Modelling and analysis of sustainable operations management: certain investigations for research and applications

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Abstract

Sustainable Operations Management (SOM) can be defined as the operations strategies, tactics and techniques, and operational policies to support both economic and environmental objectives and goals. The subject of sustainability has gained much attention from both researchers and practitioners in the past 6-8 years. Most of the articles deal with sustainability from environmental perspectives, but a limited number of them integrate both economic and environmental implications or focus on trading-off between profitability, competitiveness and environmental dimensions. Moreover, there is a limited focus on modelling and analysis of SOM integrating and balancing the interests of both economic and environmental interests. Therefore, an attempt has been made in this paper to review the extant literature on SOM. The objective is to understand the definition of SOM and present the current status of research in modelling and analysis, as well as future research directions in the field. Considering the recent focus of the subject, we review the literature on MA of SOM beginning in 2000 in order to make our study current and more relevant for both researchers and practitioners. Finally, a summary of findings and conclusions is reported.

Keywords: Sustainability; operations; modelling and analysis; literature review; future research directions.

1. Introduction

In recent years, sustainability has been a widely discussed subject amongst academics and practitioners, considering the importance of protecting the environment while sustaining the economic goals of organisations (Kleindorfer *et al*, 2005; Piplani *et al*, 2008; Wilkinson *et al*, 2001). Sustainable development remains a major challenge and opportunity for global firms. However, the role of Operations Research (OR) and Operations Management (OM) is yet to be studied in depth. Indeed, White and Lee (2009), while discussing the application of OR in sustainable development and focusing on enhancing the role of OR in an inter-generational ethic, argue towards a necessary shift to OR approaches and their implications in relation to sustainable development.

At the same time Green or environmental concerns have been receiving increasing attention from both academia and industry (Linton *et al*, 2007; Sarkis *et al*, 2011; Srivastava, 2007). Green strategies and techniques should meet the requirements of environmental regulations and contribute to the increase of organizational competitiveness and performance. According to Wang *et al* (2012), structured OR techniques such as the Analytical Hierarchy Process (AHP) with fuzzy logic can create decision variables (criteria) to be used in Modelling and Analysis (MA) and selection of different green initiatives and alternatives.

In the supply chain management field, the concept of Green Supply Chain Management (GSCM) has been developed to support the sustainability of the value chain (Sarkis *et al*, 2011; Srivastava, 2007). GSCM has been defined as an integrated environmental and supply chain model. It includes greening of product design, sourcing, manufacturing, delivery of the final product as well as end-of-life management of the product (Giovanni and Vizi, 2012; Sarkis *et al*, 2011; Srivastava, 2007). In their paper, Giovanni and Vinzi (2012), using structural equation modelling in a large set of Italian firms, investigate the relationship between Environmental Management (EM) and performance. They focus on whether the implementation of an effective internal environmental is required to become a green supply chain, determine the type of internal and external environmental practices contributing to the firm's performance and whether environmental initiatives translate into better economic performance. Furthermore, Su *et al* (2008) study the supply chain management in Chinese firms from the institutional view and global competition environment. They have used OR methods, namely Rough Set Theory (RST) and Fuzzy Aggregation (FA), to identify the organization and management determinants.

Focusing on modelling renewable energy, Kowalski *et al* (2009) study the combined use of scenario building and Participatory Multi-Criteria Analysis (PMCA). MCA is a widely-used assessment method, which evaluates alternatives on the basis of a multi-dimensional criteria framework, and calculates the rankings of alternatives. They evaluate five renewable energy scenarios for Austria for the year 2020 against 17 criteria for sustainability and study the opportunities and limitations of the methodology in terms of (1) capturing the complexity of decision-making on the long-term consequences of socio-economic and biophysical systems' changes and (2) appraising energy future.

Finally, in the logistics field, the environmental impact of automotive logistics –for instance, the logistics of new vehicle distribution from the factory to the end user– has been given limited attention in the academic literature on sustainability. For instance, Bektas and Laporte (2011) propose the Pollution Routing Problem in which they extend the classical Vehicle Routing Problem to consider *inter alia* the amount of greenhouse emissions using a mixed-integer mathematical model, whereas Nieuwenhuis *et al* (2012) use a transport cost model to track carbon dioxide emissions along the supply chain from the final assembly plant to a local distribution centre of the both the Korea-US and the Korea-Europe automotive supply chains. They found that in both cases the local option, even using road-based distribution leads to significantly lower emissions than seaborne sourcing directly from South Korea. However, they suggest that the environmental impact of automotive logistics needs due consideration (*ibid*).

In this study, following a review of 92 articles on MA of SOM, we argue that despite the focus of the literature on issues of SOM, the MA of SOM has not received due attention. Moreover, SOM has not been explicitly acknowledged though related topics such as green supply chain, green logistics, and green manufacturing. Considering the importance of MA of SOM, this paper contributes to the extant literature by a) attempting to define what SOM is and by reviewing the extant literature –such a review is necessary to structure a research field and identify its conceptual content (Easterby-Smith *et al* 2002; Srivastava, 2007); b) critically reviewing MA and SOM to identify potential gaps between theory and practice in the field; and c) presenting a list of future research directions along with tools and techniques for MA of SOM.

2. Sustainable Operations Management

Sustainable Operations Management can be defined as the planning, coordination and control of a system that creates or adds value to the customers in a most cost-effective manner, while genuinely protecting the natural resources and environment (Linton *et al*, 2007). This definition implies that the management of operations should not only have cost reduction or economic interest as an objective, but should also consider and protect the environment through reducing for instance the carbon footprint, the cost of reverse logistics, remanufacturing, and green supply chain management. There are numerous studies in the literature over many decades on the MA of OM, but there is a need to develop models for SOM. Therefore, we focus on SOM in a broader perspective, but we also consider GSCM as a sub-set of SOM.

The SOM decisions can be classified into decisions concerning 'system design', and 'system operations'. 'System design' decisions include product and process design, location planning and analysis, and capacity planning. 'System operations' decisions include procurement, production and logistics. Though these areas look traditional, they are an important element of SOM. We select the major decision making areas considering the focus of SOM, and define sustainability as having two dimensions: (i) Economic and (ii)

Environmental, although socio-economic aspects play a major role and these aspects could constitute a third SOM dimension. However, since this dimension has just started receiving attention and due to lack of articles on responsible management, in this paper we focus only on the economic and environmental dimensions of SOM. We also argue that it is important for the MA of SOM to focus on issues of balancing and trading-off between these dimensions.

3. Classification of Literature on SOM

Following the aforementioned classification of SOM decisions, we classify the literature on MA of SOM into: (i) 'System Design' and (ii) 'System Operations'. 'System Design' classification is further classified into: (1) 'Product and Process Design' (2) 'Location Planning and Analysis' and (3) 'Capacity Planning'. 'System Operations' can be further classified into: (1) 'Procurement' (2) 'Production' and (3) 'Logistics' (see Table 1). From the extant literature on the MA of SOM it can be inferred that powerful OR modelling tools and techniques are required. For example, Arnason (2009) demonstrates that the problem of fisheries' management, being complex and multi-disciplinary, requires powerful modelling and optimization techniques. He argues that most of the OR supplication to fisheries' problems are focused on identifying the optimal fisheries policy than the design of fisheries management systems. This brings to the foreground the importance of MA of SOM and indicates that it is a challenging area which requires due attention from both OR researchers and practitioners.

Insert Table 1 about here

The rationale for the suggested classification lies in revealing the functional perspective of OM so that the new paradigm, that is, SOM, can be well defined and further researched. However, the effect of such functional areas with reference to life cycle management has been emphasized in SOM.

4. Review of the Previous Literature on SOM

Since the focus of the subject is on MA of SOM, we have primarily selected the literature available from major operations research and operations management journals which should include European Journal of Operational Research (EJOR), Operations Research, Management Science, Production & Operations Management, Transportation Research – Section E, Journal of the Operational Research Society (JORS), International Journal of Production Research (IJPR), International Journal of Production Economics (IJPE), International Journal of Logistics Management (IJLM), Academy of Management Review (AMR), Academy of Management Journal (AMJ), Journal of Operations Management (JOM), International Journal of Operations and Production Management (IJOPM), International Journal of Physical Distribution & Logistics Management (IJPDLM), Corporate Social Responsibility and Environmental Management (CSREM), and Omega. We have accessed the database of the following publishers for selecting the literature: Emerald Insight, Taylor & Francis and Elsevier. The following are some of the keywords in our search of databases that have been used to precisely select the literature on modeling and analysis of sustainable operations management: Modeling, models, sustainable, green supply chain, green logistics, and cleaner production. We have had over 150 articles out of this search and we selected only 92 articles that focus on MA of SOM.

Our review reveals that there is a good number of review articles on OM, supply chain, logistics (including sustainable logistics), and supply chain management. But, apart from a few exceptions (e.g. Linton *et al*, 2007; Piplani *et al*, 2008; Sarkis *et al*, 2011; Srivastava, 2007) there are limited review articles on the MA of SOM and GSCM, integrating the aspects of both economic and environmental goals. For example, Dekker *et al* (2012) review the application of OR techniques/models to green logistics by integrating the environmental aspects with logistics. They review the green developments in the area of design, planning and control in supply chain operations and suggest the inclusion of various environmental aspects in OR models for logistics. From an OR perspective, Mingers and White (2010) reviewed the literature on systems thinking in OR practice in application areas such as strategy, information systems, organizations, production/operations, ecology and agriculture, and medicine and health. Their review covered systems approach, complexity theory, cybernetics, system dynamics, soft-OR and PSMs, critical systems and multi-methodology. They concluded that modelling and OR cover a wide range of topics including for instance inventory control, integrated models of production systems, international operations, including facilities layout, job design, and logistics (Chopra *et al* 2004; Grossler *et al* 2008; Voss, 1984) whereas systems thinking can be applied for analysing complex operations such as in supply chain management. However, their review did not reveal studies of applying systems thinking and OR practice to SOM.

