Industry 4.0 and the circular economy: Melioration of business logistics sustainability

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ABSTRACT

Mining and mineral resources help provide the requirements of everyday life by contributing to essential products and services. In the era of fourth industrial revolution, the trend in logistics is toward a smart logistics system. Therefore, it becomes important to understand how Industry 4.0 enablers effect smart logistics, i.e., instrumented logistics, interconnected logistics, and intelligent logistics. This study investigates how Industry 4.0 logistics technologies influence dynamic remanufacturing and green manufacturing capability and, the effect on business logistics sustainability. Survey data were collected from 150 respondents using an online survey of South African executives in firms operating mines, quarries, and processing plants. Partial Least Squares based structural equation modelling (PLS-SEM) was used to test the hypotheses. The findings indicate that Industry 4.0 enablers have a strong effect on intelligent logistics compared to its effect on interconnected logistics and instrumented logistics. The effect of intelligent logistics are found to be very high compared to that of interconnected logistics and instrumented logistics on dynamic remanufacturing and green manufacturing capability. Finally, dynamic remanufacturing and green manufacturing capability are found to positively influence business logistics sustainability.

Keywords: Business logistics, Industry 4.0, Circular economy, Mining and minerals, Sustainability challenges

1. Introduction

Mining and mineral resources help provide the requirements of everyday life by contributing to many products and services (Fedderke, 2002; Bouzon et al., 2015). A huge number of industries, such as cosmetics, construction, and pharmaceuticals are largely based on minerals (Azapagic, 2004; Bouzon et al., 2015). However, the on-going extraction of minerals is connected to a range of sustainability challenges (economic, social, and environmental) that operations managers must consider in addition to economic efficiencies. The important point is that every benefit comes with a cost (Hilson and Murck, 2000).

The mining industry also faces sustainability challenges due to the extraction of non-renewable resources, landscape issues, and ergonomics concerns for workers and citizens (Hilson and Murck, 2000). While the mining industry is an important economic contributor, the heavy resource consumption has raised questions about the industry's long-term sustainable existence in this emerging era of the circular economy (Campbell, 2012; Careddu et al., 2018; Luthra et al., 2020). The initiative of the Mining, Minerals, and Sustainable Development Project (https://www.iied.org/mining-minerals-sustainable-development-mmsd) confirms the need for the mining industry to think through and prioritize sustainability in their operations. Major sustainability challenges faced by the mining industry covers mining leftovers (e.g., the wastes from rocks, operating residues, and tailings) and the difficulties connected to management of critical raw materials and secondary raw materials (Dino et al., 2018). Addressing these environmental concerns is important as failures to meet expectations or legislated standards leads to the destruction of company value whether these failures are environmental (Wood et al., 2018) or safety related (Wood, Wang et al., 2017).

To meet changing customer demands at higher speed than competitors, logistics networks must be connected globally (Stank et al., 2001). Such networks often combine resources and capabilities allowing firms to achieve outcomes not possible when working separately (Breidbach et al., 2015). The business logistics process emphasizes routinization and standardization of inputs and outputs, particularly through the analysis and development of a logical sequences of meticulously designed activities (Van Looy et al*.*, 2011; Klun and Trkman, 2018; Thennakoon et al*.*, 2018). In manufacturing, this may appear simple; however, BLP management becomes more challenging for mining firms engaged in reverse logistics as these activities increase complexity and uncertainties (Mabert and Venkataramanan, 1998; Lambert and Cooper, 2000). Mining firms must improve process maturity and capabilities before they can successfully manage reverse logistics, remanufacturing, and green manufacturing activities (Van Looy et al., 2011).

This research is important as Industry 4.0 can connect the shop floor system with the enterprise level system to communicate effectively which is essential in modern mining

(Sishi and Telukdarie, 2017). However, there is a scarcity of literature on the application of Industry 4.0 on smart logistics processes and how Industry 4.0 affects remanufacturing and green manufacturing practices in the mining industry. Keeping in mind the importance of reducing waste and the emerging circular economy literature (Margherita, 2014; Jaaron and Backhouse, 2016; Schniederjans, 2018; Bag, Wood, Mangla et al., 2020; Bag, Wood, Xu et al., 2020), the present study highlights the following research questions (RQ) to address the calls of previous researchers on how to improve their operations in the shift to the circular economy:

RQ1: How can improved operations management using Industry 4.0 be supported by drawing on concepts of smart logistics, technology readiness, and deployment strategies for business logistics sustainability in the circular economy?

RQ2: Can we develop a theoretical model that links improved operations management using Industry 4.0 enablers, smart logistics, dynamic remanufacturing capability, green manufacturing capability and business logistics sustainability?

In connection with the research questions, the research team aimed to contribute to the literature focusing on business processes for forward, reverse, remanufacturing, and green manufacturing logistical networks. We developed a theoretical framework for smart logistics maturity and technology readiness. The data was collected from senior executives of South African mines, quarries, and processing plants. We identified infrastructure and technology tools to evaluate how they can be integrated with Industry 4.0 principles.

The rest of the sections are organised as follows. Section two presents the literature review covering business processes and Industry 4.0 technologies. Section three presents the research framework and research hypotheses. Section four presents the survey and analysis methods. Section five presents the data analysis and discussion on findings. The paper concludes with a discussion on implications for policymakers, managers, and society, and future research directions.

2. Literature review

This section presents the key concepts involved in this study such as business process management, dynamic remanufacturing and green manufacturing capability, Industry 4.0, instrumented logistics, interconnected logistics, intelligent logistics and business logistics sustainability.

2.1 Business process management

There is a range of sustainability challenges in the mining industry concerning the natural environment, society, and economic outcomes (refer to Table 1). To manage these effectively requires additional consideration of firms' business processes. When considering business processes, there are different ways of categorizing the constituent processes. The categorizations include core processes (those adding value to a customer), support processes (required to support the core processes), management processes, and business network processes; processes can also be considered by level of structure in the development, ranging from fully to non-structured (Van Looy et al., 2011; Margherita, 2014). This discipline of business process management includes activities such as process modelling, automation, deployment, and optimization (Figure 1). Each component supports superior results and operational excellence (Vergidis et al., 2007, Vergidis et al., 2008, Vergidis et al., 2012).

Technology and business process management can support smoother mining operations in environments characterized by volatility, uncertainty, complexity, and ambiguity (Dehghani and Ataee-pour, 2012; Vom Brocke et al., 2014). Business processes management supports firms to achieve superior outcomes by optimizing the structure, functions, and organizational elements of the firm (Samaranayake, 2009) over a range of regularly occurring business process cycles. For instance, business logistics plays a critical role in mining operations and this can be exploited to significantly reduce the use of scarce natural resources and provide a conservatory role (Glenn Richey et al., 2005; Kelle and Akbulut, 2005). Process optimization for logistics reduces costs while improving lead times and enhancing customer satisfaction. However, the business logistics process in mining operations is complex like any manufacturing business and requires Industry 4.0 driven smart logistics (instrumented logistics, interconnected logistics, and intelligent logistics) to succeed (Lee and Choi, 2016; Mardonova and Choi, 2018; Gupta et al., 2019). Industry 4.0 technologies will make global supply chain operations more competitive (Deloitte, 2016) by integrating Industry 4.0 tools with all functions to share data, information, and knowledge between users and over the supply chain. While Industry 4.0 tools can provide superior outcomes by automating critical logistics and operational activities (Wood, Reiners et al., 2017), the key benefit is from access to real-time information for increased visibility and mitigating risks in the logistics network (Telukdarie et al., 2018) while reducing costs (Zetzmann and Fein, 2017).

