564	0.517	0.228	(0.757)	0.037	0.436
FA1	0.000	0.000	0.000	0.000	(1.000)	0.000

(Source: Own compilation)

Table 9. Hypothesis testing summary

Hypothesis	Beta and p value	Findings
H1: Manufacturing companies with high degree of I4.0 adoption to apply front end and base technologies will demonstrate higher level of 10R advanced manufacturing capabilities	β=0.55 p<.01	Supported
H2: Manufacturing companies with more (less) I4.0 delivery system has a greater (lower) level of 10R advanced manufacturing capabilities for a given level of I4.0 adoption	β=0.13 p=.05	Supported

H3: 10R advanced manufacturing capability has a positive impact on sustainable development	β=0.64 p<.01	Supported

(Source: Own Compilation)

References

Albers, A., Gladysz, B., Pinner, T., Butenko, V. & Stürmlinger, T. (2016). Procedure for defining the system of objectives in the initial phase of an industry 4.0 project focusing on intelligent quality control systems. Procedia Cirp, 52, 262-267.

Amoako-Gyampah, K., & Acquaah, M. (2008). Manufacturing strategy, competitive strategy and firm performance: An empirical study in a developing economy environment. International Journal of Production Economics, 111(2), 575-592.

Armstrong, J. S., & Overton, T. S. (1977). Estimating nonresponse bias in mail surveys. Journal of Marketing Research, 396-402.

Bag, S., Gupta, S., & Foropon, C. (2018a). Examining the Role of Dynamic Remanufacturing Capability and Supply Chain Resilience in the Circular Economy. Management Decision. 57(4), 863-885.

Bag, S., Telukdarie, A., Pretorius, J. H. C., & Gupta, S. (2018b). Industry 4.0 and supply chain sustainability: framework and future research directions. Benchmarking: An International Journal. Vol. ahead of print. https://doi.org/10.1108/BIJ-03-2018-0056

Bag, S., Wood, L. C., Mangla, S. K., & Luthra, S. (2020a). Procurement 4.0 and its implications on business process performance in a circular economy. Resources, Conservation and Recycling, 152(January), 104502.

Bag, S., Wood, L. C., Xu, L., Dhamija, P., & Kayikci, Y. (2020b). Big data analytics as an operational excellence approach to enhance sustainable supply chain performance. Resources, Conservation and Recycling, 153(February), 104559.

Barreto, I. (2010). Dynamic capabilities: A review of past research and an agenda for the future. Journal of Management, 36(1), 256-280

Barney, J. B., & Arikan, A. M. (2001). The resource-based view: Origins and implications. Handbook of Strategic Management, 124188.

Bell, J. E., Mollenkopf, D. A., & Stolze, H. J. (2013). Natural resource scarcity and the closed-loop supply chain: a resource-advantage view. International Journal of Physical Distribution & Logistics Management, 43(5/6), 351-379.

Bromiley, P., & Rau, D. (2016). Operations management and the resource based view: Another view. Journal of Operations Management, 41, 95-106.

Cant, M. C., & Wiid, J. A. (2016). Internet-Based ICT Usage by South African SMEs: The Barriers Faced By SMEs. Journal of Applied Business Research, 32(6), 1877.

Carter, C. R., & Rogers, D. S. (2008). A framework of sustainable supply chain management: moving toward new theory. International Journal of Physical Distribution & Logistics Management, 38(5), 360-387.

Cecconet, D., Molognoni, D. Callegari, A., & Capodaglio, A. G. (2017). Agro-food industry wastewater treatment with microbial fuel cells: energetic recovery issues. International Journal Hydrogen Energy, 43(1), 500-511.

Chan, H. K., Griffin, J., Lim, J. J., Zeng, F., & Chiu, A. S. (2018). The impact of 3D Printing Technology on the supply chain: Manufacturing and legal perspectives. International Journal of Production Economics, 205(November), 156-162.

Chen, D., Heyer, S., Ibbotson, S., Salonitis, K., Steingrímsson, J. G., & Thiede, S. (2015). Direct digital manufacturing: definition, evolution, and sustainability implications. Journal of Cleaner Production, 107(November), 615-625.