From an OM perspective, Sarkis *et al* (2011) and Srivastava (2007) reviewed the literature available on GSCM. In their review they included complexity theory, ecological modernization, institutional theory, resource-based view, resource dependence theory, social network theory, stakeholder theory and transaction cost economics. However, the main focus is not on MA of GSCM. Furthermore, Klibi *et al* (2010) discussed the supply chain network (SCN) design problem under uncertainty, and presented a critical review of the optimization models. SCN design involves strategic decisions on the number of location, capacity and production-distribution facilities of a company, or a set of collaborating companies, in order to identify the market opportunities. This also involves decisions such as the selection of suppliers, subcontractors and third-party logistics (3PLs) and make-to-order system. By analyzing supply chains uncertainty sources and risk exposures, the study determined some key random environmental factors and discussed the nature of major disruptive events threatening SCN. These review papers have focused on specific themes such as green marketing, green production and green logistics, but not on a functional approach to SOM. The functional approach to SOM provides opportunities for detailing the initiatives and changes to various functional areas, but at the same time it considers the perspective of an integrated supply chain management for SOM. Moreover, this approach identifies suitable strategies and tactics for SOM, and tools and techniques for MA of SOM.

4.1 System Design

The 'System Design' involves long-term decisions such as product and process design, location planning and analysis and capacity planning. In this section the literature on sustainable design, location planning and capacity planning are reviewed with the objective of exploring and bridging the gap between theory and practice.

From a 'System Design' viewpoint, Green Supply Chains (GSCs) focus on environmental issues such as eco-design, pollution prevention, depletive resources, and End-Of-Life (EOL) processes. The management of GSCs is concerned with all form of wastage reduction along with other performance objectives, including that of environmental. An integrated Activity-Based Costing (ABC) and performance evaluation system can reduce wastage and raise performance of GSC. Tsai and Hung (2009) develop a Fuzzy Goal Programming (FGP) model for the selection of suppliers and material flow allocation in an integrated ABC and performance assessment system of a value chain. The FGP comprises a suitable approach for system design MA of SOM.

4.1.1 Product and Process Design

Sustainable Operations Management demands sustainable product design as this influences some of the most important sustainable operational performance objectives. To improve the environmental performance through product design, firms often need to deal with challenging technical trade-offs between traditional and environmental attributes which require new design concepts and engineering specifications (Chen *et al*, 2012). This particular problem situation warrants modelling of costs and benefits given the constraints for sustainable product design. Chen *et al* (2012) propose a two-stage network Data Envelopment Analysis (DEA) to evaluate sustainable product design performance and conceptualize "design efficiency" as a key measurement of design performance in a product design that results in lower environmental impact or better performance evaluation with an "industrial design module" and a "bio design module". Their results show that sustainable design does not compromise between traditional and environmental design attributes.

Green product design has received significant attention due to the fact that product design significantly influences the cost of disassembly, component inspection and repair, and remanufacturing and recycling. Chung and Wee (2008) studied the impact of green product design, the new technology and remanufacturing on the production-inventory policy, and developed an integrated perishable inventory model with green-component life cycle value design and remanufacturing. This model and scope could be changed to incorporate the SOM issues.

Therefore, it is needed to focus on how product and process design affects the sustainable manufacturing and service organizations. The type of design and process would lead to the type of materials used, workforce training and development, regulation and standards, and type of processes used and their consequences on economic, social and environmental issues such as carbon footprint, recycling, wastes, disposal, energy cost and socio-economic demand. Models informed by complexity theory, multi-criteria decision making, linear programming, and risk assessment techniques need to be developed for evaluating the impact of product and process design parameters on sustainable enterprise management and optimization.

4.1.2 Location Planning and Analysis

Location planning and analysis determine the availability of materials, taxes, transportation, site development, schools and hospitals, utilities, labour cost, people and regulatory compliances and government policies which may impact SOM. Moreover, transportation costs depend upon the location planning of operations and markets, whereas onshore and offshore outsourcing have significant influence on sustainability issues, policies, strategies and actions.

Dou and Sarkis (2010) consider the joint location and outsourcing sustainability analysis for a strategic offshoring decision. To decide on a facility location decision, various factors (such as strategic issues, community factors, business climate factors, accessibility factors, labour factors, utility factors, risk factors, plant site factors and financial and special factors, environmental health, ecosystem vitality, consumption and production patterns, education, demographics, natural hazards, individual development, poverty, governance, health, and community development) need to be considered. The supplier selection related factors include cost, quality, time, flexibility, innovativeness, culture, technology, relationship, environmental practices and performance, internal and external social criteria and contractual stakeholders influence and other stakeholders' influence. Dou and Sarkis developed an ANP model which was verified with help of a case study. They modelled outsourcing and supplier selection decisions in a multi-criteria optimization model with appropriate objective function and constraints.

A large population of developing countries live in rural areas where access to healthcare is lacking. Poor healthcare will lead to poverty, because of inability to work or the necessity to sell assets to pay for medical treatment (Smith *et al*, 2009). These authors study the planning of community healthcare by non-governmental or faith-based organizations in rural areas of developing countries and suggest that both types of planning approach are necessary for sustainability of such developments. This approach can be employed when modelling the community related factors and their impact on location planning decisions and in turn supporting the sustainable enterprise management. Long-term implications are tremendous in the case of location planning on sustainable operations economically, socially and environmentally. Therefore, there is a need for appropriate models apart from centre of gravity method and raking method.

Due to the preliminary development stage of production technologies for second generation ethanol and a high demand for diesel in developed countries, Walther *et al* (2012) focus on the planning problem of selecting and locating production capacities for synthetic bio-diesel production considering decision makers' attitude towards risk. They propose a multi-period Mixed Integer Programming (MIP)-model for integrated location, capacity and technology planning for the design of production synthetic bio-diesel networks. This approach can be extended to consider the various regional, community and site related factors and their impact on the organizational sustainability performance. This offers more opportunities to develop cost-benefit analysis by appropriate modelling that could be either OR mathematical models or simulation.

4.1.3 Capacity Planning

Capacity planning involves determining the various facilities' resources required which include space and number of machines and equipment with the objective to match the demand for the products and services, but at the same time meet the sustainability challenges. Queuing models, aggregate planning models and simulation have been widely used for determining the capacity required to match the demand for products and services. From a SOM perspective, the issue is how these models can be extended or how new models can be developed to incorporate the sustainable business development objectives incorporating the social, environmental and economical dimensions.

Currently the focus is on effective management of key logistical processes within the supply chain as a means of achieving sustainable competitive advantage. The paper by Robertson *et al* (2002) develops a model and then illustrates its application in a major multinational steel producer. They discuss the logistical processes used to effectively manage supply chain operations and particularly the feed-forward and feedback operations. Also, they develop a generic model for a multi-stage approach to the planning and scheduling of manufacturing supply chains. These models can be extended to incorporate the sustainable parameters and variables in optimization for both capacity planning and logistics operations.

Various strategies have been developed to mitigate the effects of pollution, but strategies are expensive to implement and it may take years to have the desired effect. Radulescu *et al* (2009) developed a multi-objective programming model for production technologies considering suitable pollutant emissions constraints. They studied two optimization problems: (i) minimum pollution risk; and (b) maximum expected return. The objective function of the minimum pollution risk problem can be solved by formulating an alternative linear programming model. These modelling approaches can be employed for optimizing the type and level of different capacity required in order to minimize the pollution and maximize the return as well as meeting social obligations.

The objective of supply chain planning and control systems with dynamic configurations should be agile, flexible, and responsive. In supply chains, different configurations (such as functional, organizational, informational, and financial) are reformed. These configurations interrelate with each other and change in dynamics. The paper by Ivanov *et al* (2010) introduces a new conceptual framework and multi-disciplinary modelling for multi-structural planning and operations of adaptive supply chains with dynamic configurations. The adaptive supply chain management framework has three major building blocks (i) supply chain management (Integration, cooperation, and coordination); (ii) agility: virtual enterprises (Web-services, responsiveness, and core competencies); and (iii) sustainable supply chain management (product life cycle, public and society). The outcome of the model is competitiveness, survival, sustainability, responsiveness, cost-efficiency, robustness, quality and flexibility. The research approach is based on the combined application of control theory, OR, and agent-based modelling. Ivanov *et al* reported a framework for the implementation of multi-structural supply chain management and the closed-loop adaptive supply chain optimization and management for value chain adaptability and stability. This modelling approach is utilized for optimizing the system configuration in order to address the socio-economic issues, environmental concerns and corporate objectives.

Limited models have been developed for the integrated planning and scheduling of the inventory, production and distribution in SOM. Amongst these exceptions, Lejeune (2006) develops a sustainable inventory-production-distribution plan over a multi-period horizon for a three-stage supply chain. The model developed is of a general MIP. They use a solution algorithm based on the variable neighbourhood decomposition search meta-heuristics. This MIP-model includes the minimization of pollution and maximization of return while addressing the social concerns and related constraints.

This section has reviewed the literature on 'System Design', and has illustrated that despite the interest on sustainability, there are yet more issues to resolve. Decisions with regard to sustainable design, location planning and capacity planning need to be taken, and more in-depth studies should be conducted with the objective of exploring and bridging the gap between theory and practice.

4.2 Systems Operations

'System Operations' includes purchasing production planning, scheduling, quality control and logistics. For the purpose of clarity and significance of the focus on the key functional areas, in this study we restrict our attention to procurement, production planning, and scheduling and logistics. Quality control is an integral part of the whole supply chain and sustainability objectives.

4.2.1 Procurement

Purchasing or procurement has received significant attention in recent years as part of supply chain management. Procurement function has significant impact on social, environmental and economic performance. For example, transportation and its implications on carbon footprint and energy cost could impact the sustainability of organizations. Since procurement plays a major role in the 21st century supply chain operations, this function deserves more attention from the perspective of sustainable enterprise management and subsequently SOM. A new research operations paradigm focusing on environmentally conscious supply chains or green supply chain management has recently started receiving attention (Ghosh and Shah, 2012). This study focused on an apparel supply chain whose participants started working on product greening, and evaluated different scenarios in which participants work together. Ghosh and Shah developed game theoretic models and demonstrated how greening levels, prices and profits are influenced by supply chain structures. The authors proposed the development of cooperative models of cost sharing and revenue sharing contracts in apparel supply chains as a future research extension. From a sustainability point of view, these models can be redeveloped to incorporate sustainable objective functions and related constraints.

