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A case analysis of a sustainable food supply chain distribution system—A multi-objective approach

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ABSTRACT

Sustainable supply chain management is a topical area which is continuing to grow and evolve. Within supply chains, downstream distribution from producers to customers plays a significant role in the environmental performance of production supply chains. With consumer consciousness growing in the area of sustainable food supply, food distribution needs to embrace and adapt to improve its environmental performance, while still remaining economically competitive. With a particular focus on the dairy industry, a robust solution approach is presented for the design of a capacitated distribution network for a two-layer supply chain involved in the distribution of milk in Ireland. In particular the green multi-objective optimisation model minimises CO_2 emissions from transportation and total costs in the distribution chain. These distribution channels are analysed to ensure the non-dominated solutions are distributed along the Pareto fronts. A multi-attribute decision-making approach, TOPSIS, has been used to rank the realistic feasible transportation routes resulting from the trade-offs between total costs and CO_2 emissions. The refined realistic solution space allows the decision-makers to geographically locate the sustainable transportation routes. In addition to geographical mapping the decision maker is also presented with a number of alternative analysed scenarios which forcibly open closed distribution routes to build resiliency into the solution approach. In terms of model performance, three separate GA based optimisers have been evaluated and reported upon. In the case presented NSGA-II was found to outperform its counterparts of MOGA-II and HYBRID.

1. Introduction

The concept of the 'Triple Bottom Line' (Kleindorfer et al., 2005) or the 'Three Pillars' (White and Lee, 2009) based on the principles of a balanced approach to the three P's of people, profit (or prosperity) and planet are now well known dimensions in modern business activities. There is now also clearer evidence that consumers are continuing to demand more environmentally friendly products and services, which in itself presents both opportunities and threats to many organisations (Byrne et al., 2013). From a global perspective, the introduction of the Kyoto protocol progressed this agenda while also encouraging firms to reduce carbon emissions throughout their operations (Diabat and Simchi-Levi, 2009). It has also been reported that it is in the logistic operations where most organisations can and do implement green supply chain strategies (Kewill, 2008).

The food industry is one such example of a dynamic environment where customers have high expectations for food safety and a growing demand for sustainably produced food and a high awareness of how food is produced and offered (Beske et al., this issue). The downstream distribution of food products to retailers or drop-off points plays a significant role in the environmental performance of food supply chains. Efficient logistics and technologies are critical success factors for distribution systems in most supply chain networks, including food (Tarantilis et al., 2005). Traditionally, the critical success factors for an effective distribution system included meeting the requirement of the demand side of the supply chain through delivery of good quality products in appropriate quantities to the right place using the optimal path at the right time with optimal costs (Aghazadeh, 2004). However, distribution systems based solely on this singular dimension have over time begun to become obsolete as it does not consider the environmental impact of the system and increasing governmental regulations. The dairy industry is one such sector which is highly regulated and has been subjected to continued introduction of new environmental legislation in the last few years from both European and international directives (Glover et al., this issue). Hence, an effective blueprint for an economically competitive

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modern food market distribution systems calls for the inclusion of a methodology which can collectively deliver reduced environmental impact, lower operating costs and optimised traversed paths. This distribution strategy promotes an approach that seeks to achieve mutually reinforcing benefits for the economy, environment and society (Ilbery and Maye, 2005).

This paper presents a robust solution approach which specifically focuses on a capacitated distribution model for the demand side of a two-layer dairy market supply chain in Ireland. Through a case, the development of the green multi-objective optimisation model which incorporates both cost and environmental performance is reported upon. The main objective of this solution approach is the provision of optimised distribution routes based on carbon output and costs for the demand side of a dairy supply chain producing milk products. The model has also been extended to incorporate a resiliency component, through the presentation of alternative scenarios, which necessitate the opening of heretofore closed routes. Three different Genetic Algorithm (GA) based metaheuristic optimisers have been applied to the solution approach. GA optimisers are used due to the NP-hard nature of the green distribution problem under investigation, so as to yield feasible optimal and realistic distribution routes. A comparative assessment of these three GA optimisers aids in precisely selecting the best optimiser for a green distribution system for the case in hand.

The remainder of this paper is organised as follows. The following section highlights the role of distribution systems in the overall sustainable supply chain context and includes identification and analyses of varying optimisation approaches that have been used in varying distribution settings. Section 3 introduces the case of the two-layer Irish dairy market supply chain, discusses the importance of the dairy sector in Ireland and presents the GA based multi-objective solution approach. The solution procedure including case results and model performance is presented in Section 4 using three different Genetic Algorithm (GA)-based optimisers. Section 5 analyses the case results further and provides a scenario analysis based on the realistic solutions. Finally, Section 6 summarises the findings from the case and presents opportunities for further research in this domain.