Chuks, M., & Telukdarie, A., (2018). Decision-support for Business Process Optimization Modelling Framework Based on Industry 4.0 Enablement. Proceedings of the International Conference on Industrial Engineering and Operations Management Paris, France, July 26-27, 2018, retrieved from http://www.ieomsociety.org/paris2018/papers/111.pdf on 20.3.19

Čolaković, A., & Hadžialić, M. (2018). Internet of Things (IoT): A review of enabling technologies, challenges, and open research issues. Computer Networks, 144(October), 17-39

Dalenogare, L. S., Benitez, G. B., Ayala, N. F., & Frank, A. G. (2018). The expected contribution of Industry 4.0 technologies for industrial performance. International Journal of Production Economics, 204(October), 383-394.

Delic, M., & Eyers, D. R. (2020). The effect of additive manufacturing adoption on supply chain flexibility and performance: an empirical analysis from the automotive industry. International Journal of Production Economics, 228(October), 107689.

Deloitte, Industry 4.0 Is Africa ready for digital transformation? Retrieved from https://www2.deloitte.com/content/dam/Deloitte/za/Documents/manufacturing/za-Africa-industry-4.0-report-April14.pdf on 12.5.18

de Sousa Jabbour, A. B. L., Jabbour, C. J. C., Foropon, C., & Godinho Filho, M. (2018a). When titans meet–Can industry 4.0 revolutionise the environmentally-sustainable manufacturing wave? The role of critical success factors. Technological Forecasting and Social Change, 132(July), 18-25.

de Sousa Jabbour, A. B. L., Jabbour, C. J. C., Godinho Filho, M., & Roubaud, D. (2018b). "Industry 4.0 and the circular economy: a proposed research agenda and original roadmap for sustainable operations. Annals of Operations Research, 270(1-2), 273-286.

de Sousa Jabbour, A. B. L., Ndubisi, N. O., & Seles, B. M. R. P. (2019). Sustainable development in Asian manufacturing SMEs: Progress and directions. International Journal of Production Economics, 107567.

Dev, N. K., Shankar, R., & Swami, S. (2019). Diffusion of green products in industry 4.0: Reverse logistics issues during design of inventory and production planning system. International Journal of Production Economics, 107519.

Dlamini, L., (2015). 2030 Agenda, Retrieved from http://www.un.org.za/sdgs/2030-agenda/ on 19.3.19.

DTI report. Why invest in South Africa. Retrieved from https://www.thedti.gov.za/trade_investment/why_invest_insa.jsp on 19.2.19

Dubey, R., Gunasekaran, A. and Childe, S. J. (2019a), "Big data analytics capability in supply chain agility", Management Decision.

Dubey, R., Gunasekaran, A., Childe, S. J., Blome, C. and Papadopoulos, T. (2019b), Big data and predictive analytics and manufacturing performance: integrating institutional theory, resource-based view and big data culture, British Journal of Management, 30(2), 341-361.

Dubey, R., Gunasekaran, A., Papadopoulos, T., Childe, S. J., Shibin, K. T., & Wamba, S. F. (2017a). Sustainable supply chain management: framework and further research directions. Journal of Cleaner Production, 142(Part 2 January), 1119-1130.

Dubey, R., Gunasekaran, A., Childe, S. J., Papadopoulos, T., Luo, Z., Wamba, S. F., & Roubaud, D. (2017b). Can big data and predictive analytics improve social and environmental sustainability?". Technological Forecasting and Social Change. 144(July), 534-545.

Dubey, R., Gunasekaran, A., Childe, S. J., Papadopoulos, T., Luo, Z., & Roubaud, D. (2017c). Upstream supply chain visibility and complexity effect on focal company's

sustainable performance: Indian manufacturers' perspective. Annals of Operations Research, (May 2017), 1-25.

Dubey, R., Gunasekaran, A., Childe, S. J., Wamba, S. F., & Papadopoulos, T. 2016. The impact of big data on world-class sustainable manufacturing. The International Journal of Advanced Manufacturing Technology, 84(1-4), 631-645.