Ferretti *et al* (2007) discussed the implications of greening the aluminium supply chain using a case study in a company consisting of one refiner (single-vendor) and one component producer (single-buyer). The contribution of this research lies in using an alternative supply method (liquid and solid) for raw material (aluminium) in manufacturing. The basic model was used to introduce a complete method of the economic and environmental evaluation of the aluminium supply chain. Furthermore, Wu and Kleindorfer (2005) proposed a framework for studying B2B transactions and supply chain management, based on integrating contract procurement markets and spot markets using capacity options and forwards. The idea was motivated by the development of B2B transactions in several industrial sectors. The optimization of B2B transactions in supply chain operations can include sustainability variables and parameters, such as carbon footprint, energy cost, human rights, recycling and remanufacturing.

Toktay *et al* (2000) have presented a model for the optimal procurement of new components for recyclable products for a single-use camera. The objective of the model was to determine an optimal ordering policy that minimizes the total procurement, inventory holding and lost sales cost. They modelled the system as a closed queuing network, developed heuristic procedure for adaptive estimation and control, and illustrated their methods using data from Kodak. Queuing models can be developed for sustainable procurement among other multi-criteria decision making models.

Supply chain partners have traditionally focused on aligning their economic incentives. Recent studies indicate that a social preference may influence behaviour in supply chain transactions. Loch and Wu (2008) have developed a game structure for a linear contract between a wholesale price, and order quantity and market price. Their results suggested that there are social preferences in business transactions. Social preferences impact the performance and a perceived relationship can induce collaborative behaviour and enhanced performance, whereas perceived competition for status can induce competitive behaviour and compromise performance. This approach can be extended to study the impact of social preferences on sustainable development activities and performance.

4.2.2 Production

Production includes planning, scheduling, and quality control. Diverse stakeholder groups, such as end-consumers, industrial customers, suppliers and financial institutions are serious about environmental management, including remanufacturing, in manufacturing companies (Henriques and Sardorsky, 1997; Vachon and Klassen, 2008). Remanufacturing can be defined as the process, by which used products are recovered, processed, manufactured and sold as new products. Suitable models can be developed for remanufacturing so that the life cycle costing approach is utilized for sustainable production management. Various strategies have been developed to mitigate the effects of pollution, but strategies are expensive to implement and it will take years to have the desired effect. Radulescu *et al* (2009) developed a multi-objective programming model for production processes considering suitable pollutant emissions constraints. The objective function of the minimum pollution risk problem can be solved by formulating an alternative linear programming model. Additional objectives and real-life system constraints should be incorporated in the multi-objective programming model.

The paper by Liu *et al* (2012) illustrated the impact of competition and consumers' environmental awareness on key supply chain partners. It considered the production competition between partially substitutable products made by different manufacturers, and the competition between retail stores. It employed two-stage Stackelberg game models with quadratic functions to analyze the dynamics between the supply chain partners given three supply chain network structures. They found that the profitability of the manufacturers with superior eco-friendly operations will decrease unless the environmental awareness of consumers is high. Moreover, they reported that a superior manufacturer has a significant cost advantage related to product environmental improvement. Their suggested game models and agency theory can be used to develop models for optimizing the production activities in alignment with retail competitiveness.

Vachon and Klasssen (2008) studied the impact of environmental collaboration on cost, quality, delivery, and flexibility and environmental performance as well as the impact of environmental collaboration in the supply chain on manufacturing and environmental performance. They defined environmental collaboration as the interaction between organizations in the supply chain related to joint environmental planning and shared environmental knowledge. Due to increasing competitive pressure, shortened life cycle and environmental consciousness, serious attention was paid to resource usage reduction and ecology protection. This is an interesting investment model approach for optimizing the effort and resources for SOM.

Santos *et al* (2010) dealt with an agricultural production problem, in which one must meet a known demand of crops while respecting ecologically-based production constraints. The problem has two dimensions: (i) meeting demand and (ii) determining the division of the available heterogeneous arable areas in plots and for each plot, and deciding an appropriate crop rotation schedule. Rotation plans should consider ecologically-based constraints including the interdiction crop successions, and the regular addition of fallows and green manures. Santos *et al* developed a linear programming model incorporating each variable that is related to a crop rotation schedule and solved the model using a column-generation approach. The sustainability issues arising from short-term activities should also be given due attention as they could impact organizational performance in all three areas, that is, social, environmental and economical.

In recent years, research on sustainability performance has significantly advanced the OM literature. However, quantitative models are still limited when it comes to dealing with SOM. Bouchery *et al* (2012) revisited classical inventory models taking into account sustainability. They proposed the classical Economic Order Quantity (EOQ) model as a multi-objective problem and defined it as the Sustainable EOQ (SEOQ) model, and subsequently extended the SEOQ model to a multi-echelon system. For both the models, a set of efficient solutions (Pareto Optimal Solutions) was presented. Therefore, the traditional inventory models can be extended to consider sustainability criteria and constrains while optimizing the order quantity and timings.

The major enablers of supply chains and reverse supply chains should be managed from an integrated perspective to maximize profit and manage product life cycles and in turn contribute to green supply chain management. Sheu and Chen (2012) studied the effects of governmental financial intervention on green supply chain competition using a three-stage game-theoretic model. Nash equilibrium solutions for governmental and chain member decisions were derived. Their results suggested that the government should adopt green taxation and subsidization to ensure the green profit attributed to green-product production is positive. The risk assessment models based on game-theoretic models can be considered for sustainable production management in supply chains.

Companies around the world increasingly demanding green products and therefore, the need for quality green products has been a core challenge. People are aware of the global environmental problems such as global warming, heat waves, and environmental pollution. The demand from Waste Electrical and Electronic Equipment (WEEE) of European Union (EU), Restriction of Hazardous Substance (RoHS) and Eco-Design Requirements for Energy Using Products (EuP) has played a significant role in greening of products and processes (Wee *et al.* 2011). These researchers proposed a model to consider Vendor Managed Inventory (VMI) and conducted a life cycle cost and benefit analysis for green electronic products. Their results demonstrate that selling price, deteriorating rate, holding cost, product return rate and remanufactured quality have a significant effect on the green product design and supply chain performance. Chung and Wee (2011) presented an integrated production-inventory deteriorating model considering the greening of operation processes over a finite planning horizon from an end-of-life perspective. Reducing the design has been considered in the supplier's forward and remanufacturing processes. Moreover, the study incorporated the costs regarding inspection, transportation, less flexibility, as well as green-component life-cycle value design, green design cost of reducing gas emission and reverse manufacturing. All these sustainable enablers can be considered while optimizing the production planning and scheduling as well as quality control activities.

4.2.3 Logistics

Logistics and the use of Radio-Frequency Identification (RFID) in particular have been studied from an MA of SOM perspective. For instance, Whang (2010) investigated the benefits for adopting RFID in a supply chain. RFID has been viewed as a supply chain technology which provides real-time status of material flows along the value chain. Whang developed a game-theoretic model where two firms in a supply chain are engaged in an adoption game in the presence of such a one-sided free-rider opportunity. One major feature of RFID is that once RFID tags are attached to the items at an upstream site, the same tags can be used at its downstream sites at lower or zero variable cost. He then studied the dual benefits of technology coordination between the two firms and reports that it will not only save redundant costs of tagging, but also speed up the downstream's RFID adoption.

Dekker *et al* (2012) postulated that OR models are most often associated with cost minimization, but a substantial impact on the environment is not considered. For example, in logistics, reducing the speed of container ships will reduce their fuel consumption by 30%. This can be incorporated in the OR modelling and analysis of logistics and the environmental impact. Their main focus was on the transportation and its economic and environmental impact on the logistics. They looked at different alternatives including mode choice, intermodal transport, equipment choice and efficiency and fuel choice and carbon intensity. Also, they studied reverse logistics and their effect on transportation and environmental issues from the perspective of life cycle management or costing. They indicated that there are studies discussing OR models for sourcing, production concepts, facility location including sustainable supply chain network design, transportations alternatives, supply chain planning and control as well as metrics. Some of the specific OR methods should include multi-objective mixed integer programming models incorporating the additional objective functions (sustainability) and constraints created by both internal and external parameters.

Neto *et al* (2009) developed a methodology for assessing eco-efficiency in logistics networks and explored Pareto-optimal solutions for business and its environment. Their methodology allowed decision makers to assess their preferred solution via one of the decision-makers' most effective cognitive capabilities and visual inspection. Most developed countries have environmental regulations prescribing the responsibilities of manufacturers, generators, and users of chemicals to properly dispose of chemical wastes. These regulatory parameters should be incorporated in optimizing the logistics networks for SOM.

Modern environmental management deals with sustainable manufacturing practices to prevent waste and ensure responsible care of natural resources. The focus on recovery of resources, recycling and reuse can be described as 'cradle-to-cradle' resource management (Kumar and Putnam, 2008). These researchers suggest that further research is needed for end-of-life reverse logistics systems including: (i) methods of gaining economic efficiency for collection, disassembly, reuse, recycling and remanufacturing; (ii) methods of improving recycling technology, (iii) methods of improving information sharing throughout the Closed-Loop Supply Chain (CLSC) for lifecycle cradle-to-cradle management, and (iv) determining whether business eco-efficiency and the internationalization of environmental costs is a way of aligning market forces with environmental goals (Kumar and Putnam, 2008). Therefore the MA of life cycle costing management will support all stages of SOM. The end-of-life reverse logistics systems modelling has not received explicit attention from academics and practitioners, but such a shift will support data-based decisions taking into account all the metrics in more accurate decision making.

Environmental issues can impact on numerous logistical decisions throughout the supply chain such as location, sourcing of raw material, model selection, and transport planning, among others (Wu and Dunn, 1995) and design of reverse logistics networks (Mar-Ortiz *et al*, 2011) In the past, organizations have excelled in environmental management of product development, process design, operations, logistics, marketing and waste management. In their paper, Ubeda *et al* (2011) have focused on transportation, which is one of the important aspects at the operational level of green logistics. The activity of transport may cause a high rate of negative effects on the environment, such as pollution, noise or congestion. Thus, the efficient use of transport resources aimed at the selection of vehicle types, the scheduling of deliveries, consolidation of freight flows and selection type of fuel can help mitigate these problems. Ubeda *et al* and Maden *et al* (2010) designed applicable algorithms to solve the capacitated vehicle routing problem. These algorithms should include additional constraints related to sustainability objectives. Bektas and Laporte (2011) and Demir *et al* (2012) suggested and discussed the 'Pollution-Routing Problem', an extension of the Vehicle Routing Problem using a broader and more complete objective function which considers travel distance, the amount of greenhouse emissions, fuel, travel times and their costs. However, research on environmental issues and relevant algorithms needs further attention from both researchers and practitioners.

