An integrated business model for supply chain environmental sustainability through 'Internet of Things'

Michael Leigh (m.leigh@shu.ac.uk)
Department of Computing, Sheffield Hallam University, Sheffield, S11WB, UK

Xiaohong Li
Sheffield Business School, Sheffield Hallam University, Sheffield, S11WB, UK

Abstract

The supply chain management literature indicates that limited research has explored the integration of environmentally sustainable approaches and technologies such as the Internet of Things (IoT) to support environmental sustainability development. In this study, an exploratory case study is used to explore the potential integration of the environmental sustainability approaches using IoT technologies. The initial findings suggest the potential integration of design for environment (DfE) and cleaner production approaches with IoT technologies to enhance environmentally sustainable performance of companies and their supply chains.

Keywords: environmental sustainability, integrated business models, Internet of Things (IoT)

Introduction

Studies in environmental sustainability development seek to develop methods for the improvement of human welfare by protecting sources of raw materials and ensuring waste produced from human activities causes no harm to humanity and the nature environment (Ekins, 2000; Goodland, 1995; Morelli, 2011). An imbalance between the carrying capacity of the environment and waste generated from human activities has caused serious consequences for humanity and the nature environment (Meadows et al., 2005; Song, 1972). Studying approaches and developing business integrated models to reduce the negative impact of industrial activities along supply chains on the environment is an important topic for achieving a sustainable future. One such approach is to integrate supply chain processes with different kinds of technologies (Handfield et al., 2005), for example, integrating computing technology for the collection of mass data to assist business decision making. Over the last four decades, the world has witnessed the use of technologies to impact on business activities positively. In particular, the development of the internet, initially via the Internet of Information and now through the development of the Internet of Things (IoT) (Lee and Lee, 2015).

The aim of this research is to investigate how IoT technologies can be deployed to support the development of environmentally sustainable supply chains. To achieve this aim, the literature review focuses on different environmental sustainability models, environmental supply chain approaches and IoT technologies. This is followed by the research method, the case study company, results, discussions and conclusions.

Environmental sustainability models

In order to support the development of an integrated model for environmentally sustainable supply chains using IoT, the following environmental sustainable models where identified from the literature, are summarised in Table 1.

Table 1 - Environmental Sustainability Models

Author(s)	Model
Goodland and Daly (1996), Page 1008	"The fundamental definition of environmental sustainability is contained in the input-output rule" "Output Rule: Waste emissions from a project should be within the assimilative capacity of the local environment to absorb without unacceptable degradation of its future waste absorptive capacity or other important services." "Input Rule: (a) Renewables: harvest rates of renewable-resource inputs should be within the regenerative capacity of the natural system that generates them. (b) Non-renewables: depletion rates of non-renewable-resource inputs should be equal to the rate at which renewable substitutes are developed by human invention and investment. Part of the proceeds from liquidating non-renewables should be allocated to research in pursuit of sustainable substitutes."
Ekins (2000), Page 80	"The environmental sustainability of human ways of life refers to the ability of the environment to sustain those ways of life. The environmental sustainability of economic activity refers to the continuing ability of the environment to provide the necessary inputs to the economy to enable it to maintain economic welfare. Both of these sustainabilities in turn depend on the maintenance of the requisite environmental functions."
OCED (2001), Page 8	"Thus, four specific criteria can be defined for environmental sustainability: I. Regeneration: Renewable resources shall be used efficiently and their use shall not be permitted to exceed their long-term rates of natural regeneration. II. Substitutability: Non-renewable resources shall be used efficiently and their use limited to levels which can be offset by substitution by renewable resources or other forms of capital. III. Assimilation: Releases of hazardous or polluting substances to the environment shall not exceed its assimilative capacity; concentrations shall be kept below established critical levels necessary for the protection of human health and the environment. When assimilative capacity is effectively zero (e.g. for hazardous substances that are persistent and/or bio-accumulative), effectively a zero release of such substances is required to avoid their accumulation in the environment. IV. Avoiding Irreversibility: Irreversible adverse effects of human activities on ecosystems and on biogeochemical and hydrological cycles shall be avoided. The natural processes capable of maintaining or restoring the integrity of ecosystems should be safeguarded from adverse impacts of human activities. The differing levels of resilience and carrying capacity of ecosystems must be considered in order to conserve their populations of threatened, endangered and critical species."