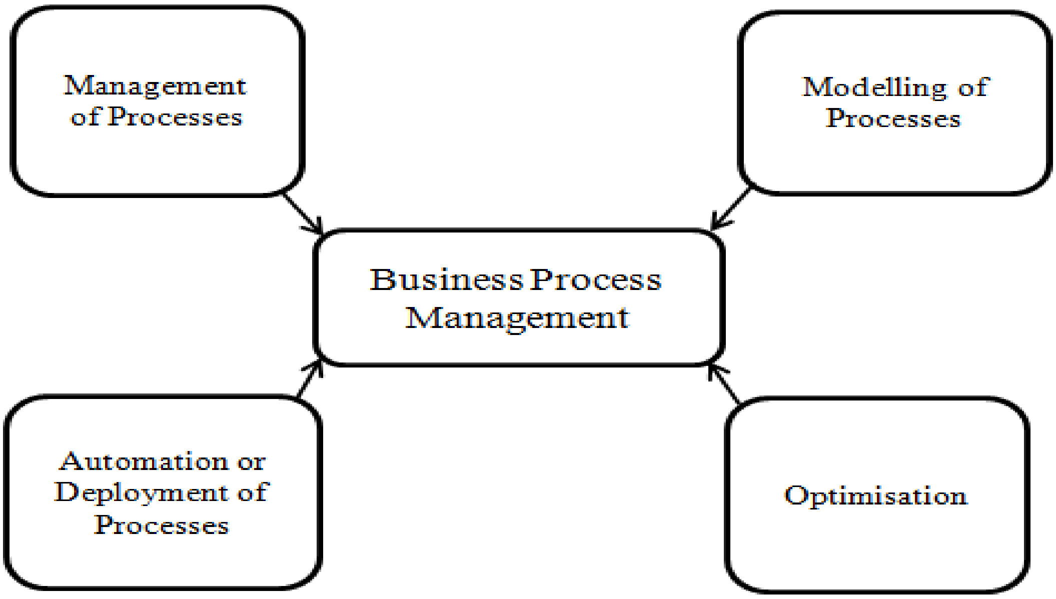
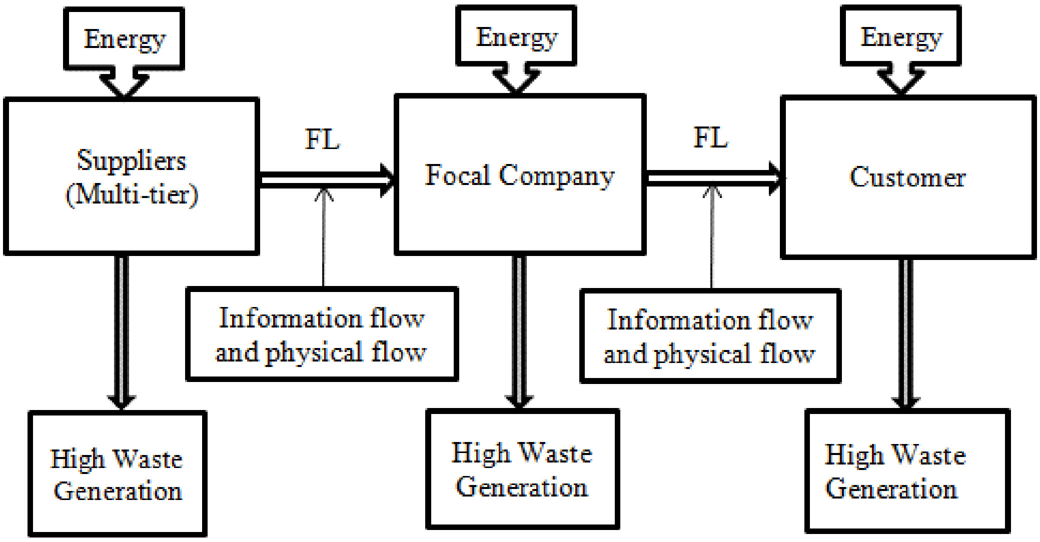


Figure 1. Components of business process management (Source: Authors' compilation)

Our traditional model for a supply chain is considered a 'forward supply chain' (Figure 2). This focuses on the development and transfer of goods from suppliers to consumers. Raw materials are gradually transformed into items and goods for a market and are transported around the world. Automation and Industry 4.0 technologies can improve many of these processes over the business, such as the procurement process (Bag, Wood, Mangla et al., 2020). The focus in these supply chains is often on material procurement, managing suppliers, and distribution, all of which are sensitive to cost concerns, however attention should also be paid to customer service levels and responding to market concerns (Beamon, 1999; Hervani et al., 2005; Srivastava, 2007).



Note: FL: Forward logistics

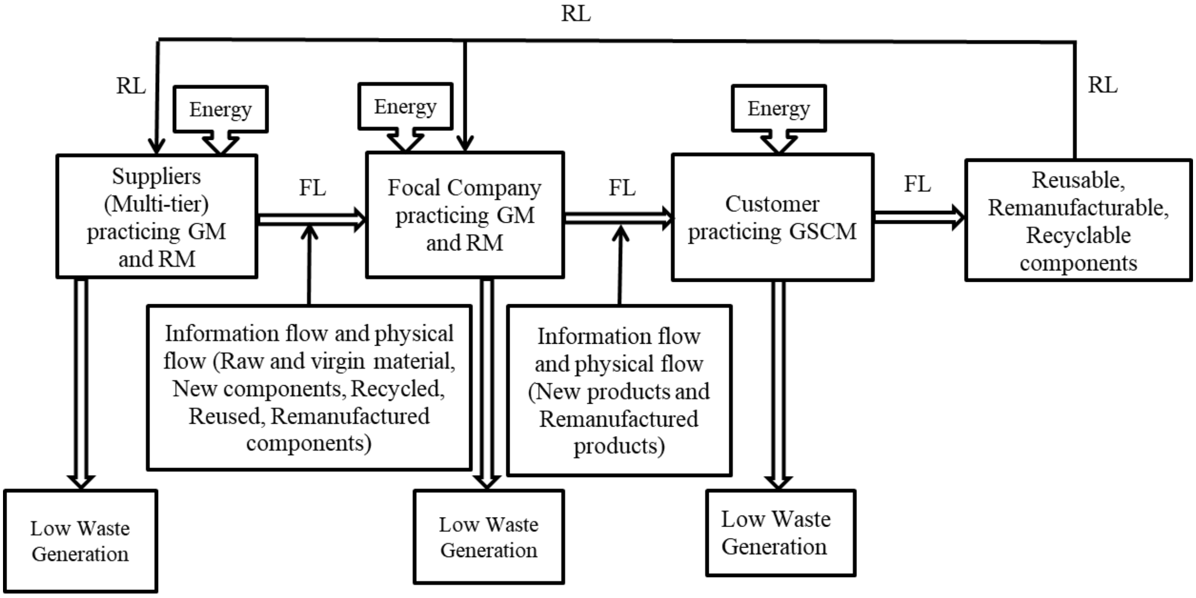
Figure 2. Forward logistics chain (Source: Authors' compilation)

Optimization toolsets that are commonly used in forward supply chains include: total quality management, lean sigma, just-in-time, the supply chain operations reference (SCOR) model, pipeline mapping, supplier relationship grids, and enterprise resource planning (Scott and Westbrook, 1991; Ptak and Schragenheim, 2016).

2.2 Dynamic remanufacturing and green manufacturing capability

Climate change is at the forefront of global warming which shifts gear to circular economy business models for sustainability (Dubey et al., 2018). The renewed importance of green manufacturing has sharpened professional and research attention on remanufacturing principles (Ijomah et al*.*, 2007; Kocabasoglu et al., 2007; Nasr et al., 2011; Rashid et al., 2013). Remanufacturing is more than re-use of materials and instead focuses on "value-added recovery" of resources (Kapetanopoulou and Tagaras, 2009; Francas and Minner, 2009). The remanufacturing approach reduces waste and enhances product life cycles. These outcomes ensure that remanufacturing principles gain popularity, as we increasingly need to consider end-of-life product management, where many designs have limited opportunity for recovery operations. Through the design and provision of a well-structured logistics network, firms can ensure old products are returned to the plant for disassembly, cleaning, refurbishment, and re-assembling, so the product is suitable for re-sale (Lund and Skeels, 1983; Kin et al., 2014).

The process in remanufacturing and green manufacturing involves both forward and reverse logistics (Figure 3). However, the quantum of waste generated is lower than traditional business models because of the usage of 3R principles (Reduce, Recycle, and Reuse) in green manufacturing and remanufacturing process. Prior studies have noted a range of toolsets and techniques that have value in supporting the 3R principles over reverse, remanufacturing, and green manufacturing logistical chains. These approaches include: activity-based costing, balanced scorecard, collaborative supplier relationships, customer relationship management consumption analysis (energy/material), design for environment analysis, environmental management systems, enterprise resource planning, green kaizen, green procurement, green stream mapping, life cycle assessment, predictive maintenance, product stewardship, statistical process control, and sustainability metrics, (e.g., Deif, 2011; Bartolacci et al., 2012; Rogers et al., 2012; Dubey and Bag, 2014; Fahimnia et al., 2015; Hervani et al., 2015; Tognetti et al., 2015; Cannella et al., 2016; Battini et al., 2017; Calleja et al., 2017; Guo et al., 2017; Habibi et al., 2017; He, 2017; Zhao et al., 2017; Heydari et al., 2018; Flygansvær et al., 2018).