Closed-Loop Supply Chains have evolved to assist companies in recognizing potential benefits and overcoming challenges associated with its operations and strategies. CLSCs are concerned with the integration of material flows, financial flows, and information flows throughout both forward chain and reverse chain, and reflect a generalization and extension of traditional supply chain concepts. Krikke *et al* (2003) conducted one of the first studies to consider environmental issues by examining a supply chain design for refrigerators and offering a model which aims to study cost minimisation while focusing on the environmental costs of energy and waste. Paksoy *et al* (2011) suggested a mathematical model in the form of a linear programming formulation is used to model the trade-offs between various costs including emissions and transporting commodities. Huang *et al* (2009) considered three uncertainties in their dynamic CLSC models: (i) time-delay in re-manufacturing and returns, (ii) system cost parameters in product return, re-manufacturing and the third-party-reverse logistics (3PRL) providers collecting and (iii) disturbances in customer demand. Furthermore, Neto *et al* (2010) argued that the primary objective of CLSCs is to improve the maximum economic benefit from end-of-use products. To them, CLSCs are assumed to be sustainable supply chains and the literature on CLSCs focuses on two main questions: (i) which action is best to improve the environmental footprint of the CSLC (e.g. Recycling, remanufacturing, and product design)? And (ii) how can CLSC models be extended to represent the trade-off between environmental and economic benefits in the supply chain? Neto *et al* have looked at three different sets of models: management of recovery and distribution of end-of-life products, production planning and inventory management and supply chain management issues in reverse logistics. They used the example of the efficient lot-size with remanufacturing options to illustrate how to integrate sustainable supply chain issues in CLSC models. These models can be extended to consider more realistic sustainable objective functions and system constraints.

The environmental performance of products and processes for sustainable manufacturing and service operations has received due attention from both researchers and practitioners. Savaskan *et al* (2004) developed a model for distribution channel design considering the trade-offs between costs and benefits in CLSC. Design of a CLSC does not only provide the firm with much-needed flexibility to reduce logistics costs in forward and reverse activities, but also enables it to signal the impact of environmental issues. Literature (e.g. Mar-Ortiz *et al*, 2011; Nativi and Lee, 2012; Ramos and Oliveira, 2011) studied the environmental operations of reverse logistics, in particular the collection of recycled materials used to replace traditional raw materials. The paper by Nativi and Lee (2012) discussed the impact of RFID information-sharing strategies on supply chain using environmental practices such as reverse logistics. The RFID information-sharing strategies help coordinate the inventory policies among the decentralized players in the supply chain. Consequently, the players attain higher environmental and economic cost reduction. Therefore, from these studies it can be inferred that the contribution of logistics to sustainability is significant in terms of saving energy cost, cost of transportation, reducing the carbon footprint and related social parameters. Many of the models discussed consider a selected set of variables and parameters in their optimization. This provides opportunities for developing new models and extending the existing models to determine optimal logistics decisions in order to maximize the return, but at the same time contribute to the social and environmental objectives.

5. Discussion: key observations from the literature review on Modelling and Analysis of Sustainable Operations Management

In this study the key literature concerning modelling and analysis of SOM was discussed. The majority of the extant literature focuses on green supply chain management and logistics at the strategic and planning levels. Indeed, Kleindorfer *et al* (2005), in their study of sustainable operations until 2005, illustrate the debate in the literature regarding early discussions about sustainable operations and the trade-offs between sustainability and economic competitiveness. Following Porter (1991, p. 96) and his suggestion that 'conflict between environmental protection and economic competitiveness is a false dichotomy based on a narrow view of the sources of prosperity and a static view of competition', Kleindorfer *et al* argued towards a necessary shift from strategy and development to implementation of sustainability in organisations. In this attempt, OM is vital in implementing sustainable strategies; these authors suggest that more importance should be placed in revisiting the current OR models of OM to incorporate sustainability variables and deal with human and environmental issues. This paper, examining the literature on MA of SOM suggests that there is still limited literature on the implementation of SOM strategies, tactics and techniques. Furthermore, a number of the few existing studies which examine MA of SOM provide suggestions at the theoretical level, but these have either limited practical implications, or these implications have yet to be tested in practice using real case study data. Despite the need to use OR models to study the relationship of profit, people, and the planet –the 3P's of sustainability (*ibid*)– and the realisation that it is not only profits and profitability that determines the success of economies and firms (Hay *et al*, 2005), there is still research to be conducted in the MA of SOM.

This paper illustrated the lack of adequate OR models for MA of SOM and supply chains, despite the existence of studies discussing sustainability issues in supply chains (Linton *et al*, 2007; Sarkis *et al*, 2011; Srivastava, 2007). The majority of studies (e.g. Kleindorfer *et al*, 2005) have discussed SSCM/GSCM as part of SOM, including remanufacturing and CLSCs. Since organisations need to take responsibility for the lives of their products from conception to recycling and disposal, they need to understand that incorporating sustainability in their operations strategy enhances their image and profitability (*ibid*). Moreover, limited research has been conducted in the area of capacity planning and control which could influence the effectiveness of SOM and SSCM. In particular, generic models including multi-objective and general integer programming models have been used (Ivanov *et al*, 2010; Lejeune, 2006; Radulescu *et al*, 2009; Robertson *et al*, 2002). However, studies of SOM need to focus from the strategic to operational level and implementation. To this end, OR models and concepts are needed to incorporate sustainability (e.g. green) variables in their CLSCs. We therefore propose that if SOM is the future operations strategy, then it requires due attention from OR researchers and practitioners. The movement from 'profit to value' is the first step; but the implementation of OR models of SOM is essential.

Considering the role of off-shoring/outsourcing in organizational competitiveness, there is limited research about the selection of outsourcer and suppliers incorporating the sustainability requirements. Indeed, apart from few exceptions (Dou and Sarkis, 2010) sustainability rarely is included in the discussion or modelling of outsourcing supplier decisions. Brown (2008) has mentioned the dearth of studies into sustainability factors in sub-contractor selection: the focus remains on traditional economic factors and also those concerning cost, quality, delivery, and flexibility. Therefore, MA of SOM in the area of outsourcing and off-shoring is rarely taken under consideration. Moreover, even in cases where environmental factors are included, Dou and Sarkis (2010) suggest that a more systematic inclusion of sustainability factors needs to occur in the off-shoring decisions and to this extent, OR modelling for evaluation and selection of off-shoring/outsourcing alternatives including sustainability factors is needed.

However, the area of logistics has received significant attention from researchers regarding its sustainability considering the fact many traditional OR transportation models can be applied to SOM and SSCM (Srivastava, 2007; Linton *et al*, 2007). In particular, various OR models have been used, such as Network design models, Multi-objective MIP models, logistical decision models, optimisation and inventory models, and models for solving known transportation problems (Bektas and Laporte, 2011; Dekker *et al,* 2012; Kumar and Putnam, 2008; Nativi and Lee, 2012; Savaskan *et al*, 2004; Ubeda *et al*, 2011; Wu and Dunn, 1995). However, tools such as discrete event simulation, although used for Logistics, do not focus on sustainability (van der Vorst *et al*, 2009). Therefore, there are yet studies to be conducted in MA of SOM in logistics.

Finally, we argue that organisations need to consider the trade-offs between profitability and SOM, and in particular to deal with pressures to remain economically viable while adopting SOM (Wu and Pagell, 2011; Zhu and Sarkis, 2004) and with how to address the underpinning social and environmental challenges of SOM while maintaining competitiveness (Kleindorfer *et al*, 2005; Schrettle *et al*, *In Press*). Indeed, literature suggests that organisations, when making such decisions, "face information uncertainty, evolving decision parameters, and changing decision boundaries" (ibid: p. 577) and they need to consider the impact of these decisions on operational practices and re-engineering of their supply chains, for instance (Devinney, 2009). Such decisions require the participation of stakeholders, who have multiple and conflicting values (White and Lee, 2009). Furthermore, organisations, in the absence or in light of the limited information available on interactions between environment, society, and economical factors which constitute SOM make decisions which may have less than optimal outcomes (Wu and Pagell, 2011). OR modelling and analysis can help decision makers understand the trade-offs of profitability and competitiveness versus SOM and its underlying social and environmental challenges. Paular-Caceres and Espinosa (2011) in their review have identified 186 articles which discuss OR applications on environmental management and sustainability. These articles, in their majority, suggest methods to assess the cost-effectiveness of environmental and sustainable issues for an organisation in general, but a limited number of them address decision making in SOM and balancing between social, environmental, and economic challenges. Stuart *et al* (1999) have developed a mixed-integer programming model to choose between product and process when considering trade-offs of yield, reliability, and business-focused environmental impacts in an electronics assembly supply chain. In a later study Higgins *et al* (2010) demonstrate the use of various methods such as agent-based modelling, dynamical systems modelling and network analysis in agricultural value chains to gain insights, *inter alia*, into the trade-offs between efficiency and agility for optimal balance, identify the appropriate point of trade-off between efficiency and resilience in a dynamic environment as well as on improve collaboration, risk management, and supply chain visibility. Simoes *et al* (2008) have used multi-criteria analysis to analyse the problem of waste management using two cases with different decision making preferences, and to rank alternatives, whereas Beynon and Wells (2008) have used a multi-criteria decision making technique for the ranking of motor vehicles based on their exhaust emission. The popularity of multi-criteria decision making has also been highlighted by Cruz (2009) in his study of a decision support system for modelling and analysis of supply chain networks with corporate social responsibility. Chen *et al* (2012) and Hwang *et al* (2013) have suggested a two-stage network Data Envelopment Analysis (DEA) to trade-off between product specifications and desirable product competitiveness and lower environmental impacts. These studies, which utilise OR models and techniques to trade-off between desirable outputs and environmental and social impacts to achieve the necessary product/service performance demonstrate that OR can help decision makers balance between different objectives. Finally, multi-agent modelling has been used to model agricultural and resource problems considering their socio-economic and environmental dimensions (Higgins *et al*, 2010). However, as depicted in the literature (e.g. Higgins *et al*, 2010; Paular-Caceres and Espinosa, 2011), the dialogue between OR modelling and analysis and sustainability and in our case SOM has just started; there are yet studies to be conducted in the area of decision making and trading-off between social, environmental, and economic factors for SOM.