The suitability of the environmental sustainability models are discussed in order to support the development of an integrated business model of environmentally sustainable approaches using IoT technologies. Goodland and Daly (1996) focus on the carrying capacity of the environment, supported by an input-output rule. On the output side, the wastes produced from all human activities should not exceed the absorptive capacity of the environmental services over a period of time. On the input side, the use of renewable resources should be within the regenerative capacity of the environmental services that provide them, and the usage of non-renewables, the depletion rate should be equal to the rate at which renewable substitutes can be found or sustain.

Ekins' (2000) conceptualisation is similar to that of Goodland and Daly (1996), where the focus is on the ability of the environment to sustain and support human ways of life. Thus, it ensures that the environment services are able to provide the necessary inputs to the economy to support the maintenance of economic welfare. It is necessary to ensure the maintenance of the vital environmental functions.

The OECD (2000) focus on four specific criteria that can be associated with or measure environmental sustainability. These four criteria are regeneration, substitutability, assimilation and avoiding irreversibility. In relation to Goodland and Daly (1996), the assimilation of waste and avoiding reversibility expands on the output rule, where releases of hazardous or polluting substances to the environment should not exceed its assimilative capacity and must be kept below established critical levels. However, the final criteria for avoiding irreversibility can be seen as a point of departure from Goodland and Daly's definition, as this considers the carrying capacity and the associated biodiversity of the supporting environmental services. With respect to the input rule, usage of renewables should be within the regenerative capacity of the services that produce them, and the usage of non-renewables should be at the rate where alternative renewable sources can be found.

Environmentally sustainable supply chain approaches

In order to develop technological integrated environmental sustainability business models, organisations need to explore how different business models can be integrated and supported with the deployment of advanced technologies. In particular, thinking towards how the various environmentally sustainable supply chain approaches can be adopted in line with the input-output rule (Goodland and Daly, 1996) and the associated factors (OECD, 2000) identified in environmental sustainability literature. How the business model can be developed to achieve superior environmental performance of supply chains, along the business economic performance. Environmental sustainability approaches, which support the development of environmentally friendly sustainable supply chains, include: environmental purchasing, design for environment (DfE), cleaner production, recycling and remanufacturing.

Table 2 - Environmentally Sustainable Supply Chain Approaches

Approach	Key Features
Environmental Purchasing	• Sourcing from supplier that are environmentally certified (Zhu et al., 2007). • Maximum potential reuse of products, parts, or materials to become an input into the production of another product (Tsoulfas and Pappis, 2006). • Requires the building of relationships with suppliers to develop the supply process (Gold et al., 2010).
Design for Environment	• Consideration at the design and development stage of products that are more environmentally friendly, containing recoverable parts that are durable, reusable, and recoverable at the disposal stage (Kurk and Eagan, 2008; Tsoulfas and Pappis, 2006). • The development of products that are free from toxic substances, biodegradable, recyclable, upgradeable, and low energy consumption (Soylu and Dumville, 2011). • Focuses on lifecycle impact of product, process and supply chain on the environment (Bevilacqua et al., 2012).
Cleaner Production	• Efficient use of raw materials, energy and water, operations procedures, recycling wastes and the use of cleaner technologies (Van Hoof, 2014). • Five guiding principles: input substitution, good housekeeping, internal recycling, technical process optimisation change and product optimisation (Nilsson, 2007)
Reverse Logistics, Recycling, Reuse, and Remanufacturing.	• The recovery or disposal of returned products, whilst generating value whenever possible (Blumberg, 2004). • Products are either re-sold or used to replace faulty products under warranty, alternatively, products may be remanufactured and re-marketed through different channels, or products parts can be used as spares for another product (Kleindorfer et al., 2009) • Waste products and materials can be recycled as an input into the same or a different production process wherever possible (Gupta, 1995).