Note: FL: Forward logistics; RL: Reverse logistics; GM: Green manufacturing; RM: Remanufacturing; GSCM: Green supply chain management

Figure 3. Reverse logistics, remanufacturing and green manufacturing logistics chain (Source: Authors' compilation)

2.3 Industry 4.0

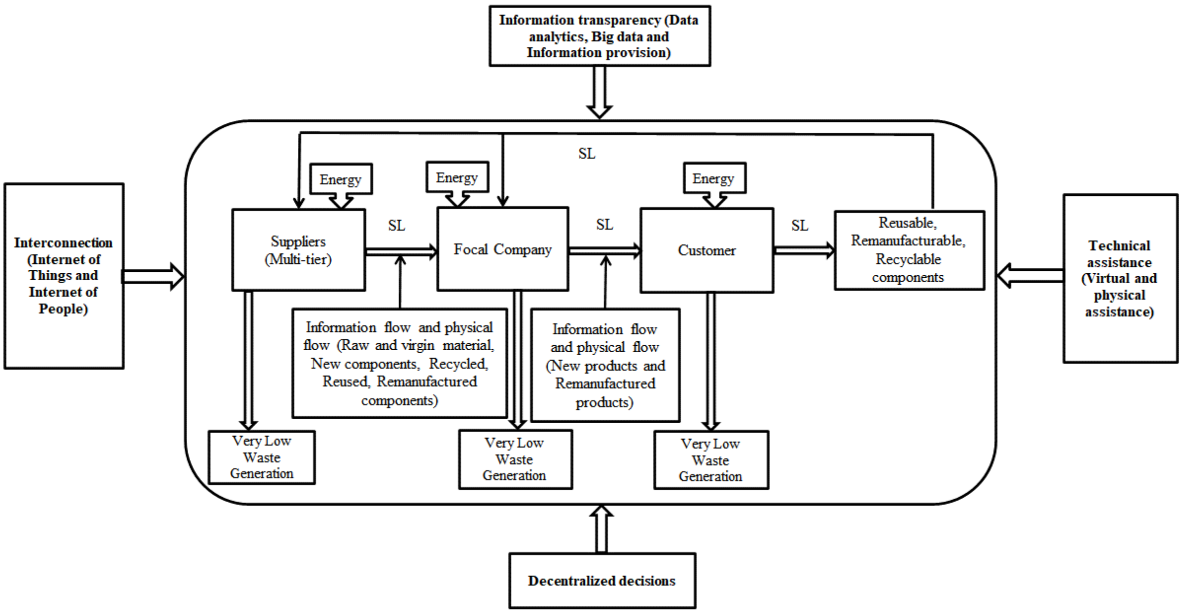
When considering the ‘fourth industrial revolution,’ or *‘Industry 4.0’,* due to environmental uncertainty, the focus is often on improved information processing to enhance business responses. Accordingly, Industry 4.0 changes include development and application of technologies to connect the organization internally (both vertically and horizontally) and with external stakeholders (e.g., suppliers or customers) to ensure smooth flow of information. Industry 4.0 can drive productivity by supporting several key functions, such as logistics and operations (Schuh et al., 2013).

Further, we aim to discuss selected Industry 4.0 papers on smart manufacturing/smart logistics, which are relevant to sustainability. There are frameworks for evaluating production system performance considering sustainability indicators (Watanabe, da Silva, Junqueira et al., 2016; Watanabe, da Silva, Tsuzuki et al., 2016). The study of Cardin et al. (2017) focused on synthesizing the regular issues of intelligent manufacturing and further presented a critical evaluation of different methods to propose a 2030 roadmap.

The article by Kusiak (2018) presents a smart manufacturing perspective. The findings indicated that the change in the system would be the biggest problem faced by firms. It also identified that automation in heavy industry is possible when there are affordable robotics options, which will generate new, highly skilled jobs. However, these forms of employment would require defining new job descriptions and training of workforce by institutes. Such factory-based shifts would be supported by a reconfigurable and customizable micro-machine tool that can help for functioning of new generation products in sensing, supporting the shift to a smart environment (Miranda et al., 2019).

From the smart warehouse and smart logistics perspective, a data collection and administrative module can provide a web-oriented architecture based on the REST framework, which integrates the physical environment of the warehouse with information systems, by enabling objects to communicate via the web (Jabbar et al., 2016). Such a system is an Internet of Things (IoT) based warehouse management system, supporting analytics as a foundation for ‘smart logistics’, improving picking accuracy and productivity (Lee et al., 2017). A major benefit of a smart working environment is that it may reduce dangerous situations for human operators. When objects can digitally communicate and integrate over the environment, we can create "IoT-controlled Safe Areas" to enhance safety using warehouse management systems (Trab et al., 2017). While there are many technical approaches to Industry 4.0 supply chains, guides do exist. For example, Trappey et al. (2017) generated a roadmap of IoT-focused patents and technology evolution for logistics, allowing an analysis of technology-related strengths and strategies. Small- and medium-sized enterprises (SMEs) have use Industry 4.0 to monitor logistics and supply chain processes but frequently neglect planning or other possible applications; there is little indication of business model transformation for SMEs from Industry 4.0 projects (Moeuf et al., 2018). These outcomes suggest many SMEs lack the ability to transform their operations using IoT and Industry 4.0.

Despite the infrequent use of a full range of Industry 4.0 technologies, the four crucial Industry 4.0 components (viz., decentralized decisions, information transparency, interconnection, and technical assistance) are linked with smart logistics throughout the remanufacturing and green supply chain (Figure 4). The result is business excellence and achievement of sustainability goals through resource optimization, cost optimization, and wastage reduction.



Note: SL: Smart logistics

Figure 4. Industry 4.0 and smart logistics driven remanufacturing and green manufacturing chain (Source: Authors' compilation)

Optimization toolsets that are based on Industry 4.0 technologies can often provide significant support for operations in remanufacturing, green manufacturing, and reverse logistics chains. While the full range is beyond the scope of this article, interested readers can follow discussions on optimization, automation, digital enhancement of manufacturing and quality, and augmented and virtual reality applications (Liao et al., 2017; Medoh and Telukdarie, 2017; Sung, 2018; Theorin et al., 2017; Wang et al., 2017; Dolgui et al., 2018; Dubey et al., 2018; Xu et al., 2018).

2.4 Instrumented logistics

In smart factories, the application of instrumentation provides a foundation for Industry 4.0 technologies and the use of smart logistics. The range of technologies includes automated guided vehicles (AGVs); global information systems (GIS); global positioning systems (GPS); human-machine interfaces (HMI); programmable logic controllers (PLC), radio-frequency identifications devices (RFID) tags and sensors; smart mobile devices; supervisory control and data acquisition (SCADA); and, vehicular ad-hoc networks (VANETS). Together, these approaches enable effective materials handling, production on the shop floor, inbound and outbound logistics movements. The application of such instrumentation in vehicles (e.g., forklifts, trucks, trailers, vans, or cars) makes tracking easier and thus enhancing visibility in the supply chain. The basics instrumentation sets include balances and scales, calibration equipment, chart recorders, data loggers, handheld devices, process controllers, panel meters, and sensors and probes. Instrumented logistics is a combination of instrumentation and logistics for real-time tracking and monitoring of certain key parameters in logistics operations. The level of instrumentation and set up depends upon the organization's logistics strategy and customer's information needs (Gupta et al., 2019).

2.5 Interconnected logistics

Interconnected logistics means the connection of two or multiple vehicles in the logistics network for better communication and information flow. Interconnected logistics help to move goods faster; provides real-time analysis of logistics movements; improves synchronization of logistics process and provides better tracking and traceability. Delivery reliability enhances customer satisfaction levels. The system architecture for interconnected logistics development is complex and depends upon the number of customers, number of cluster locations across various zones, number of inbound and outbound vehicle movements expected on a daily, weekly, and monthly basis, nature of goods, customer delivery dates, loading, and unloading facilities. The integration of logistics in the network will enable smart IoT-based devices to feed into the enterprise resource planning system and data captured in real-time to support management decisions (Gupta et al., 2019).

2.6 Intelligent logistics

Logistics systems are considered intelligent when they have the ability to autonomously communicate and transmit information over the organization to the individuals responsible for the process (Amodu and Othman, 2018). Intelligent logistics use IoT and artificial intelligence-based systems to plan machine loadings, control production flows, plan vehicle routing, schedule deliveries, and vehicle movements. IoT based applications play a key role in enabling the physical world to be integrated with and managed by the virtual or digital world (Čolaković and Hadžialić, 2018). IoT uses a combination of devices to produce data and send it to other equipment and further to the cloud. This data is useful for management decisions and mined by data analysts to get the key information from the data. The critical information and knowledge extracted from the shop floor/inbound logistics/outbound logistics can be used to develop new applications. Machine-to-machine communication enables data exchange between different objects, IoT equipment, and enterprise software. Further, with the use of the internet, the data flows to centralized servers for analytics and decision support purposes (Montori et al., 2018).

2.7 Business logistics sustainability

The history of logistics has witnessed developments from the early nineteenth-century rail applications through to movement by airplanes and later containerization in 1956. Now, the term ‘logistics’ generally describes the flows of both goods and information along a sequence of manufacturers and distributors through to customers. Therefore, effective logistics support customer satisfaction and through this, business success and performance (Speranza, 2018). Business logistics operations mainly focus on four key parameters; visibility, resilience, greenness, and costs to achieve sustainable development goals (Bag, 2016). Inbound and outbound logistics operations are becoming more complex than ever before. This is due to changing customer preferences and increased technological product innovations, which require special logistics arrangements (Barreto et al., 2017).