Table 2 provides a summary of reviews of the selected literature on SOM.

Insert Table 2 about here

The key observations from the literature review state the need for future research in MA of SOM, which is further discussed in the following section.

6. Future Research Directions on Modelling and Analysis of Sustainable Operations Management

Based on the review of selected literature on modelling and analysis of SOM, in this section we present some future research directions on MA of SOM considering the gap between theory and practice. Integrating environmental concerns into supply chain management has become increasingly important for manufacturers to gain and maintain competitive advantage. Zhu *et al* (2008) empirically investigate the construct of and the scale for evaluating GSCM practices among manufactures. The list of measurement items for the implementation of GSCM practices and the relevant performance outcomes will form an important basis for modelling and analysis of GSCM. Furthermore, reviews of sustainable and green supply chains (Linton *et al*, 2007; Sarkis *et al*, 2011; Srivastava, 2007) suggest that more research should be directed towards the use of mathematical OR modelling and analysis of GSCM, which as we showed in this review of the extant literature, have received limited attention.

Table 3 summarizes the sustainability issues, problems and proposed OR models and techniques for each decision making area in SOM.

Insert Table 3 about here

Our literature review has revealed that in the majority, papers tend to stress the importance of sustainability for OM and suggest ways to explore the area in depth; this is a fact in any emerging area (Srivastava, 2007). However, the majority of the papers do not shed light into the use of OR modelling and analysis of SOM. Therefore, future research should focus on developing models considering the economic and environmental parameters and variables for the optimal SOM and SSCM. To this extent, OR models and techniques such as DEA, Linear Programming and Multi-Objective Optimization (Chen *et al*, 2012; Hwang *et al*, 2013) can assist in studying and providing the necessary conditions and variables for sustainable product and process design. Additionally, there is a further need for the development of models for the optimisation of SOM/SSCM configuration which would simultaneously minimize the cost and maximize the environmental protection. Srivastava (2007) refers to a variety of tools used for the mathematical modelling of various areas within the context of green supply chains and logistics such as redesigning logistics networks considering product returns and remanufacturing, and problems of physical location of facilities and transportation. However, very few OR models have been used for integrated green supply chains, such as AHP/ANP and DEA, as well as for green design. Our study aligns with Srivastava in that further research is needed to this direction.

The extant literature has used various OR models and tools to study the logistics and transportation from a sustainability perspective. However, as shown in tables 1 and 2, more research is needed in this stream and in particular the utilisation of transportation models for SOM and SSCM, but with additional variables and parameters such as cost of logistics both forward and reverse and reducing carbon footprint. Such models could be tested across the supply chain, be applied to real supply chain network environments and across several supply chains (Sundarakani *et al*, 2010). Since the majority of studies on SSCM illustrate and model emissions and pollution reduction based on the impact of government regulations, it is important that they also include factors based on market forces. Regulatory factors such as carbon tax are important; but, nevertheless, the preferences and response of the customers as well as the market competition which pressurise businesses and make them greener need to be also included in the models. Hence, another future research direction would be to model the purchasing behaviour of customers when choosing between green and non-green products (Morrow and Skerlos, 2012; Tang and Zhou, 2012).

Suitable OR models for outsourcing which will incorporate the environmental dimension are needed, whereas additional sustainability factors need to be considered in off-shoring decision processes and location planning (Dou and Sarkis, 2010). Such models need to be applied in practice to be validated and optimised. However, this application may create two further research avenues: the first has to do with creating the appropriate tools to feedback the results as future criteria to be optimised; and second, with solving the resulting formulations by using efficient algorithms and appropriate technological infrastructures. Grossman and Guillén-Gosálbez (2010) comment on such intentions suggesting that these problems are affected by a variety of uncertainty sources (such as inventory of emissions, generated waste) and can influence the conclusions and recommendations made. Therefore, it is imperative to develop innovative stochastic methods that will anticipate the effect of such variations. According to Gunasekaran and Ngai (2012), companies should adopt a responsible supply chain management (ResSCM) rather than simply responsive supply chain management (RSCM). ResSCM holds a great future in 21st century organizational competitiveness. This necessitates the modelling and analysis of ResSCM taking into account various social constraints and issues apart from economic and environmental aspects.

Tang and Zhou (2012) suggest that the extant literature on OR and SOM is based on planet factors, such as emissions and waste reduction, but models which focus on the role of people are still lacking and they have to be investigated, since sustainability looks at operations from a broader perspective (Linton *et al* 2007). Therefore, it would be fruitful to model and measure the impact of sustainable practices on people and society. To this extent, models which include emerging markets, micro-entrepreneurs (Sodhi and Tang, 2011), and involve the poor, or countries which face social or debt issues will be a step forward. Furthermore, another extension of the already existing research on the MA of SOM would be through the acknowledgement that since firms do not operate in a vacuum, they need to align their sustainable strategies and practices with those of their upstream suppliers and downstream customers. Although the extant research illustrates the trade-offs between environmental sustainability, social responsibility, and business performance (Lee, 2010), it is yet to understand the vertical and horizontal interactions between supply chain partners. In such situations, researchers may illustrate the role of environmental regulations, people, and market in the operations and performance of the supply chain, whereas they will also be in a position to suggest appropriate strategies and practices for the coordination of sustainable activities across the supply chain; developing models on performance measures and metrics in SOM could be a way forward (Ageron *et al*, 2012). It would be also interesting to examine, model, and analyse the utilisation of the different inter-organisational resources and capabilities and the conditions under which these lead to the creation of competitive GSCM. To this extent, the integration of OR with OM and resource-based (Barney, 1991) strategic management would be a possible route (Gold *et al*, 2010).

A paradigm shift from the firm level to the individual level of analysis may be needed. While the extant research has started to provide evidence and models of sustainable firm behaviour, it is lacking an understanding of the drivers behind the behaviour and the decision making regarding sustainable strategies and practices of individual managers (Krause *et al*, 2009). Such models could, for instance, incorporate factors on biases and how these impact the decisions on SOM, or factors which lie behind the gain of commitment of key stakeholders to promote sustainability and SOM projects across the firms. They would also reduce the uncertainty inherent on SOM decisions and guide their function. Hence, building and testing such models is crucial if researchers need to understand the practices and trade-offs between businesses and the environment (Wu and Pagell, 2011).

The introduction of OR modelling and analysis methods for trading-off between productivity, markets, environment, and people (Higgins *et al*, 2010), and hence balancing between desirable outputs for organisations (for instance, profitability and competitiveness and product/service specifications), and desirable outputs for the environment and the society, is needed to create a reciprocal relationship between environment management and operations (Bloemhof-Ruwaard *et al*, 1995; Kleindorfer *et al*, 2005; Sundrakani *et al*, 2010). The existing studies (e.g. Beynon and Wells, 2008; Chen *et al*, 2012; Cruz, 2009; Higgins *et al*, 2010; Hwang *et al*, 2013; Stuart *et al*, 1999; Simoes *et al*, 2008) are limited in addressing all the aforementioned dimensions and call for explicit and holistic modelling and analysis of the balance between these dimensions for SOM. Furthermore, modelling and analysis of resilience (Christopher and

Peck, 2004) in supply chains (which incorporates balancing between profitability and sustainability, accommodating social and environmental dimensions) constitutes another research direction for the OR field. Therefore, driven by the need (a) to overcome the limitations of current OR models in modelling and analysing trade-offs by paying a holistic attention to the dimensions of profit and competitiveness, social and environmental objectives, and uncertainty (Higgins *et al*, 2010) and subsequently implementing these models in practice; and (b) to provide a thorough understanding of the trading-off impacts of SOM on organisations so that managers decide what action is needed (Schrettle *et al*, *In Press*), OR academics and practitioners need to model and analyse sustainability in a progressive way; the incorporation of social and environmental issues in OR models and techniques is the key to business excellence than a threat (Sharma, 2000).

These research avenues, however, create further methodological challenges, which research should also consider. In particular, when aiming to record factors which drive firms to adopt SOM either through questionnaires or through interviews, researchers get a positive reaction by respondents since they feel a pressure due to social desirability bias (Krause *et al*, 2009) to be perceived as being positive towards sustainability. Additionally, research on SSCM may involve global supply chains, and in this case there is a risk of cultural differences on sustainability; views of managers may differ from individual to individual and among different sectors or countries. Consequently, researchers should pay attention to ways of recording factors and building their models since findings could be more positive or embracing than in reality, and should be in a position to understand how to balance different views between individuals, sectors, and countries across the supply chains (Walker *et al*, 2012). Hence, future research on the MA of SOM could focus on different sectors, services and developing countries, creating thereby informative models which could also draw on behavioural and psychological perspectives. Especially in the SSCM field, cross-country empirical studies would provide insights and illustrate any differences in the emerging models (Ageron *et al*, 2012). Such research could be facilitated by the use of appropriate models, based on for instance AHP, which could assist researchers in arriving at those factors which need to be considered when looking at MA of SOM. Finally, introducing appropriate measures of research on MA of SOM is another challenge to be tackled. Since OR may involve learning, it would be fruitful of both researchers and organisations to feed the results of their models into new research, which will further expand MA of SOM.

Since a small number of studies are based on real case study data (e.g. Maden *et al*, 2011; Mar-Ortiz *et al*, 2011; Ramos and Oliveira, 2011), there is a need for more applied research on the MA of SOM either through testing or by building practical theories. Such research would provide managers with insights on how to adopt SOM and how to use MA for sustainable operations, supply chains, and businesses. This is particularly important, since legal trends may force changes towards sustainability no matter if firms or academia are prepared to deal with the challenges brought by these changes (Linton *et al*, 2007). Further implications would involve, for instance, the building of evaluation tools based on OR models which will assess the level of sustainable operations. These tools could assist the managers with selecting appropriate strategies to tackle issues in the implementation of sustainable operations. Although theory emerging from case-studies may be limited due to the characteristics of case-study research (Eisenhardt, 1989) it would nevertheless address the gap between theory and practice.