In particular, thinking about how the integration of these environmentally sustainable supply chain processes (Evans et al., 2017; Leigh and Li, 2015) may lead to towards the development of closed loops of resource exchanges amongst different industrial activities across industries, and the natural environment.

Internet of Things

The Internet of Things (IoT) (Wortmann and Flüchter, 2015) is one type of internet technology that can utilise the collection of big data. Big data are not just the size of data but also their complexity. IoT can support the development of the integration of supply chain activities towards closed-loops of resource exchanges (Fang et al., 2014).

IoT has been used for the deployment of successful applications for both monitoring and actuating, and business process and data analysis. Monitoring and actuating devices can report power usage, equipment performance, sensor status, and actions in response to predefined commands. Existing technologies used for the deployment of IoT applications include: radio frequency identification (RFID), wireless sensor networks, and cloud computing technologies (Lee and Lee, 2015). The ability to capture and store vast amounts of individual data has brought new opportunities for the analysis of business processes (Lee and Lee, 2015). The analysis of these business processes can derive benefits at the societal, industrial, organisational and individual levels (Riggins and Wamba, 2015). The World Economic Forum identifies IoT as a sustainability game changer and encourages the use of IoT to accelerate the progress on the United Nations Sustainable Development Goals (SDGs). To achieve the SDGs, the project explores scalable and replicable models of business, investment and collaboration across industries and with public authorities to support the design of commercially viable IoT deployments that can maximize the environmental sustainability potential (WEF, 2018).

This research investigates the potential utilisation of IoT in supporting the development of an advanced environmentally sustainable business model integrating the environmental sustainability approaches identified from the literature. The application of IoT technologies to capture big data from supply chain operations for environmental sustainability purposes across industries is an area requiring further research. In particular, the literature confirms that limited research has been conducted in developing sustainable business models to support the integration between supply chains environmental sustainability activities and IoT to support capturing of big data to support across industrial collaborations.

Research Method

An exploratory case study was used as it offers an insightful understanding towards how improvements can be made in a topic area. To ensure the rigour of the case study method, a five-stage generic research process model identified by Stuart *et al.* (2002, p. 420) is proposed for this study. These five stages are given in Figure 1.

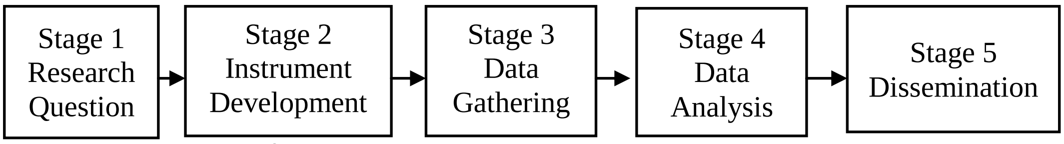

Figure 1 - The five-stage research process model (Stuart et al., 2002, p. 420)

At stage 1, the research question was developed: How can IoT technologies be deployed to support the development of environmentally sustainable supply chains? In relation to the research question, the following dimensions were investigated: Factors impacting on environmental sustainability within the Company's supply chain; Environmental aspects of products, materials, service processes offered by the Company. Opportunities for IoT to be integrated into the current environmental sustainability development along the Company's supply chain.

At stage 2, Instrument Development, open-ended interview questions were developed and used to collect the information regarding the listed dimensions. At stage 3, data collection took place, where an initial discussion took place with a key contact within the case study company, this was supported by secondary sources of data to support the potential application for IoT technologies within the case study company and develop the analysis and discussion. At stage 4, analysis of the transcriptions of the discussions took place to identify the possibilities for integration between the environmental sustainability approaches. At stage 5, the dissemination of the research took place via the production of this research article.

Case Study Company

A UK based case study company has been used to explore the potential deployment of IoT technologies in relation to its current environmentally sustainable supply chain model and its further development. The company was selected because of its high achievement in sustainability credentials and a leader within its industry. The company produces mechanical seals that are used in a wide range of pumps and rotating equipment. The company operates globally, with multiple manufacturing and repair locations. The company's manufacturing activities are supported by refurbishment services. The company recognises the importance of environmental issues and takes a holistic view to its impact of its activities on the environment, recognising the need to prevent pollution and continually improve environmental performance of its activities, products and services.