To cope in such dynamic times, gradually manufacturers are moving towards smart logistics concepts for sustainability. Smart logistics can adjust to market changes and are much more flexible and resilient than traditional logistics models. Smart logistics relies on applications such as intelligent transportation systems, information security systems, resource planning, transportation management systems, and warehouse management systems (Barreto et al., 2017; Trab et al., 2017). Additional infrastructure for smart connected logistics systems includes mobile automated platforms, mobile robotics systems, multi-agent cloud-based controllers, and IoT systems (Gregor et al., 2017). Traditional logistics models involve mostly manual operations, which are changing dramatically with the evolution of smart logistics. Modern logistics systems are becoming automated, adaptive and intelligent (Gregor et al., 2017; Witkowski, 2017). A logistics strategy must be aligned with the Industry 4.0 strategy for sustainability (Kayikci, 2018).

3. Theoretical framework and hypotheses development

3.1 Theoretical underpinning

Investigating the links between the integration of information sharing and business logistics practices is an established research area (e.g., Yu et al., 2013) where the primary focus is on demonstrating how information sharing and information use enhances business logistics outcomes. Dynamic business environments exert positive pressure on information sharing and logistics practices (Hong et al*.*, 2018). Business logistics dynamism is more influential on information sharing practices than on business logistics practices; logistics practice capabilities are more important when there is a greater level of information sharing (Zhou and Benton, 2007).

Our purpose is to propose an Industry 4.0 enabled optimization of the business logistics network, considering both forward and reverse logistics under remanufacturing and green manufacturing environment. We use Organization Information Processing Theory (OIPT) as a theoretical basis due to the importance of information processing, and analysis and use that has long been recognized as important to logistics success (Egelhoff, 1991). Business logistics network systems must rapidly respond to the external environment while minimizing risks and uncertainties. Galbraith (1974) extended the OIPT, based on two concepts: that an increasingly dynamic environment requires improved information processing on the part of the firm and that the firm could design and improve their capability of information processing. Interested readers are referred to seminal articles describing OIPT and its applications in different areas (Galbraith, 1974; Gattiker and Goodhue, 2005; Cegielski et al., 2012; Rosada Feger, 2014; Peng et al*.,* 2014; Wong et al., 2015; Ling et al., 2015; Srinivasan and Swink, 2017).

The proposed framework presents both the forward and reverse logistics chains, considering the scenario of remanufacturing and green manufacturing practices. These logistics chains suffer from high levels of supply and demand uncertainties and also are exposed to multiple risks. Here, we argue that the application of Industry 4.0 tools will benefit such logistics chains by reducing uncertainties. Firms can reduce uncertainty by improving their information processing capabilities to allow them to manage more effectively within this volatile, uncertain, complex and ambiguous environment. The reduction in uncertainty will influence several parts of their business and will have the end effect of improving the overall logistics process sustainability. The ability of an organization to share the required information promptly across functional barriers also supports organizational learning.

The proposed research framework is founded on how Industry 4.0 tools and technologies will drive smart logistical chains, which will further enhance the remanufacturing and green manufacturing capability and optimize the entire logistics processes. This will finally help to achieve business logistics sustainability. The uncertainties from the supply and demand perspective will be reduced through enhanced information processing capability. Improved information processing results in seamless vertical and horizontal flow of information in the forward and reverse logistical chains enabled through the application of Industry 4.0 technologies (IoT, cyber-physical systems, big data, and cloud computing) (Haddud et al., 2017; Sung, 2018).

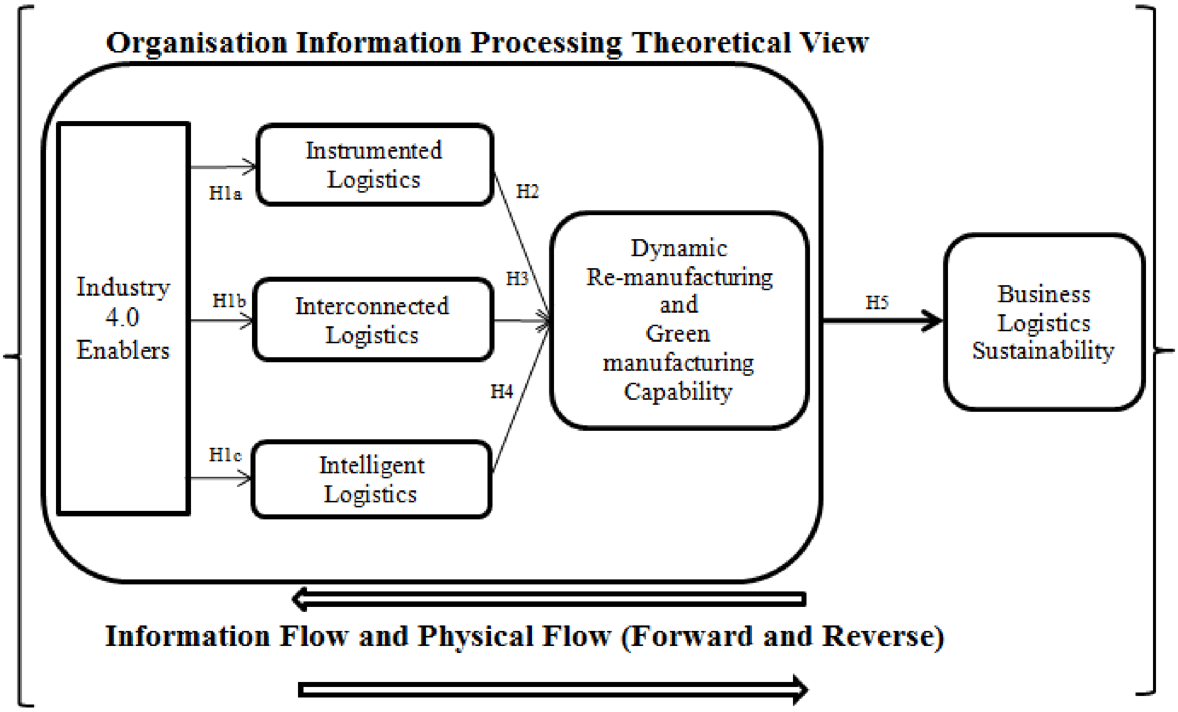


Figure 5. Research framework (Source: Authors' compilation)

3.2. Research hypotheses

Modeling instrumented logistics is based on applications of the multiple level instrumented physical monitoring platforms that are enabled through RFID technologies and enterprise information systems (Wang et al., 2010; Cabanes et al., 2010). Interconnected logistics is the connection of logistics chains enabled through the physical internet for interconnectivity. This will result in better information sharing and knowledge transfer between suppliers and customers (Ben-Daya et al., 2017). Intelligent logistics systems are implemented on Industry 4.0 platforms and embed autonomous learning principles and autonomous decision-making capabilities to support and maintain optimization efforts (Pan et al., 2017).

Autonomous logistics operations, transhipment technology and handling of logistics units can be enabled through Industry 4.0 tools such as IoT, big data analytics, smart objects, RFID and robotics (Wang et al., 2010; Benias et al., 2017; Ben-Daya et al., 2017; Liao et al., 2017; Sung, 2018; Sishi and Telukdarie, 2017).

Therefore, it is a clear indication that Industry 4.0 has advanced smart logistics and made it more user-friendly than before. The various challenges (lack of integrity; poor network design) faced previously in smart logistics can be overcome using Industry 4.0 technologies. Now, all systems in the logistics network can work in a synchronized manner with the objective of performing certain tasks sustainably. The enablers of Industry 4.0, which plays an instrumental role in driving smart logistics, are support from various departments including support government, technological enablement, human capital and process integration (Gupta et al., 2019). As a result, we hypothesize:

H1a: Industry 4.0 enablers are positively related to the instrumented logistics in an organization
H1b: Industry 4.0 enablers are positively related to the interconnected logistics in an organization
H1c: Industry 4.0 enablers are positively related to the intelligent logistics in an organization

An RFID device attached to any material automatically transforms it into a smart object, which can be tracked and traced during its physical movement in the supply chain. Tracking such smart objects during packaging, handling, loading, shipping, unloading, and warehousing provides visibility and generates data which is useful for managing inventory in a systematic manner. RFID based technologies, such as IoT, GPS, and GIS, can assist a remanufacturer in providing key information in real-time for timely decision making, and meeting customer demands efficiently. Therefore, technological integration across the verticals in the logistics chain enhances remanufacturing and green manufacturing capability in an organization (Majeed and Rupasinghe, 2017; Bag et al., 2018). As a result, we hypothesize:

H2: Instrumented logistics chain is positively related to the remanufacturing, green manufacturing capability in an organization

Interconnected logistics is characterized by the ability of machines, devices, and sensors to communicate and share information using the IoT for better interconnectivity. The interconnection builds real-time enterprise monitoring capabilities, which is helpful for decentralized decision making in remanufacturing and green manufacturing processes