The SOM is a promising area for OR modelling and analysis, since the issues entailed are both complex and challenging, and involve a large number of factors, parameters, decision variables, constraints, and estimation requirements (Srivastava, 2007). We argue, therefore, towards the use of OR methodologies, tools, and techniques for modelling and analysing SOM.

7. Conclusions

In this paper, an attempt has been made to review the literature available on SOM and SSCM for the purpose of modelling and analysis. A focus on sustainability considers the impact of planning, coordination, and control of operations on people, the organisation, and the environment, that is, on both adding value to customers in a cost-effective manner while paying attention to the natural resources and reducing for instance the carbon footprint, the cost of reverse logistics, remanufacturing, and focusing on green supply chain management. Furthermore, it needs to consider trading-off and balancing between all these dimensions for achieving the organisational objectives.

The selected literature has been classified based on the key decision making areas and detailed decision making areas underneath each of them. We have considered product and process design, location planning and analysis and capacity planning under system design decisions. System operations decisions include procurement, production and logistics. Based on the review of selected literature, gaps between theory and practice have been identified and discussed for determining future research directions.

Our literature review illustrated the importance for future studies to shift discussions on MA of SOM from strategic to implementation level, using real case data. This shift will offer a better understanding of SOM and green supply chains, and in this vein incorporating OR modelling tools and techniques is crucial. The development of these models should consider the appropriate economic and environmental parameters and variables for the optimal SOM and SSCM and aim at minimising cost while maximising the protection of people and the planet, balancing and trading-off between these objectives; for instance, transportation and location planning models should incorporate sustainability dimensions, including human resource and social issues, which have been ignored in SOM (Klassen and Vereecke, 2012). We highlight the challenges associated with these future research avenues which concern the development of appropriate tools to measure the impact of the lifecycle of a product so that these observations are incorporated as further optimisation criteria; the development of algorithms and infrastructure to solve these formulations; and the development of innovative stochastic methods that will anticipate the effect of uncertainty in the models.

We believe this paper will serve as a forum for further discussion and research on MA of SOM (including SSCM/GSCM) which needs due attention from both researchers and practitioners. For academics, our literature review highlights the multiplicity of factors which need to be considered when embedding OR models and techniques in SOM. Furthermore, our suggested classification of studies in SOM can be used as reference system to develop and test models, algorithms, and technologies in each of the decision areas of SOM. For practitioners, our study provides insight into the importance of applying MA of SOM in firms and the ways firms could develop and evaluate their own practices of SOM using OR models and analysis. Therefore, our study contributes to a better understanding of the MA of SOM, bridging thereby the gap between theory and practice.

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References

Ageron B, Gunasekaran A and Spalanzani A (2012). Sustainable supply management: An empirical study. *International Journal of Production Economics* **140** (1): 168-182.

Arnason R (2009). Fisheries Management and Operations research. *European Journal of Operational Research* **193**(3): 741-751.

Barney J B (1991). Firm resources and sustained competitive advantage. *Journal of Management* **17**(1): 99-120.

Bektas T and Laporte G (2011). The pollution-routing problem. *Transportation Research Part B: Methodological* **45**(8): 1232-1250.

Beynon M J, and Wells P. (2008) The lean improvement of the chemical emissions of motor vehicles based on preference ranking: A PROMETHEE uncertainty analysis, *Omega* **36** (3): 384–394

Bloemhof-Ruwaard J M, van Beek P, Hordijk L, and Van Wassenhove L N (1995). Interactions between operational research and environmental management. *European Journal of Operational Research* **85**: 229–243.

Bouchery Y, Ghaffari A, Jemai Z and Dallery Y (2012). Including Sustainability Criteria into Inventory Models. *European Journal of Operational Research* **222**(2): 229-240.

Brown D (2008). It is good to be green: environmentally friendly credentials are influencing business outsourcing decisions. *Strategic Outsourcing: An international Journal* **1**(1): 87-95.

Chen C, Zhu J, Yu J - Y and Noori H (2012). A New Methodology for Evaluating Sustainable Product Design Performance with Two-Stage Network Data Envelopment Analysis. *European Journal of Operational Research* **221**(2): 348-359.

Chopra S, Lovejoy W and Yano C (2004). Five decades of operations management and the prospects ahead. *Management Science* **50**(1): 8-14.

Christopher M and Peck H (2004). Building the resilient supply chain. International Journal of Logistics Management **15**: 1–14.

Chung C - J and Wee H - M (2011). Short life-cycle deteriorating product remanufacturing in a green supply chain inventory control system. *International Journal of Production Economics* **129**(1): 195-203.

Chung C - J, and Wee H- M (2008). Green-component life-cycle value on design and reverse manufacturing in semi-closed supply Chain. *International Journal of Production Economics* **113**(2): 528-545.

Cruz J M (2009). The impact of corporate social responsibility in supply chain management: Multicriteria decision-making approach. *Decision Support Systems* **48**: 224–236.

Dekker R, Bloemhof J and Mallidis J (2012). Operations Research for Green Logistics – An Overview of Aspects, Issues, Contributions and Challenges. *European Journal of Operational Research* **219**(3): 671-679.

Demir E, Bektas T and Laporte G (2012). An adaptive large neighborhood search heuristic for the pollution-routing problem. *European Journal of Operational Research*, **223**(2): 346-359.

Devinney T M (2009). Is the socially responsible corporation a myth? The good, the bad, and the ugly of corporate social responsibility. *Academy of Management Perspectives* **23**(2): 44–56.

Dou Y, and Sarkis J (2010). A Joint Location and Outsourcing Sustainability Analysis for a Strategic Offshoring Decision. *International Journal of Production Research* **48**(2): 567-592.

Easterby-Smith M, Thorpe R and Lowe A (2002). *Management Research – An Introduction*. Sage Publications: London.

Eisenhardt K (1989). Building theories from case study research. *Academy of Management Review* **14**(4): 532-550.

Ferretti I, Zanoni S, Zavanella L and Diana A (2007). Greening the Aluminium Supply Chain. *International Journal of Production Economics* **108**(1-2): 236-245.

Ghosh D. and Shah J (2012). A Comparative Analysis of Greening Policies across Supply Chain Structures. *International Journal of Production Economics* **135**(2): 568-583.

Giovanni P D and Vinzi V E (2012). Covariance versus Component-based Estimations of Performance in Green Supply Chain Management. *International Journal of Production Economics* **135**(2): 907-916.

Gold S, Seuring S and Beske P (2010). Sustainable Supply Chain Management and Inter-Organizational Resources: A Literature Review. *Corporate Social Responsibility and Environmental Management* **17**(4): 230-245.

Grossler A, Thun J. H and Milling P. M (2008). System dynamics as a structural theory in operations management. *Production and Operations Management* **17**(3): 373-384.

Grossman I E and Guillén-Gosálbezb G (2010). Scope for the Application of Mathematical Programming Techniques in the Synthesis and Planning of Sustainable Processes. *Computers & Chemical Engineering* **34**(9): 1365–1376.

Gunasekaran, A. and Ngai, E.W.T., 2012. The Future of Operations Management: An Outlook and Analysis. *International Journal of Production Economics* **135(**2), 687-701.

Hay R L, Stavins R N and Vietor R H K (2005). *Environmental Protection and the Social Responsibility of Firms: Perspectives from Law, Economics and Business. Resources for the Future*. RFF Press: Washington DC.

Henriques, J. and Sadorsky P (1999). The Relationship between Environmental Commitment and Managerial Perceptions of Stakeholder Importance. *Academy of Management Journal* **42**(1): 87-99.

Higgins A J, Miller, C J, Archer A A, Ton T, Fletcher C S, and McAllister R R J (2010) Challenges of operations research practice in agricultural value chains. *Journal of the Operational Research Society* **61**: 964-973.

Huang X - Y, Yan N - N and Qiu R - Z (2009). Dynamic Models of Closed-Loop Supply Chain and Robust H Control Strategies. *International Journal of Production research* **47**(9): 2279-2300.

Hwang S – N, Chen C, Chen Y, Lee H – S and Shen P – D (2013). Sustainable design performance evaluation with applications in the automobile industry: Focusing on inefficiency by undesirable factors. *Omega* **41**(3): 553-558.

Ivanov D, Sokolov B and Kaeschel J (2010). A Multi-Structural Framework for Adaptive Supply Chain Planning and Operations Control with Structure Dynamics Considerations. *European Journal of Operational Research* **200**(2): 409-420.

Klassen R D and Vereecke A (2012). Social Issues in Supply Chains: Capabilities Link Responsibility, Risk (Opportunity) and Performance. *International Journal of Production Economics* **140**(1): 103-115.

Kleindorfer P R, Singhal K and van Wassenhove L N (2005). Sustainable Operations Management. *Production and Operations Management* **14**(4): 482-492.

Klibi W, Martel A and Guitouni A (2010). The Design of Robust Value-Creating Supply Chain Networks: A Critical Review. *European Journal of Operational Research* **203**(2): 283-293.

Kowlaski K, Stagl S, Madlener R and Omann I (2009). Sustainable Energy Futures: Methodological Challenges in Combining Scenarios and Participatory Multi-criteria Analysis. *European Journal of Operational Research*, **197**(3): 1063-1074.

Krause D R, Vachon S and Klassen R D (2009). Special topic forum on sustainable supply chain management: introduction and reflections on the role of purchasing management. *Journal of Supply Chain Management* **45**(4): 18-25.

Krikke H, Bloemhof-Ruwaard J and van Wassenhove L (2003). Concurrent product and closed-loop supply chain design with an application to refrigerators. *International Journal of Production Research* **41**(16): 3689–3719.

Kumar S and Putnam V (2008). Cradle to Cradle: Reverse Logistics Strategies and Opportunities across Three Industry Sectors. *International Journal of Production Economics* **115**(2): 305-315.

Lee H L (2010). Do not Tweak Your Supply Chain – Rethink it End to End. Harvard Business Review **October**, 1-8.