2. Distribution systems and the food supply chain

One of the major sources of environmental concern is in relation to the distribution of products and from the emissions through their transportation. This concern is expected to increase faster than the growth of GNP in the industrialised world (Aronsson and Brodin, 2006). Such concerns and proactive planning have been in existence now since the early parts of the 2000s (European Commission, 2001). Since then there have been continued efforts by individual organisations, supply chains and international bodies, including the European Union (EU) to decrease the total emissions from the transportation sector. However, plenty of scope is still available to optimise the carbon emissions from a two-layer distribution system.

The traditional methodologies of handling food market distribution through storage and transportation of perishable food products (Aghazadeh, 2004) is not sufficient on its own in today's sustainable environment. In addition to ensuring a regular and complete coverage of all facilities in the supply chain (Aghazadeh, 2004) significant management of the carbon issues in the distribution system is also required (Benjaafar et al., 2013). Wu and Dunn (1995) focus on the use of proactive environmental management within the logistics framework. It has been well reported that one of the main challenges for modern logistic systems is to determine how environmental management principles can be incorporated into the system's operational decision-making process (Wu and Dunn, 1995; Robinson and Wilcox, 2008; Pagell and Wu, 2009). An example of a coordinated distribution system, which incorporates an improvement in logistics efficiency while simultaneously reducing environmental impact, is reported by Bosona and Gebresenbet (2011) for a Swedish food market supply chain.

An improved food distribution system can be designed using location routing optimisation techniques (Bosona et al., 2011). Several optimisation techniques have been applied in designing distribution systems. Optimisation techniques are used for reducing operational and overall costs in different distribution systems, for example, food and drink distribution (Watson-Gandy and Dohrn, 1973), goods distribution (Perl and Daskin 1984, 1985), agricultural goods transport (Ljungberg et al., 2007), forest harvesting (Rönnqvist et al., 2007), waste collection (Apaydin and Gonullu, 2008; Caballero et al., 2007; Kulcar, 1996), disposal of hazardous material (Alumur and Kara, 2007), obnoxious facility location-routing (Cappanera et al., 2004), small package shippers (Stenger et al., 2012), shipping industry (Gunnarsson et al., 2006), blood bank location (Or and Pierskalla, 1979) and medical evacuation (Chan et al., 2001).

Green supply chain initiatives have been comprehensively categorised by Srivastava (2007). One of these defined initiatives is green operations in the distribution of products. The solution approach presented in this paper focuses on the green operations of a two-layer supply chain from a transportation logistics perspective. Green initiatives associated with distribution in supply chains have in recent years been presented, particularly in green reverse logistics (Fleischmann et al., 2001; Zhu et al., 2008; Neto et al., 2009). Trade-offs between cost factors and environmental impact of a supply chain is reported in Wang et al. (2011). A green-vehicle routing problem is reported by Erdoğan and Miller-Hooks (2012), which uses a mixed integer linear programming approach. A dairy manufacturer's two-layer supply chain distribution system

Table 1
A synopsis of the reported optimisation techniques.

Optimisation techniques used	Publications
Self-organised optimisation using artificial neural network	Schwardt and Fischer (2009)
Honey bees mating optimisation	Marinakis et al. (2008)
Ant colony optimisation	Bell and McMullen (2004), Bin et al. (2009), Ting and Chen (2013)
Particle swarm optimisation	Yang and Zi-Xia (2009), Liu et al. (2012)
Tabu search	Gendreau et al. (1994), Melechovský et al. (2005), Albareda-Sambola et al. (2005), Caballero et al. (2007)
Simulated annealing	Lin et al. (2002), Yu et al. (2010), Stenger et al. (2012), Karaoglan et al. (2012)
Greedy randomised adaptive search optimisation	Prins et al. (2006), Duhamel et al. (2010), Nguyen et al. (2012)
Variable neighbourhood search optimisation	Melechovský et al. (2005), Ghodsi and Amiri (2010), Derbel et al. (2011)
Genetic algorithms	Zhou and Liu (2007), Marinakis and Marinaki (2008), Jin et al. (2010), Karaoglan and Altiparmak (2010)
Branch and cut optimisation	Belenguer et al. (2011), Karaoglan et al. (2011)
Mixed-integer programming; integer linear programming	Alumur and Kara (2007), Diabat and Simchi-Levi (2009), Laporte et al. (1989), Ambrosino and Scutellà (2005)

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