(Uzsoy, 1997; Ben-Daya et al., 2017; Bag et al., 2018). The seamless flow of information across all verticals provides increased visibility and ability to plan and schedule jobs much more accurately. Multiple product bill of material can be managed at one point of time due to flexibility in production lines due to smart logistics systems. Overall equipment utilization is high, and capacity utilization is also high due to availability of information. Higher asset sweating leads to increases in operational performance and remanufacturing performance (Bag et al., 2019). Xiong et al. (2013) suggested that suppliers must not be forgotten in remanufacturing operations. Interconnected logistics can be used to connect suppliers at all levels and improve the communication and coordination to strengthen green manufacturing and remanufacturing chain. Therefore, we hypothesize that:

H3: Interconnected logistics chain is positively related to the remanufacturing, green manufacturing capability in an organization

Intelligent logistics can be utilized for adopting smart logistics processes useful for planning, sourcing, producing and delivering goods. Firms focusing on automating analytics and using machine learning and artificial intelligence insights in decision making will enhance the remanufacturing and green manufacturing capability in an organization. Smart machines can autonomously communicate with each other and plan production according to standard operation process guidelines. Robotics can be used to handle logistics movements on the shop floor to bring the components and fasteners to the right work station in a timely manner for assembly operations in remanufacturing operations. This is supported by prior studies such as (e.g., Bendavid and Cassivi, 2010; Bowles and Lu, 2014; Gupta et al., 2019). As a result, we hypothesize:

H4: Intelligent logistics chain is positively related to the remanufacturing, green manufacturing capability in an organization

Building the capability for green manufacturing and remanufacturing through smart management of available resources can avoid losses, reduce uncertainties, aid in meeting the supply and demand requirements in a timely fashion, thus resulting in enhancing customer satisfaction and sustainability. Remanufacturing and green manufacturing capability building can be done in multiple ways, such as developing capacity to handle variation in customer demands for remanufactured products; develop robust supply network to minimize uncertainties in quantity and quality of remanufactured products; design green products with interchangeable features and options; commit technical, managerial, and financial resources to support the development of capabilities in reverse logistics and the establishment of testing, packaging, and storage facilities for remanufactured products. Building remanufacturing and green manufacturing capability provides a competitive edge to the firm. A greater degree of resilience will be developed from the remanufacturing and green manufacturing capability building exercise and firms will quickly return to normal operations after any disruptions over the supply chain (Matsumoto and Ikeda, 2015; Aljuneidi and Bulgak, 2016; Aydin et al., 2017; Cahen et al., 2017; Xie and Li, 2017). As a result, we hypothesize:

H5: Remanufacturing, green manufacturing capability has a positive impact on business logistics sustainability in an organization.

4. Research methods

To address the research questions, we used a survey and structural equation modelling as a form of multivariate data analysis that would support concurrent examination of multiple relationships among both manifest and latent variables. We first present information about the research instrument design and the sample, and then give a survey description. We used Warp PLS version 6.0 software for the data analysis as it can process a full range of both direct and moderated effects in the model (Kock, 2016).

We designed the survey based on existing scales that operationalize the variables of interest (refer to Table 2) and can, therefore, provide measures for five concepts (Industry 4.0 enablers; instrumented logistics; interconnected logistics; intelligent logistics; dynamic remanufacturing and green manufacturing capability), and the final outcome variable (business logistics sustainability).

4.1 Sample and survey description

Empirical research is based on data collected about business events. Empirical data is useful for theory building and verification in operations management studies. The sample for this study is based on random sampling from the list of companies in the directory no: D1/2016 named “Operating mines and quarries and mineral processing plants in the Republic of South

Africa, 2016" Directorate: Mineral Economics. This database was compiled by Ms M C Lourens, and this 25th revised edition was published in January 2016.

In this study, for the final survey we used an online email survey that was pre-tested with thirty industry experts whom each had over ten years' experience. Based on the feedback, we slightly modified the wording on the questionnaire to increase the clarity of several items but did not remove any items. A Likert-type scale (five-points) was used to collect the data, where 1 means "strongly disagree"; 2 means "agree"; 3 means "neutral"; 4 means "agree" and 5 means "strongly agree".

Initially, the link for the online questionnaire was emailed to 321 working professionals selected from the directory: D/2016. After two rounds of follow-up; we received 150 valid and completed questionnaires, an effective response rate of 46.72%. We used the inverse square root method to confirm that our sample size (150) exceeded the minimum sample size required (85); the inverse square root method is simple to calculate and conservative as it leads to small over estimations of the required sample size (Kock and Hadaya, 2018). We found that 72.66% of the respondents have more than ten years' work experience; 22.66% respondents between 6-10 years; and, 4.66% respondents between 3-5 years (refer to Table 3).

We observed that 18% of responses were received from professionals working in a company having more than 1000 employees; 17.33% of responses received from professionals working in a company having 500-1000 employees; 7.33% of responses received from professionals working in companies employing 300-500 employees; 57.33% from companies employing 50-300 employees (refer to Table 4).

4.2 Common method bias

Our survey respondents tend to be senior managers that have a rich logistics management experience. The survey presentation of constructs on separate pages minimized the item-priming effect. Due to their position and roles, they are able to assess and answer all survey questions; we categorize the design as a Type I study (Flynn et al., 2018). We used Harman's single factor test (Podsakoff et al., 2003) and established that there was no one factor that was representative of the majority of the total variance; the highest loading was 47.68% on the first factor, which is lower than the suggested limit of 50%. Therefore, we are confident that common method bias is not an issue.

4.3 Non-response bias

The email-based survey method has frequently been criticized for the potential of non-response bias. If the responses received vary considerably from the probable answers from our non-respondents then generalization of results would be problematic. The only way out of this problem is to reduce non-response bias itself. Completeness of data and the data collection method also plays an important role in reducing non-response bias (Armstrong and Overton, 1977). We took all necessary measures to ensure gathering of complete and correct data during the survey. The sample data was received in two phases. One set of responses was received before follow-up and second set was received after follow-up with the potential respondents.

To assess further the potential for non-response bias, the two sets of responses were compared using Leven's test, and we did not find any significant variation between them.

Leven's homogeneity of variance test was conducted to check if the distribution of our variables varied between the two waves. SPSS software was used to compare means and perform an initial analysis by selecting one-way ANOVA and to further check the Levene statistic. We found that none of the values were significant, suggesting there was no difference between the waves and providing evidence there is no non-response bias (Armstrong and Overton, 1977).

4.4 Data analysis tool

Structural Equation Modelling (SEM) is commonly used in a range of disciplines, including social sciences, business management, and engineering (Astrachan et al., 2014). There are two categories of SEM methods: Covariance-based (CB) SEM and Partial Least Squares (PLS) SEM (Hair et al., 2014). PLS-SEM can be applied in research studies with smaller sample size and secondly in studies which have considered exploratory research design. More importantly, PLS-SEM does not require normally distributed data for data analysis purposes

(Hair et al., 2011; Kock, 2016). PLS based SEM is considered suitable for more exploratory research studies without well-established relationships between the dependent variables and the outcome or independent variables (Hair et al., 2014).

WarpPLS version 6.0 software is designed based on the concept of PLS-SEM and was applied to analyze the survey data collected from samples. There is higher efficiency in the PLS-SEM technique for estimating parameters, and this increases the likelihood for the modelled relationships to be recognized in the analysis as significant when they are considered significant by respondents (Hair et al., 2014).

5. Data analysis and discussions

After the data preparation stage, the pre-processed data was checked to see whether it was suitable for PLS-based SEM analysis. We confirmed that there were no missing values, that no columns had zero variance, and there was no rank problem. Finally, all the columns were standardized. Post this, the researcher proceeded with the path modelling and the results are presented in the sub sections.

5.1 Model fit and quality indices

To assess the model fit, we used the APC, ARS, and AARS tests (refer to Table 5). The test results showed a p-value of less than 0.05 (refer to Table 5). There is the presence of minor collinearity, likely due to the high number of related scales we used, but it was within suggested limits of under 3.3 (Kock, 2016).

5.2 Causality assessment

A causality assessment was completed, and the results are provided in Table 6. The obtained results are found to be satisfactory. Factor loadings were calculated item wise and presented in Table 7. All loadings are above 0.50 and are therefore satisfactory.

We next assessed the discriminant validity. The square roots of average variance extracted should be greater than construct correlations; Table 8 shows the matrix, and the square roots on the diagonals are clearly greater than the construct correlations, so we are satisfied in the discriminant validity. The construct reliability test results (refer to Table 9) show composite reliability and Cronbach's alpha to be above 0.70, suggesting we can be satisfied with the construct reliability (Nunnally and Bernstein, 1994, Kock, 2014). The average variance extracted was greater than 0.50, which exceeded the minimum threshold (Hair et al*.,* 1998).