Lejeune M A (2006). A Variable Neighbourhood Decomposition Search Method for Supply Chain Management Planning Problems. *European Journal of Operational Research* **175**(2): 959-976.

Linton J D, Klassen R and Jayaraman V (2007). Sustainable supply chains: An introduction. *Journal of Operations Management* **25**(6): 1075-1082.

Liu Z, Anderson T D and Cruz J M (2012). Consumer environmental awareness and competition in two-stage supply chains. *European Journal of Operational Research* **218**(3): 602-613.

Loch C H and Wu Y (2008). Social Preferences and Supply Chain Performance: An Experimental Study. *Management Science* **54**(11): 18535-1849.

Mar-Ortiz J, Adenso-Diaz B, and Gonzalez-Velarde J L (2011). Design of a recovery network for WEEE, collection: the case of Galicia, Spain. *Journal of the Operational Research Society* **62**(8):1471-1484.

Maden W, Eglese R, and Black D (2010). Vehicle routing and scheduling with time-varying data: A case study. *Journal of the Operational Research Society* **61**(3):515-522.

Mingers J, and White L (2010). A Review of the Recent Contribution of Systems Thinking to Operational Research and Management Science. *European Journal of Operational Research* **207**(3): 1147-1161.

Morrow W R and Skerlos S J (2012). Fixed-point approaches to computing Bertrand–Nash equilibrium prices under mixed-logit demand. *Operations Research* **59**(2), 328–345.

Nativi J J and Lee S (2012). Impact of RFID Information-Sharing Strategies on a Decentralized Supply Chain with Reverse Logistics Operations. *International Journal of Production Economics* **136**(2): 366-377.

Neto J Q F, Walther G, Bloemhof J., van Nunen J A E E and Spengler T (2009). A Methodology for Assessing Eco-Efficiency in Logistics Networks. *European Journal of Operational Research* **193**(3): 670-682.

Neto Q F J, Walther G, Bloemhof J, van Nunen J A E E and Spengler T (2010). From Closed-Loop to Sustainable Supply Chains: The WWW Case. *International Journal of Production Research* **48**(15): 4463-4481.

Nieuwenhuis P, Beresford A and Choi A K - Y (2012). Shipping or Local Production? CO_2 Impact of a Strategic Decision: An Automotive Industry Case Study. *International Journal of Production Economics* **140**(1): 138-148.

Paksoy T, Bektas T and Ozceylan E (2011). Operational and environmental performance measures in a multi-product closed-loop supply chain. *Transportation Research Part E: Logistics and Transportation Review* **47**(4): 532-546.

Paular-Caceres A, and Espinosa A (2011). Management science methodologies in environmental management and sustainability: discourses and applications. Journal of the Operational Research Society **62**, 1601-1620.

Piplani R, Pujawan N and Ray S (2008). Sustainable supply chain management. *International Journal of Production Economics* **111**(2): 193-194.

Porter M (1991). America's Green Strategy. *Scientific American* **264**(4): 90-168.

Radulescu M, Radulescu S and Radulescu C Z (2009). Sustainable Production Technologies which take into Account Environmental Constraints. *European Journal of Operational Research* **193**(3): 730-740.

Ramos T R P, and Oliveira R C (2010). Delimitation of service areas in reverse logistics networks with multiple depots. *Journal of the Operational Research Society* **62**(7):1198-1210

Robertson P W, Gibson P R and Flanagan J T (2002). Strategic Supply Chain Development by Integration of Key Global Logistical Process Linkages. *International Journal of Production Research* **40**(16): 4021-4040.

Santos L M R D, Costa A M, Arenales M N and Santos R H S (2010). Sustainable Vegetable Crop Supply Problem. *European Journal of Operational Research* **204**(3): 639-647.

Sarkis S, Zhu Q and Lai K - H (2011). An Organizational Theoretic Review of Green Supply Chain Management Literature. *International Journal of Production Economics* **130**(1): 1-15.

Savaskan R C, Bhattacharya S and van Wassenhove L N (2004). Closed-Loop Supply Chain Models with Product Remanufacturing. *Management Science* **50**(2): 239-252.

Schrettle S, Hinz A, MaikeScherrer-Rathje M, and Friedli T (*In Press)*. Turning sustainability into action: Explainign firms' sustainability efforts and their impact on firm performance. *International Journal of Production Economics*.

Sharma S. (2000). Managerial interpretations and organizational context as pre- dictors of corporate choice of environmental strategy. *Academy of Management Journal* **43**(4): 681–697.

Sheu J - B and Chen Y J (2012). Impact of Government Financial Intervention on Competition among Green Supply Chains. *International Journal of Production Economics* **138**(1): 201-213.

Simoes C F, Gomes, Nunes K R A, Xavier L E, Cardoso R, and Valle R. (2008) Multicriteria decision making applied to waste recycling in Brazil, *Omega*. **36**(3): 395–404.

Smith H K, Harper P R, Potts C N and Thyle A (2009). Planning Sustainable Community Health Schemes in Rural Areas of Developing Countries. *European Journal of Operational Research* **193**: 768-777.

Sodhi M and Tang C S (2011). Social enterprises as supply-chain enablers for the poor. *Socio-Economic Planning Sciences* **45**(4): 146-153.

Srivastava S K (2007). Green Supply Chain Management: A State-of-the-Art Literature Review. *International Journal of Management Reviews* **9**(1): 53-80.

Stuart J A, Ammons J C, and Turbini L J (1999). A Product and Process Selection Model with Multidisciplinary Environmental Considerations. *Operations Research*, **47**: 221–234.

Su Q, Shi J - H and Lai S - J (2008). Study on Supply Chain Management of Chinese Firms from the Institutional View. *International Journal of Production Economics* **115**(2): 362-373.

Sundarakani B, de Souza R, Goh M, Wagner S M and Manikandan S (2010). Modeling carbon footprints across the supply chain. *International Journal of Production Economics* **128**(1): 43-50.

Tang C S and Zhou S (2012). Research advances in environmentally and socially sustainable operations. *European Journal of Operational Research* **223**(13): 585-594.

Toktay L B, Wein L M and Zenios S A (2000). Inventory Management of Remanufacturable Products. *Management Science* **46**(11): 1412-1426.

Tsai W - H and Hung S - J (2009). A Fuzzy Goal Programming Approach for Green Supply Chain Optimization under Activity-Based Costing and Performance Evaluation with a Value-Chain Structure. *International Journal of Production Research* **47**(18): 4991-5017.

Ubeda S, Arcelus F J and Faulin J (2011). Green logistics at Eroski: A Case Study. *International Journal of Production Economics* **131**(1): 44-51.

Vachon S and Klassen R D (2008). Environmental Management and Manufacturing Performance: The Role of Collaboration in the Supply Chain. *International Journal of Production Economics* **111**(2): 299-315.

van der Vorst J, Tromp S and Zee D J (2009). Simulation modelling for food supply chain redesign; Integrated decision making on product quality, sustainability and logistics. *International Journal of Production Research* **47**(23): 6611-6631.

Voss C. A. (1984). Production Operations Management - a Key Discipline and Area for Research. *Omega* **12**(3): 309-319.

Walker H, Miemczyk J, Johnsen T and Spencer R (2012). Editorial: Sustainable procurement: Past, present and future. *Journal of Purchasing and Supply Management* **18**(4): 201-206.

Walther G, Schatka A and Spengler T S (2012). Design of Regional Production Networks for Second Generation Synthetic Bi-Fuel: A Case Study in Northern Germany. *European Journal of Operational Research* **218**(1): 280-292.

Wang Z, Chan H K, Yee R W Y and Diaz-Rainey I (2012). A Two-Stage Fuzzy-AHP Model for Risk Assessment of Implementing Green Initiatives in the Fashion Supply Chain. *International Journal of Production Economics* **135**(2): 595-606.

Wee H - M, Lee M - C, Yu J C P and Wang C E (2011). Optimal Replenishment Policy for a Deteriorating Green Product: Life Cycle Costing Analysis. *International Journal of Production Economics* **133**(2): 603-611.

Whang S (2010). Timing of RFID Adoption in a Supply Chain. *Management Science* **56**(2): 343-355.

White L and Lee G J (2009). Operational Research and Sustainable Development: Tackling the Social Dimension. *European Journal of Operational Research* **193**(3): 683-692.

Wilkinson A, Hill M and Gollan P (2001). The sustainability debate. *International Journal of Operations & Production Management* **21**(12): 1492 - 1502

Wu D J and Kleindorfer P R (2005). Competitive Options, Supply Contracting, and Electronic Markets. *Management Science* **51**(3): 452-466.

Wu H J and Dunn S C (1995). Environmental Responsible Logistics Systems. *International Journal of Physical Distribution and Logistics Management* **25**(2): 265-289.

Wu Z and Pagell M (2011). Balancing priorities: Decision-making in sustainable supply chain management. *Journal of Operations Management* **29**(6): 577-590.

Zhu Q and Sarkis J (2012). The Moderating Effects of Institutional Pressures on Emergent Green Supply Chain Practices and Performance. *International Journal of Production Research* **45**(18-19): 4333-4355.

Zhu Q, Sarkis J and Lai K - H (2008). Confirmation of a Measurement Model for Green Supply Chain Management Practices Implementation. *International Journal of Production Economics* **111**(2): 261-273.