Dubey, R., Gunasekaran, A., Sushil., & Singh, T. (2015). Building theory of sustainable manufacturing using total interpretive structural modelling. International Journal of Systems Science: Operations & Logistics, 2(4), 231-247.

Durach, C. F., Kurpjuweit, S., & Wagner, S. M. (2017). The impact of additive manufacturing on supply chains. International Journal of Physical Distribution & Logistics Management, 47(10), 954-971.

Fahy, J. (2002). A resource-based analysis of sustainable competitive advantage in a global environment. International Business Review, 11(1), 57-77.

Flynn, B. B., Sakakibara, S., Schroeder, R. G., Bates, K. A., & Flynn, E. J. (1990). Empirical research methods in operations management. Journal of Operations Management, 9(2), 250-284.

Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. Journal of Marketing Research, (February), 39-50.

Frank, A. G., Dalenogare, L. S., & Ayala, N. F. (2019). Industry 4.0 technologies: implementation patterns in manufacturing companies. International Journal of Production Economics, 210(April), 15-26.

Gimenez, C., Sierra, V., & Rodon, J. (2012). Sustainable operations: Their impact on the triple bottom line. International Journal of Production Economics, 140(1), 149-159.

Glas, A. H., & Kleemann, F. C. (2016). The impact of industry 4.0 on procurement and supply management: a conceptual and qualitative analysis. International Journal of Business and Management Invention, 5(6), 55-66.

Gould, O., & Colwill, J. (2015). A framework for material flow assessment in manufacturing systems. Journal of Industrial and Production Engineering, 32(1), 55-66.

Govindan, K., Shankar, K. M., & Kannan, D. (2020). Achieving sustainable development goals through identifying and analyzing barriers to industrial sharing economy: A framework development. International Journal of Production Economics, 227(September), 107575.

Gunasekaran, A., & Gallear, D. (2012). Special Issue on Sustainable development of manufacturing and services. International Journal of Production Economics, 1(140), 1-6.

Gunasekaran, A., Papadopoulos, T., Dubey, R., Wamba, S. F., Childe, S. J., Hazen, B., & Akter, S. (2017). Big data and predictive analytics for supply chain and organizational performance. Journal of Business Research, 70(January), 308-317.

Hair, J. F., Ringle, C. M. and Sarstedt, M. (2011), PLS-SEM: Indeed a silver bullet, Journal of Marketing Theory and Practice, 19(2), 139-152.

Hannibal, M., & Knight, G. (2018). Additive manufacturing and the global factory: Disruptive technologies and the location of international business. International Business Review, 27(6), 1116-1127.

Hazen, B. T., Boone, C. A., Ezell, J. D., & Jones-Farmer, L. A. (2014). Data quality for data science, predictive analytics, and big data in supply chain management: An introduction to the problem and suggestions for research and applications. International Journal of Production Economics, 154(August), 72-80.

Hazen, B. T., Skipper, J. B., Ezell, J. D., & Boone, C. A. (2016). Big Data and predictive analytics for supply chain sustainability: A theory-driven research agenda. Computers & Industrial Engineering, 101(November), 592-598.

Hazen, B. T., Mollenkopf, D. A., & Wang, Y. (2017). Remanufacturing for the circular economy: An examination of consumer switching behaviour. Business Strategy and the Environment, 26(4), 451-464.

Inderfurth, K. (2005). Impact of uncertainties on recovery behavior in a remanufacturing environment: a numerical analysis. International Journal of Physical Distribution & Logistics Management, 35(5), 318-336.

Jiang, Z., Zhou, T., Zhang, H., Wang, Y., Cao, H., & Tian, G. (2016). Reliability and cost optimization for remanufacturing process planning. Journal of Cleaner Production, 135(November), 1602-1610.

Karimi, J., Somers, T. M., & Bhattacherjee, A. (2007). The role of information systems resources in ERP capability building and business process outcomes. Journal of Management Information Systems, 24(2), 221-260.

Kawai, N., Strange, R., & Zucchella, A. (2018). Stakeholder pressures, EMS implementation, and green innovation in MNC overseas subsidiaries. International Business Review, 27(5), 933-946.