5.3 Discussion of findings

The tested structural equation model is presented in Figure 6. The results suggest that the Industry 4.0 associated factors contributed 51% variance in instrumented logistics chains (INLS); explained 70% variance in interconnected logistics chains (ICLS); explained 76% variance in intelligent logistics chains (ITLS); 97% variance in dynamic remanufacturing, green manufacturing capability (DRGM) and overall 84% variance in business logistics sustainability (BLS) which justifies that the assessed model is robust. In our analysis, we use the standard alpha value of 0.05 (5%) as the cut-off for significance. The results of hypothesis tests are presented in Table 10. The results show support for the seven research hypotheses.

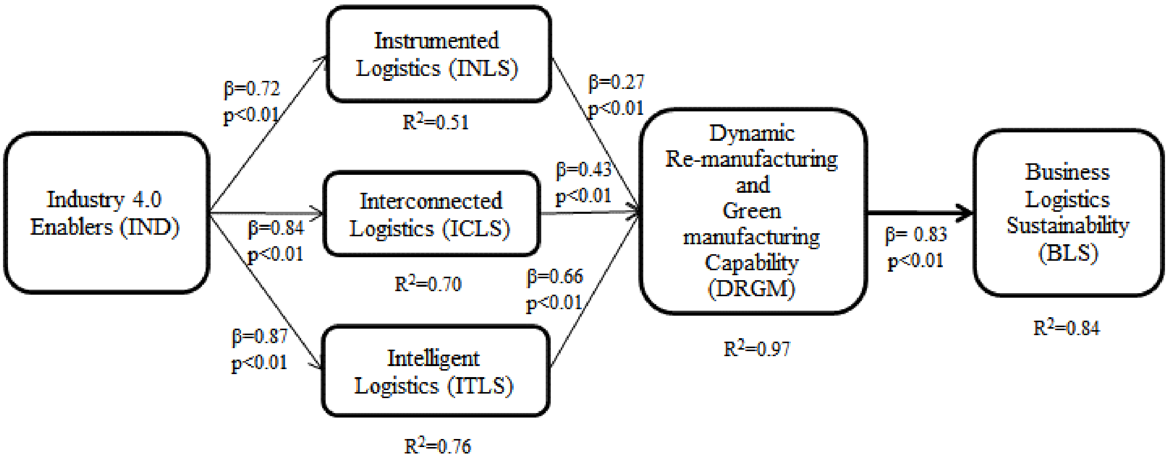


Figure 6. Tested model and results with WarpPLS 6.0 output.

The findings of the present study are viewed from the perspective of the research questions, objectives and the results. First, it is worthwhile to understand that this work is a contribution that begins to address the scarcity of this research in this area. While the existing literature has research that acknowledges the key variables (Industry 4.0, instrumented logistics, interconnected logistics, intelligent logistics, dynamic green manufacturing, and business logistics sustainability), this study has presented them collectively and modelled the associations between them. Our results also suggest that while the implementation of instrumented logistics can contribute to business logistics sustainability, the practical importance may not be as great as previously suggested in earlier research (e.g., Ben-Daya et al., 2017; Pan et al., 2017). In contrast, we show that the other pathways, through interconnected logistics and intelligent logistics, are stronger drivers of operational and logistics sustainability. In this way, our results confirm the emerging body of work that connects Industry 4.0 and sustainability outcomes (e.g., Majeed and Rupasinghe, 2017; Bag et al*.*, 2018; Bag et al., 2019; Gupta et al., 2019).

Second, it is pertinent to understand that in every aspect in today's world, everything revolves around technology. The majority of activities are accomplished with the involvement of technology. The results stated in the above framework confirm the positive association between hypothesized relationships. With due consideration given to the circular economy and economic empowerment for South Africa, it also becomes essential to understand black economic empowerment, which has become broad-based black economic empowerment (BBBEE) scorecards for holistic sustainable development. The studies previously conducted talk about various initiatives aimed at conceptualization of different variables, but this work presents an empirical and interesting contribution to the existing body of knowledge and future work. We show that managers can plan and leverage particular Industry 4.0 implementations to drive sustainable outcomes. In this way, we contribute to the emerging body of literature that shows that not only does Industry 4.0 provide operational and cost efficiencies (e.g., Bendavid and Cassivi, 2010; Wood, Reiners et al. 2017; Wood and Wang, 2018; Bag et al., 2019), it also provides environmental benefits.

6. Conclusion

In this era of globalization and heightened competition, every organization aims to optimize their operations management, not only to meet customer commitments, but also resources optimization, costs reductions, and business sustainability. The fourth industrial revolution, Industry 4.0, drives digitalization and smart systems. When used effectively, Industry 4.0 supports optimization of operations over the protracted and complex global business logistics chains. The scientific contribution of this research study is the proposed theoretical framework and its statistical validation in context to the mining business. The study builds on OIPT, and the findings show how Industry 4.0 based logistics automation supports operations management excellence by enhancing business logistics sustainability. Novel services and IoT based technologies help to build the information processing capability for meeting the information processing requirement under this dynamic remanufacturing and green manufacturing environment. The supply and demand uncertainties in the forward and reverse logistics network will reduce significantly followed by lowering of wastages in the supply chain network, enhancing the operations management success in firms.

The literature review identified optimization tools and techniques used in forward, reverse, remanufacturing, and green manufacturing chains. However, the empirical survey provided us an update on the current status of Industry 4.0 approaches to optimizing business logistics processes. The findings show that Industry 4.0 enablers (such as support from government and research institutes), focus on human capital, and process integration drives smart logistics (instrumented logistics, interconnected logistics, and intelligent logistics). Industry 4.0 enablers are found to exert a very strong effect on intelligent logistics (β=0.87); compared to its effect on interconnected logistics (β=0.84) and instrumented logistics chain (β=0.72).

Smart logistics systems can enhance dynamic remanufacturing and green manufacturing capabilities. We found that the effect of intelligent logistics is very high on dynamic remanufacturing and green manufacturing capability (β=0.66) as compared to the effect of interconnected logistics (β=0.43) and instrumented logistics (β=0.27) on dynamic remanufacturing and green manufacturing capability.

Finally, dynamic capabilities directly support organizations to achieve operations management success through business logistics sustainability. All factors explain 84% of the variance in the model, which is good compared with past research studies in this area. Based on the OIPT, we found that Industry 4.0 enabled smart logistics is effective in sharing information, which further enhances business logistics sustainability. Remanufacturing and green manufacturing logistics suffer from high levels of uncertainty (Guide Jr., 2000) which further increases the need for more information sharing. Therefore, Industry 4.0 plays an instrumental role in building the dynamic capability to meet such information collection, processing, and sharing requirements and activate smart logistics systems for gradually transforming into a green economy.

6.1 Policy implications

The present paper provides several directions for policymakers dealing with mining and related sectors. The foremost implication for policymakers is that there should be a thorough understanding of the circular economy, and how it contributes towards sustainability. The mining industry constitutes one of the major industries for economic development in South Africa and involves significant investments (e.g., social, financial, and infrastructural). Policymakers must pursue socially responsible investments in the mining sector as part of their social sustainability obligation. Policymakers are responsible for comparing and contrasting the cost and benefits of their every move towards societal development. A critical development is the liberalization of the African mining industry; while privatizations have resulted in more employment and output, they may raise the question of job insecurity. Policymakers must realise that sustainable development is possible only when social and environmental sustainability leads to economic sustainability and vice-versa. The effective combination of Industry 4.0 and the circular economy to address amelioration of logistics sustainability should be considered by policymakers as an area they need to support. Current Industry 4.0 technology presents many opportunities for the mining industry and therefore it should come to the attention of policymakers to support proliferation of smart logistics in South Africa.

6.2 Managerial implications

There are three key implications for operations and logistics managers. First, operations managers must focus on establishing core Industry 4.0 enablers (such as financial support from central government, technical support from department of trade and industry, and support from department of science and technology). It is important to develop an appropriate set of basic and advanced Industry 4.0 technologies. A focus on human capital, continuous education, and training of operational workers is necessary to ensure the effectiveness of the workforce in the smarter organization. There should be more focus on data privacy, security, and information sharing. Finally, process integration supports the seamless flow of information. However, managers must take care when selecting the combination of Industry 4.0 technological toolsets as each tool has different characteristics and pose unique challenges; the selection should depend on the nature of the operations and logistics process.

Operations managers must increase use of instrumented logistics, interconnected logistics, and intelligent logistics systems to enhance dynamic remanufacturing and green manufacturing capability. These smart logistics systems will improve performance in the remanufacturing and green manufacturing environments through the building of dynamic capability, and aid survival in this highly uncertain business environment. Smart logistics systems can collect real-time data for processing and extracting key information, which can be useful for enhancing productivity in remanufacturing operations. The technologies eliminate uncertainties and risks for remanufacturers and green manufacturers.

Dynamic remanufacturing and green manufacturing capability must be developed by operations managers to enhance business logistics sustainability. The development of such dynamic capabilities can improve visibility of operations while enhancing resilience, greenness and cost savings.