Table 1: Classification of the Literature on SOM

Major Classification Criteria	Sub-Classification Criteria	References
System Design	Product and Process Design	Chen *et al* (2012); Chung and Wee (2008)
	Location Planning and Analysis	Dou and Sarkis (2010); Smith *et al* (2009); Walther *et al* (2012)
	Capacity Planning	Ivanov *et al* (2010); Lejeune (2006); Radulescu *et al* (2009); Robertson *et al* (2002)
System Operations	Procurement	Ghosh and Shah (2012); Ferretti *et al* (2007); Loch and Wu (2008); Toktay *et al* (2000); Wu and Kleindorfer (2005)
	Production	Bouchery *et al* (2012); Henriques and Sardorsky (1997); Klassen (2008); Liu *et al* (2012); Sheu and Chen (2012); Vachon and Santos *et al* (2010); Wee *et al* (2011); Chung and Wee (2011)
	Logistics	Bektas and Laporte (2011); Dekker *et al* (2012); Demir *et al* (2012); Huang *et al* (2009); Kumar and Putnam (2008); Maden *et al* (2010); Mar-Otiz *et al* (2011); Nativi and Lee (2012); Neto *et al* (2009); Neto *et al* (2010); Paksoy et al (2011); Ramos and Oliveira (2010); Savaskan *et al* (2004); Ubeda *et al* (2011); Wu and Dunn (1995); Whang (2010);

Table 2: Summary of Literature Review and Findings on SOM

Classification Criteria	References	Contribution	OR Models and Techniques	Future Research Directions
		System Design		
Product & Process Design	Chen *et al* (2012)	New design attributes and engineering specifications for SOM	Two-Stage Network Data Envelopment Analysis	A multi-criteria decision making models incorporating the parameters of sustainable product and process design
Location Planning & Analysis	Dou and Sarkis (2010)	Offshore Outsourcing and Sustainability	ANP Model	Linear Programming models for outsourcing and supplier selection for sustainability
	Smith *et al* (2009)	Rural Healthcare Sustainability	Planning Model	Social parameters in the optimization
	Walther *et al* (2012)	Planning problem for selection and location of production	Multi-Period and Multi-Integer Programming Model	The same model can be extended to consider the outsourcing and sustainability factors
Capacity Planning	Ivanov *et al* (2010)	Adaptive supply chain management Framework	Conceptual framework and multi-structural planning models	Develop a multi-objective model incorporating supply chain agility and sustainability
	Lejeune (2006)	Sustainable inventory-production-distribution plan over a multi-period horizon	General Mixed-Integer Programming	Develop an integrated procurement-production-logistics model for sustainability
	Radulescu *et al* (2009)	Optimal strategies to reduce the effect of pollution	Multi-objective programming model	Incorporate the impact of economic and supply chain factors
	Robertson *et al* (2002)	Managing end to end key logistical processes within a supply chain	A Generic Model for a tiered approach for planning and scheduling	A closed loop multi-criteria model for optimizing the end to end activities while incorporating sustainable factors

System Operations				
Procurement	Ferretti *et al* (2007)	Greening the aluminium supply chain	Economic and environmental evaluation	Single-vendor and single-buyer model
	Ghosh and Shah (2012)	Impact of green product development on supply chain	Cooperative models of cost sharing contract and revenue sharing contract	Agency theory-based models
	Loch and Wu (2008)	Supply chain contracting focusing on sustainability	Game theoretic model	Incorporate the implications of social preferences in sustainable development
	Wu and Kleindorfer (2005)	Analysing B2B transactions and supply chain management	Agency theory models	Extend the model to consider the sustainable factors
Production	Bouchery *et al* (2012)	Sustainability in inventory management	SOQ model, Multi-echelon model	Develop green inventory models
	Chung and Wee (2011)	Green-component life-cycle value design, reverse manufacturing	An integrated production-inventory deteriorating model	Greening production process using reverse logistics and green-component life-cycle design
	Henriques and Sardorsky (1997)	Environmental management, Remanufacturing	Cost Model	Generalization to GSCM
	Liu *et al* (2012)	Environmental awareness on key supply chain players, Eco-friendly operations	Two-stage Stackelberg game models (Quadratic function models)	Substitutable products impact on sustainable supply chain
	Santos *et al* (2010)	Ecologically based production planning	Column-generation approach, LP model	Apply to other supply chain or production problem
	Sheu and Chen (2012)	Reverse supply chain, product life cycle	Three-stage game theoretic model	Develop models for designing green product production and green supply chain competition

	Vachon and Klassen (2008)	Remanufacturing, Environmental collaboration	Life cycle costing model	Extend the model for the application of RFID
	Wee *et al* (2011)	Eco-design requirements for energy using products	VMI and product life cycle analysis	Apply the concept to green supply chain management
Logistics	Bektas and Laporte (2011)	Pollution-Routing Problem (an extension of the Vehicle Routing Problem). Considers the travel distance, greenhouse emissions, fuel, travel times and their costs	Mixed-integer mathematical model which could be linearized	Use a heterogeneous or mixed fleet of vehicles to provide more flexibility and thus further reductions in energy consumption, total cost and vehicle utilization.
	Dekker *et al* (2012)	Impact of transport options on greening, Life cycle costing, and supply chain planning	Network design models, Multi-objective mixed integer programming models	Impact of transport on reverse logistics and environmental performance
	Demir *et al* (2012)	A heuristic algorithm to solve the Pollution-Routing Problem.	A heuristic algorithm which iterates between a classical Vehicle Routing Problem with Time Windows and a speed optimization Problem	Present further OR modelling and analysis techniques and tools to solve the Pollution-Routing Problem effectively
	Huang *et al* (2009)	Closed loop supply chain (CLSC), Remanufacturing, 3PRL	Dynamic CLSC models	Develop stochastic models and queuing models
	Krikke *et al* (2003)	Examine a supply chain design for refrigerators considering environmental issues using real life R&D data	Mathematical model based on mixed-integer linear programming, for supply chain design aiming to study cost minimisation while on the environmental costs of energy and waste	Consider variables in OR modelling and analysis
	Kumar and	Cradle-to-Cradle	Life cycle	Impact of information

	Putnam (2008)	model, End of life reverse logistics	costing model	sharing and recycling on resource management
	Maden et al (2010)	Vehicle routing and scheduling to minimise the total travel time	Heuristic algorithm and application to schedule a fleet of delivery vehicles in UK	Modify the algorithm to find the set of routes that directly minimise pollution, considering the time-varying speeds due to patterns of congestion
	Mar-Otiz *et al* (2011)	Design of the reverse logistic network for the collection of waste of electric/ electronic equipment, using a case study in Spain	Integer programming models and subsequent simulation analysis. Heuristic algorithm to solve the related collection routing problems.	Improving the OR techniques used (integer programming, heuristic algorithms and simulation) in such cases with economic and environmental significance
	Nativi and Lee (2012)	Environmental operations of reverse logistics, RFID in reverse logistics	Inventory models with reverse logistics and RFID	Study the role of RFID in life cycle costing and management
	Neto *et al* (2010)	CLSC to improve economic benefit from end-of-use products	CSLC models	Production-planning and inventory control issues should be considered
	Neto *et al* (2009)	Eco-efficiency in logistics networks, Impact of sustainable manufacturing practices	Pareto-optimal solutions	Impact of behavioural issues on sustainable operations management
	Paksoy *et al* (2011)	A mathematical model in a form of a linear programming formulation is used to model the trade-offs between various costs including emissions and transporting commodities	Linear programming formulation	Consider environmental costs within closed-loop supply chain networks
	Ramos and Oliveira (2010)	Definition of service (or	Heuristic algorithm and	Incorporating the dimension of different

		influence) areas of multiple depots in a reverse logistics network. Model which considers assignment of collection sites to depots and routing through an iterative procedure.	subsequent application in a case study in waste collection system with 5 depots in Portugal.	collection frequencies for the sites. Further inclusion of local search procedure in the model.
	Savaskan *et al* (2004)	Distribution channel design on CLSC and reverse logistics	Optimization models for best alternative selection	This can be extended to the whole supply chain including procurement and manufacturing
	Ubeda *et al* (2011)	Impact of transportation on green logistics	Capacitated vehicle routing problem	Extend the model to consider other relevant factors on green logistics
	Whang (2010)	RFID application in sustainable supply chain	Technology assessment model	Implication of RFID in GSCM
	Wu and Dunn (1995)	Environmental excellence in supply chain activities	Numerous logistical decision models	Study the impact of environmental initiatives and best practices on supply chain performance

Table 3: Modelling and Analysis of SOM

Decision Area	Sustainability Issues	Problems and Optimization	OR Models and Techniques
Product & Process Design	Product Design Performance and Design Efficiency	Optimal Product Design Parameters and Variables	DEA, Linear Programming and Multi-Objective Optimization
Location Planning & Analysis	Supplier selection, outsourcing, offshore outsourcing, Locational factors, environmental factors	Sustainability integration in outsourcing decisions, supplier selection, social factors, integrated location and capacity planning	ANP model, Production planning model, Multi-period MIP model
Capacity Planning	Life cycle planning and costing, Capacity for minimum pollution and cost, Supply chain agility and sustainability, Multi-structural supply chain management, and an integrated sustainable production-inventory-distribution model	Closed loop supply chain optimization for sustainability, minimizing pollution and cost in production process, responsive sustainable supply chain, optimal sustainable inventory-production-distribution	A multi-objective linear programming model, game theoretic models, Production planning and scheduling model, multi-objective programming approach, linear programming model, agent-based modelling and adaptive supply chain model
Procurement	Green supply chain management, Economic and environmental evaluation, B2B transactions, social implications	GSCM, Decision making models, greening strategies of players in the channel, Green procurement, and implications of social preference on sustainability	Agency theory can be applied to procurement decisions sustainability, Cost-sharing models, Single-vendor and single-buyer model, and social preference model
Production	Remanufacturing, Recycling, Environmental awareness on key supply chain players, Eco-friendly operations, eco-product design, Environmental collaboration, Green product design, ecologically-based constraints, Sustainable order quantity, Reverse logistics, Green products	Ordering policy to minimize the life cycle cost, Eco-friendly approach, Impact of environmental collaboration, Impact of green product design, Life cycle value design, remanufacturing, Inventory optimization incorporating sustainability, Reverse supply chain optimization, Eco-design requirements for energy using products, and green-component life-cycle value design.	Closed queuing network models, Game theoretic model, Production-inventory model, Linear programming, Inventory models, Vendor managed inventory system, and an integrated production-inventory deteriorating model.
	RFID in sustainability, Transportation on	Real-time information on value chain, Transport and	Multi-objective mixed integer programming

Logistics	environmental costs, Life cycle costing, Eco-efficiency in logistics Reverse logistics, cradle-to-cradle management, location and transport planning, Green logistics, Closed loop supply chain	supply network optimization, Evaluation of eco-efficiency in logistics, Reverse logistics and close-loop supply chain optimization, Location and transport optimization, Distribution channel design	models, CLSC models, Capacitated vehicle routing problem, pollution routing problem