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. Resources, Conservation and Recycling, 127(December), 221-232.

Kolberg, D., & Zühlke, D. (2015). Lean automation enabled by industry 4.0 technologies. IFAC-PapersOnLine, 48(3), 1870-1875.

Kock, N. (2016). Hypothesis testing with confidence intervals and P values in PLS-SEM. International Journal of e-Collaboration, 12(3), 1-6.

Kolk, A., & Van Tulder, R. (2010). International business, corporate social responsibility and sustainable development. International Business review, 19(2), 119-125.

Kouedeu, A. F., Kenné, J. P., Dejax, P., Songmene, V., & Polotski, V. (2014). Production planning of a failure-prone manufacturing/remanufacturing system with production-dependent failure rates. Applied Mathematics, 5(10), 1557.

Kumar, A., Baldea, M., Edgar, T. F., & Ezekoye, O. A. (2015). Smart manufacturing approach for efficient operation of industrial steam-methane reformers. Industrial & Engineering Chemistry Research, 54(16), 4360-4370.

Lasi, H., Fettke, P., Kemper, H. G., Feld, T., & Hoffmann, M. (2014). Industry 4.0. Business & Information Systems Engineering, 6(4), 239-242.

Law, K. M., & Gunasekaran, A. (2012). Sustainability development in high-tech manufacturing firms in Hong Kong: Motivators and readiness. International Journal of Production Economics, 137(1), 116-125.

Lucianetti, L., Jabbour, C. J. C., Gunasekaran, A., & Latan, H. (2018). Contingency factors and complementary effects of adopting advanced manufacturing tools and managerial practices: Effects on organizational measurement systems and firms' performance. International Journal of Production Economics, 200(June), 318-328.

Malik, J. A. N. (2016). US expects energy savings through smart manufacturing. MRS Bulletin, 41(1), 10-11.

Markley, M. J., & Davis, L. (2007). Exploring future competitive advantage through sustainable supply chains. International Journal of Physical Distribution & Logistics Management, 37(9), 763-774.

Mativenga, P. T., Agwa-Ejon, J., Mbohwa, C., & Shuaib, N. A. (2017). Circular Economy Ownership Models: A view from South Africa Industry. Procedia Manufacturing, 8, 284-291.

Meredith, J. (1993). Theory building through conceptual methods. International Journal of Operations & Production Management, 13(5), 3-11

Moeuf, A., Pellerin, R., Lamouri, S., Tamayo-Giraldo, S., & Barbaray, R. (2018). The industrial management of SMEs in the era of Industry 4.0. International Journal of Production Research, 56(3), 1118-113

Montori, F., Bedogni, L., Di Felice, M., & Bononi, L. (2018). Machine-to-machine wireless communication technologies for the Internet of Things: Taxonomy, comparison and open issues. Pervasive and Mobile Computing, 50(October), 56-81.

Nunnally, J. C., & Bernstein, I. H. (1994). The theory of measurement error", Psychometric Theory, 3, 209-247.

Podsakoff, P. M., MacKenzie, S. B., Lee, J. Y., & Podsakoff, N. P. (2003). Common method biases in behavioural research: A critical review of the literature and recommended remedies. Journal of Applied Psychology, 88(5), 879.

Podsakoff, P. M., & Organ, D. W. (1986). Self-reports in organizational research: Problems and prospects. Journal of Management, 12(4), 531-544.

Potting, J., Hekkert, M. P., Worrell, E. and Hanemaaijer, A. (2017). *Circular economy: measuring innovation in the product chain* (No. 2544). PBL Publishers.

Prause, G., & Atari, S. (2017). On sustainable production networks for Industry 4.0. DOI. 10.9770/jesi.2017.4.4(2)

PWC report (May 8, 2018). South Africa falling behind with digital transformation, Retrieved from https://www.pwc.co.za/en/press-room/south-africa-falling-behind-with-digital-transformation.html on 19.2.19

Raafat, F. (2002). A comprehensive bibliography on justification of advanced manufacturing systems. International Journal of Production Economics, 79(3), 197-208.