6.3 Social implications

The survey results indicate that Industry 4.0 enablers bring positive operational changes in the business logistics network, which ultimately have social benefits. Industry 4.0 involves vertical and horizontal integration and inter-firm integration with suppliers and customers. Therefore, a seamless flow of information is ensured across the entire business logistics network enabled through technologies such as RFID devices, smart objects, GIS, GPS systems and wireless sensor networks. Automation, real-time tracking and tracing systems in business logistics can be instrumental in timely and quality decision making. The outcomes of logistics automation can improve planning and control of fleets that will conserve resources and fuel while reducing maintenance costs and increasing vehicle life. Telematics technologies, transmitting real-time data, can be fitted as tags on the forklifts and other vehicles. Exceptions, misuse, and unsafe conditions during operation are noted by email directly to the logistics manager. Such smart systems save machine parts wear and tear and increase efficiency and life of machines. Intelligent logistics systems lower consumption of scarce resources, lower pollution levels and support organizational sustainable development goals. Thus, Industry 4.0 enabled smart operations and logistics can take the nation forward towards a cleaner and closed-loop economy where the longevity of resources will increase significantly due to capability development of remanufacturing and green manufacturing principles. The annual volume of solid waste generation will decrease; the environmental pollution levels will decrease significantly, resulting in a reduction in the numbers of residents suffering from skin and lung diseases in surrounding communities.

6.4 Limitations and future research directions

There are a few limitations to this study. First, this empirical study used a sufficient but small sample size (150 respondents), suitable for this type of exploratory study. Future research studies should consider larger sample sizes and the use of confirmatory designs based on covariance-based SEM methods. Second, all variables in the model accounted for 84% variance of business logistics sustainability. Some variables not considered in this study could be included in future studies to address the remaining variance not captured in this study. Finally, it would be interesting to compare results from the study with data from other countries and regions to ensure the generalizability of the model.

Appendix (see Tables 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10).

Table 1: Sustainable development challenges

Environmental Challenges	Social Challenges	Economic Challenges
Harmful emissions (Dubiński, 2013)	Employment generation (Hamann, 2003)	Stakeholders value (Luthra and Mangla, 2018)
Deployment of wastes (Endl et al., 2019)	Desired skill levels (Hodgkinson and Smith, 2018)	Revenue generation (Henckens et al., 2016)
Global warming (Giurco and Cooper, 2012)	Corruption and unethical practices (Mudd, 2010)	Justifiable investments (Hilson and Murck, 2000)
Optimal use of non-renewable sources of energy (Hagan et al., 2019)	Interpersonal organizational relationships (Soleimani, 2018)	Economic development (Mangla et al., 2018)
Pollution control measures (Azapagic, 2004)	Distribution of wealth (Campbell, 2012)	Economic inequality (Bouzon et al., 2015)

Source: Authors' Compilation

Table 2. Operationalization of constructs

Latent Variable	Indicator	Measurement Constructs	Source
Industry 4.0	**Support**		Gupta et al.,

(IND)	SUP1	We get financial support from Central Government for driving Industry 4.0	(2019)
	SUP2	We get support from Department of Trade and Industry for driving Industry 4.0 project	
	SUP3	Our industry sector get support from Department of Science and Technology which help in converting local innovations into commercial products	
	SUP4	We have collaborated with research institutes and universities to facilitate skills development, human resource training and transfer	
	Technology		
	TECH1	We use of internet to access data from remote sensors and control physical objects in the surrounding environment	
	TECH2	We use cyber physical systems to manage big data and control the interconnectivity of machines	
	TECH3	We use cloud computing for data management and storage processes	
	TECH4	We have employed cyber security services	
	TECH5	We use trust-based security to authenticate IoT devices and ensure only trusted components communicate between each other in a production environment	
	TECH6	We conduct annual security audit that includes industrial control systems, partner network access, maintenance network access and wireless links	
	Focus on Human Capital		
	HC1	We invest a percentage of company income in training and continuous education of workers to upgrade skill sets of workers as per Industry 4.0 requirements and develop competency for specialised jobs	

	HC2	New labour and employment legislation is required for safeguarding human quotas in this era of robotics and automation	
	HC3	We have developed a policy to support the un-employed	
	Process Integration		
	PI1	We have done horizontal integration over the business value networks which involve internal expansion, mergers and acquisitions	
	PI2	We have done vertical integration which involve collaboration with suppliers and customers	
Instrumented Logistics (INLS)	**Technology Integration**		Gupta et al., (2019)
	TECI1	We have integrated technology in our supply chain	
	TECI2	Rapid technological changes are taken care by updating software and systems on a regular basis	
	TECI3	We use RFID for factory automation to enhance logistics efficiency	
Interconnected Logistics (ICLS)	**Connection**		Gupta et al. (2019)
	CO1	In our organization all machines, devices, sensors, and people are able to connect and communicate with each other via the Internet of Things (IoT) or the Internet of People (IoP)	
	CO2	We have real time enterprise monitoring capabilities	
	CO3	We emphasize on coordination and optimization of key business processes across our logistical chain	
	CO4	We use data obtained from process monitoring to optimize business processes	
	CO5	We have systems in place for decentralised decision making	
	CO6	Our current information systems meet the logistical chain communications requirements	

	CO7	Our information applications are highly integrated within organization and logistical chain	
Intelligent Logistics (ITLS)	**Traceability**		Gupta et al. (2019)
	TRA1	We have adopted smart processes for planning, sourcing, making and delivering goods	
	TRA2	We use devices to actively monitor the proper handling conditions of goods	
	TRA3	We are automating analytics and using machine learning/artificial intelligence insights in decision-making	
	TRA4	We are applying artificial intelligence insights in production workflows	
Dynamic Remanufacturing, Green Manufacturing Capability (DRGM)	**Market Factors**		Bag et al. (2019)
	MAF1	We have increased rate of introduction of remanufactured products	
	MAF2	We do optimal pricing for our remanufactured products	
	MAF3	We would still be able to avoid cannibalization of new product sales	
	Resources and Capabilities		
	RC1	Our plant have capability to handle increasing variety of customer demands for remanufactured products	
	RC2	We have reduced uncertainties in the quantity of returned products through development of a robust global supply network	
	RC3	We have proper testing facility, safe storage and packaging facility for remanufactured products	
	RC4	Green products have interchangeable features and options	

	RC5	Options can be added to a standard green product	
	RC6	Components are shared across green products	
	RC7	We have committed resources consisting of the financial, technical, and managerial resources that are committed to reverse logistics capabilities	
	Process Optimization		
	PO1	We have optimized setup cost for disassembly operations	
	PO2	We have optimized setup cost for remanufactured components	
	PO3	We have reduced work cycles	
	PO4	We have done truck-load and route optimisation	
	PO5	We have optimized reverse logistics costs	
Business Logistics Sustainability (BLS)	**Visibility**		Dubey et al. (2017)
	VIS1	Inventory levels are visible throughout the supply chain	
	VIS2	Demand levels are visible throughout the supply chain	
	Resilience		
	RES1	Our organization is capable to anticipate and overcome disruptions in supply chain network	
	RES2	We have the ability to quickly respond to disruptions by reconfiguring resources and restore normal operations	
	RES3	Our operations is capable to continue after occurrence of any disruptions	
	RES4	Our organization performance would not deviate significantly from targets in occurrence of any disruptions	
	Greenness		

	GR1	We have created green image of our products	
	GR2	We emphasize on products designed for reuse and recycling	
	GR3	We have reduced solid waste management and waste water treatment costs significantly compared to past years	
	Cost Savings		
	CS1	We incur lower compliance costs with environmental regulations due to our returns handling method	
	CS2	Our strategy for dealing with returned merchandise improves our cost position relative to our closest competitors	
	CS3	Our reverse logistics, remanufacturing and green manufacturing program is saving us money	

(Source: Authors' compilation)

Table 3. Respondents work domain and experience

Work Domain	**Work Experience**			
	3-5 years	6-10 years	>10 years	**Total**
Mines and Quarries	5	12	72	89
Mineral processing	2	22	37	61
Total	7	34	109	150

(Source: Authors' compilation)

Table 4: Different organizational roles and employees' strength

Role in the Organisation	**Number of Employees**						
	Less than 10	10-50	50-300	300-500	500-1000	More than 1000	Total
Board Member	0	0	1	0	0	0	1
CEO/President/ Owner/ Managing Director	0	0	13	0	0	0	13
CFO/Treasurer/ Controller	0	0	0	0	0	0	0
CIO/Technology Director	0	0	0	1	0	0	1
Chief Procurement Officer	0	0	3	0	3	6	12

Senior VP/VP	0	0	0	7	12	3	22
Head of Business Unit or Department	0	0	32	0	3	0	35
Manager	0	0	37	3	8	13	61
Data Analyst	0	0	0	0	0	2	2
Data Scientist	0	0	0	0	0	3	3
Consultant	0	0	0	0	0	0	0
Researcher	0	0	0	0	0	0	0
Others	0	0	0	0	0	0	0
Total	0	0	86	11	26	27	150