Results

The initial results for the case study company show the potential implementation of IoT technologies to support the further development of design for environment, cleaner production, reverse logistics, recycling, reuse and remanufacturing. The results can be seen in Table 3.

Table 3 - Initial Results

Approach	Results
Design for Environment	• Product usage data collected during the product usage stage to determine the environmental performance of a product to identify potential improvements to support the environmental performance of current and future designs. • RFID tags incorporated in final products as a means for identifying product bill of materials to identify potential reuse, recycle and remanufacturing possibilities of products at the end of usage stage.
Cleaner Production	• RFID tag and sensor networks used to ensure the accurate monitoring of hazardous and non-hazardous materials used within the production processes. • Monitoring of production machinery and processes to determine the usage various inputs to the production processes such as energy, water and other raw materials, to ensure their optimum usage. • Identification of the reduced efficiency of aging machinery to ensure its timely replacement to ensure machinery is within its optimal usage situations.
Reverse Logistics, Recycling, Reuse, and Remanufacturing	• Sensors within the returned products to determine existing usage to date and remaining residual value in the product. • Where products can be remanufactured, usage data can be utilised to determine the remaining residual value within the re-manufacturable parts to determine if the products require remanufacturing prior to resale.

Discussions

The significance of this research is the preliminary development of a theoretical model for the integration of environmental sustainability activities with IoT technologies to support the development of environmentally sustainable supply chains. At present there is limited usage of IoT to support the development of the environmental sustainability of the case study company, however the results of the initial discussion suggest the opportunities for the implementation of IoT technologies within the Design for Environment, Cleaner Production Reverse Logistics, Recycling, Reuse, and Remanufacturing approaches.

In particular, the research begins to show the potential for the collection of data via

IoT technologies during the use stage to provide important usage information to provide greater transparency as to the usage of the products during operation. The data collected and communicated to a company of origin could be used to further improve the further development of new iterations of products to decrease the environmental impact of products during the usage stage. Combining the usage data with the take back of products to the company of origin can be used to determine if a product is suitable for resale, recondition and remanufacture old products to new, replacing the inefficient parts, or where necessary complete recycling and the production of completely new products could be produced. However, this would be dependent on the complexity/simplicity of the product and the ability to recover value from the design of the existing product.

In addition, IoT technologies can begin to show support towards the improved development of Cleaner Production principles to support the efficient usage of materials handling processes and optimum usage of production machinery. The limitations of this research are not being able to support the further development of the input-output environmental sustainability model proposed by Goodland and Daly (1996). If organisations wish to develop their environmental sustainability using IoT technologies, it is necessary for the organisations to develop environmental sustainability indicators against which they can baseline the use of IoT technologies to support their environmental sustainability development. In particular, these could be used to support the reduced usage of both renewable and non-renewable resource on the input side and be used to reduce the production of harmful wastes on the output side.

Conclusion

Analysis of empirical data has identified the potential application of IoT technologies for the improvement of supply chain environmental sustainability. The initial research suggests that sustainable business development can be enhanced by IoT technologies. IoT technologies, for example RFID and sensor technologies have demonstrated the potential integration in supporting the enhanced environmental product development to reduce the environmental impact of companies. The complexity of product/service production and delivery processes of the case study company has provided not only the evidence of limited applications of IoT technologies, but also opportunities for the integration of IoT to enhance supply chain environmental sustainability.

The developed advanced business model in this research can help organisations develop closed-loop thinking towards the environmental sustainability development of supply chains through integrating IoT technologies and further help organisations move towards a closed loop of resource exchanges. The application of IoT technologies to the developed environmental sustainable supply chain business model is not limited to the case study company. The developed business model has demonstrated potential wider applications of these technologies for the environmental sustainability development towards closing the loop of resource exchanges.

The research outputs are presented with the consideration of both academic and practical value to conclude this research. The IoT technologies to capture the complexity of data to support the development of supply chain environmental sustainability in different business areas, product/service business models, broaden the horizon in further development of theoretical models to serve business development.

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