Raj, A., Dwivedi, G., Sharma, A., de Sousa Jabbour, A. B. L., & Rajak, S. (2019). Barriers to the adoption of industry 4.0 technologies in the manufacturing sector: An inter-country comparative perspective. International Journal of Production Economics, November, 107546.

Ren, S., Eisingerich, A. B., & Tsai, H. T. (2015). How do marketing, research and development capabilities, and degree of internationalization synergistically affect the innovation performance of small and medium-sized enterprises (SMEs)? A panel data study of Chinese SMEs. International Business Review, 24(4), 642-651.

Roy, A., & Goll, I. (2014). Predictors of various facets of sustainability of nations: The role of cultural and economic factors. International Business Review, 23(5), 849-861.

Ruiz-Benitez, R., López, C., & Real, J. C. (2019). Achieving sustainability through the Lean and resilient management of the supply chain abstract. International Journal of Physical Distribution & Logistics Management, 49(2), 122-155.

Rymaszewska, A., Helo, P., & Gunasekaran, A. (2017). IoT powered servitization of manufacturing–an exploratory case study. International Journal of Production Economics, 192(October), 92-105.

Saucedo-Martínez, J. A., Pérez-Lara, M., Marmolejo-Saucedo, J. A., Salais-Fierro, T. E., & Vasant, P. (2018). Industry 4.0 framework for management and operations: a review. Journal of Ambient Intelligence and Humanized Computing, 9, 789-801.

Sung, T. K. (2018). Industry 4.0: a Korea perspective. Technological Forecasting and Social Change, 132(July), 40-45.

Teece, D. J., & Pisano, G. 1994. The dynamic capabilities of firms: An introduction. Industrial and Corporate Change, 3(3), 537-556.

Teece, D. J., Pisano, G., & Shuen, A. 1997. Dynamic capabilities and strategic management. Strategic Management Journal, 18(7), 509-533.

Teece, D. J. 2007. Explicating dynamic capabilities: The nature and microfoundations of (sustainable) enterprise performance. Strategic Management Journal, 28(13), 1319-1350.

Telukdarie, A., Buhulaiga, E., Bag, S., Gupta, S., & Luo, Z. (2018). Industry 4.0 implementation for multinationals. Process Safety and Environmental Protection, 118(August), 316-329.

Tortorella, G. L., Vergara, A. M. C., Garza-Reyes, J. A., & Sawhney, R. (2020). Organizational learning paths based upon industry 4.0 adoption: An empirical study with Brazilian manufacturers. International Journal of Production Economics, 219(January), 284-294.

Wacker, J. G. (1998). A definition of theory: research guidelines for different theory-building research methods in operations management. Journal of Operations Management, 16(4), 361-385.

Wamba, S. F., Gunasekaran, A., Akter, S., Ren, S. J. F., Dubey, R. and Childe, S. J. (2017), Big data analytics and firm performance: Effects of dynamic capabilities, Journal of Business Research, 70(January), 356-365.

Wang, G., Gunasekaran, A., Ngai, E. W., & Papadopoulos, T. (2016). Big data analytics in logistics and supply chain management: Certain investigations for research and applications. International Journal of Production Economics, 176(June), 98-110.

Winter, M., & Knemeyer, A. M. (2013). Exploring the integration of sustainability and supply chain management: Current state and opportunities for future inquiry. International Journal of Physical Distribution & Logistics Management, 43(1), 18-38.

Xu, L. D., Xu, E. L., & Li, L. (2018). Industry 4.0: state of the art and future trends. International Journal of Production Research, 56(8), 2941-2962.

Yu, W., Ramanathan, R., Wang, X., & Yang, J. (2018). Operations capability, productivity and business performance: The moderating effect of environmental dynamism. Industrial Management & Data Systems, 118(1), 126-143.

Zhang, J., Chen, X., & Fang, C. (2018a). Transmission of a supplier's disruption risk along the supply chain: a further investigation of the Chinese automotive industry. Production Planning & Control, 29(9), 773-789.

Zhang, Y., Yang, Z., & Zhang, T. (2018b). Strategic resource decisions to enhance the performance of global engineering services. International Business Review, 27(3), 678-700.