(Source: Authors' compilation)

Table 5. Model fit

Model fit and quality indices	Values
Average path coefficient (APC)	0.538, P<0.001
Average R-squared (ARS)	0.765, P<0.001
Average adjusted R-squared (AARS)	0.763, P<0.001
Average full collinearity VIF (AFVIF)	2.488, acceptable if <= 5, ideally <= 3.3

(Source: WarpPLS 6.0 output)

Table 6. Causality assessment

Causality Assessment	Values
Sympson's paradox ratio (SPR)	1.000, acceptable if >= 0.7, ideally = 1
R-squared contribution ratio (RSCR)	1.000, acceptable if >= 0.9, ideally = 1
Statistical suppression ratio (SSR)	1.000, acceptable if >= 0.7
Nonlinear bivariate causality direction ratio (NLBCDR)	0.778, acceptable if >= 0.7

(Source: WarpPLS 6.0 output)

Table 7. Combined loadings and cross loadings

	IND	INLS	ICLS	ITLS	DRGM	BLS	P value
SUP1	**0.501**	0.230	-0.418	0.072	0.282	0.165	<0.001
SUP2	**0.517**	-0.368	-0.378	0.811	0.279	-0.438	<0.001
SUP3	**0.764**	-0.331	-0.453	0.164	0.197	-0.437	<0.001
SUP4	**0.798**	-0.078	-0.024	-0.169	-0.050	0.027	<0.001
TECH1	**0.731**	-0.352	0.350	0.519	-0.650	0.409	<0.001
TECH2	**0.840**	-0.079	-0.094	0.080	0.053	0.028	<0.001
TECH3	**0.808**	0.160	0.315	-0.100	0.057	0.026	<0.001
TECH4	**0.902**	0.356	0.071	0.448	0.209	-0.601	<0.001

TECH5	**0.796**	-0.207	-0.183	0.084	-0.293	0.507	<0.001
TECH6	**0.835**	0.273	0.277	-0.273	0.172	-0.162	<0.001
HC1	**0.759**	0.018	0.047	-0.075	-0.108	0.026	<0.001
HC2	**0.510**	0.647	-0.523	-0.917	0.105	0.208	<0.001
HC3	**0.871**	-0.230	0.101	0.041	-0.002	0.006	<0.001
PI1	**0.726**	-0.249	0.429	-0.583	-0.410	0.601	<0.001
PI2	**0.619**	0.367	-0.022	-0.158	0.392	-0.317	<0.001
TECI1	-0.057	**0.935**	-0.023	0.290	-0.127	-0.240	<0.001
TECI2	0.016	**0.895**	0.017	-0.394	0.265	-0.386	<0.001
TECI3	0.046	**0.834**	0.008	0.098	-0.142	0.683	<0.001
CO1	0.035	-0.137	**0.622**	0.239	-0.280	0.936	<0.001
CO2	0.394	-0.072	**0.914**	-0.719	-0.133	0.429	<0.001
CO3	0.470	0.298	**0.845**	-0.930	0.363	-0.099	<0.001
CO4	-0.188	0.020	**0.918**	0.414	0.227	-0.784	<0.001
CO5	-0.359	-0.266	**0.934**	0.322	-0.212	0.041	<0.001
CO6	-0.292	0.140	**0.929**	0.661	-0.023	-0.226	<0.001
TRA1	0.152	0.066	0.203	**0.912**	0.082	0.080	<0.001
TRA2	-0.107	-0.062	0.396	**0.900**	-0.266	0.402	<0.001
TRA3	-0.457	0.045	-0.073	**0.830**	-0.221	-0.083	<0.001
TRA4	0.395	-0.048	-0.563	**0.854**	0.407	-0.428	<0.001
MAF1	-0.171	0.120	-0.219	0.292	**0.894**	-0.527	<0.001
MAF2	0.148	-0.049	0.069	-0.260	**0.911**	0.154	<0.001
MAF3	0.185	0.027	0.257	-0.432	**0.686**	-0.054	<0.001
RC1	-0.134	-0.040	-0.165	0.199	**0.919**	0.190	<0.001
RC2	-0.474	0.096	-0.177	0.837	**0.905**	-0.780	<0.001
RC3	-0.122	-0.010	-0.312	0.148	**0.927**	0.003	<0.001
RC4	-0.073	-0.343	0.393	0.146	**0.879**	-0.072	<0.001
RC5	0.029	-0.216	0.194	-0.044	**0.901**	-0.357	<0.001
RC6	0.110	-0.193	0.123	-0.051	**0.908**	-0.349	<0.001
RC7	0.067	0.119	0.067	-0.656	**0.873**	0.961	<0.001
PO1	0.368	-0.205	0.252	-0.407	**0.907**	0.710	<0.001
PO2	0.005	0.058	-0.242	0.132	**0.917**	-0.044	<0.001
PO3	0.140	0.057	-0.168	0.390	**0.797**	-0.511	<0.001
PO4	0.035	0.352	0.019	-0.111	**0.827**	-0.148	<0.001
PO5	-0.049	0.277	-0.023	-0.282	**0.873**	0.785	<0.001
VIS1	-0.092	-0.051	-0.230	0.038	-0.125	**0.816**	<0.001
VIS2	-0.152	-0.224	0.159	0.251	-0.225	**0.922**	<0.001
RES1	-0.148	-0.032	0.418	0.195	-0.304	**0.925**	<0.001
RES2	-0.189	-0.167	0.608	0.211	-0.494	**0.902**	<0.001
RES3	-0.089	0.129	0.366	0.455	-0.445	**0.887**	<0.001
RES4	0.094	0.067	0.330	0.217	-0.216	**0.879**	<0.001
GR1	-0.029	0.477	-0.214	0.262	0.459	**0.900**	<0.001
GR2	0.012	0.510	-0.258	-0.139	0.587	**0.905**	<0.001
GR3	0.216	-0.119	-0.380	-0.744	0.021	**0.816**	<0.001
CS1	-0.000	0.138	-0.385	-0.097	-0.055	**0.907**	<0.001
CS2	0.100	-0.445	0.155	-0.273	0.559	**0.846**	<0.001
CS3	0.347	-0.366	-0.704	-0.521	0.300	**0.790**	<0.001

(Source: WarpPLS 6.0 output)

Table 8. Correlations among latent variables with square roots of AVEs shown on diagonal

	IND	INLS	ICLS	ITLS	DRGM	BLS
IND	**0.739**					

INLS	0.703	**0.889**				
ICLS	0.833	0.750	**0.867**			
ITLS	0.854	0.698	0.831	**0.875**		
DRGM	0.678	0.527	0.743	0.785	**0.877**	
SR	0.718	0.638	0.799	0.616	0.727	
CR	0.723	0.725	0.793	0.662	0.552	
BLS	0.740	0.691	0.802	0.873	0.893	**0.876**
SR*DRGM	0.025	0.119	-0.132	0.091	-0.034	-0.039
CR*DRGM	0.207	0.220	0.004	0.202	0.076	0.174

(Source: WarpPLS 6.0 output)

Table 9. Latent variable coefficients

	IND	INLS	ICLS	ITLS	DRGM	BLS
R-squared		0.513	0.700	0.758	1.015	0.837
Adjusted R-squared		0.510	0.698	0.757	1.015	0.834
Composite reliability coefficients	0.946	0.919	0.947	0.929	0.980	0.975
Cronbach's alpha coefficients	0.936	0.866	0.930	0.897	0.978	0.972
Average variances extracted	0.546	0.791	0.752	0.765	0.769	0.767

(Source: WarpPLS 6.0 output)

Table 10. Results of hypotheses testing

Hypothesis Number	Research Hypothesis	Beta value	p value	Hypothesis supported/Not supported
H1a	Industry 4.0 is positively related to the instrumented logistics chains in an organization INLS	0.72	<0.01	Hypothesis supported
H1b	Industry 4.0 is positively related to the interconnected logistics chains in an organization ICLS	0.84	<0.01	Hypothesis supported
H1c	Industry 4.0 is positively related to the intelligent logistics chains in an organization ITLS	0.87	<0.01	Hypothesis supported
H2	Instrumented logistics chain is positively related to the remanufacturing, green manufacturing capability in an organization	0.27	<0.01	Hypothesis supported
H3	Interconnected logistics chain is positively related to the remanufacturing, green manufacturing capability in an organization	0.43	<0.01	Hypothesis supported

H4	Intelligent logistics chain is positively related to the remanufacturing, green manufacturing capability in an organization	0.66	<0.01	Hypothesis supported
H5	Remanufacturing, green manufacturing capability has a positive impact on the business logistics sustainability in an organization	0.83	<0.01	Hypothesis supported

(Source: Authors' compilation)

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