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## Invited Review

## Applications of agent-based modelling and simulation in the agri-food supply chains

Dhanan Sarwo Utomo<sup>a</sup>, Bhakti Stephan Onggo<sup>b,\*</sup>, Stephen Eldridge<sup>a</sup><sup>a</sup> Department of Management Science, Lancaster University Management School, Lancaster University, Lancaster LA1 4YX, United Kingdom<sup>b</sup> Trinity Business School, Trinity College Dublin, Dublin 2, Ireland

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## ABSTRACT

Agri-food supply chains (ASC) are an important application domain for Operational Research/Management Science. In particular, the use of agent-based simulation (ABS) has increased in ASC research in recent years. This paper reviews existing ASC research that use ABS. The review begins by analysing the characteristics of the models and modelling reported in the literature. It illustrates that existing modelling research features extensive use of: single echelon supply chains; cases from high and middle income countries; unprocessed food products, empirical (as opposed to hypothetical) data; decision-making related to production planning and investment; and the use of black box validation. The second part of the review uses bibliographic mapping to analyse areas in ASC research which are yet to be addressed using ABS. We find that areas such as collaboration and competition, buyer–seller relationships, and service are under-researched. In addition, key actors in ASC such as food processors, supermarkets and retailers have not been included in the ABS models reported. Furthermore, these models have yet to incorporate important supply chain management theories such as Transaction Cost Economics and Resource-Based View as part of their design.

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## 1. Introduction

Agri-food supply chains (ASC) comprise a network of heterogeneous actors working together in different processes and activities to deliver products and services to the market and satisfy customers' demands. Actors in ASC include various organisations from producers, distributors, processors and consumers (Ahumada & Villalobos, 2009; Borodin, Bourtembourg, Hnaien, & Labadie, 2016; Higgins et al., 2010; Pla, Sandars, & Higgins, 2014). The actors in ASC do not usually form linearly integrated businesses (Higgins et al., 2010; Kutcher & Norton, 1982). They have a high degree of autonomy with objectives that may conflict with those of the other actors. Consequently, this limited perspective makes it difficult for them to envisage how their individual decisions may affect the performance of the whole supply chain (Higgins et al., 2010). Furthermore, the dynamics in ASC are often influenced by social factors (e.g. lifestyles, personal values, safety concerns) (Busby & Onggo, 2013; Busby, Onggo, & Liu, 2016; Chebolu-Subramanian & Gaukler, 2015), economic factors (e.g. price) and the environment (e.g. climate variability) (Borodin et al., 2016). Actors in ASC have to adapt to these external factors in order to survive. In the light

of these characteristics, it is not surprising that some authors (e.g., Ahumada & Villalobos, 2009) argue that ASC are complex and hard to manage.

The complexities of ASC have attracted the interest of Operational Research and Management Science (OR/MS) researchers since the late 1940s (Borodin et al., 2016) and they have been the subject of a number of reviews. Ahumada and Villalobos (2009) reviewed the application of mathematical models in agricultural production and distribution planning while Janssen and van Ittersum (2007) reviewed the use of optimisation models (known as bio-economic farm model in the agriculture literature) to assess farm innovations and responses to policies. More recently, Soto-Silva, Nadal-Roig, González-Araya, and Pla-aragones (2016) reviewed the applications of OR/MS methods in fresh fruit supply chain and Borodin et al. (2016) reviewed the methods to handling uncertainty in ASC. The OR/MS techniques in these reviews include Agent-Based Simulation (ABS) and the benefits of using ABS in ASC have been highlighted by a number of authors (e.g., Higgins, Miller, Archer, Ton, Fletcher, & Mcallister, 2010; Higgins, Thorburn, Archer, & Jakku, 2007; Krejci & Beamon, 2012; Pla et al., 2014; Nolan, Parker, van Kooten, & Berger, 2009).

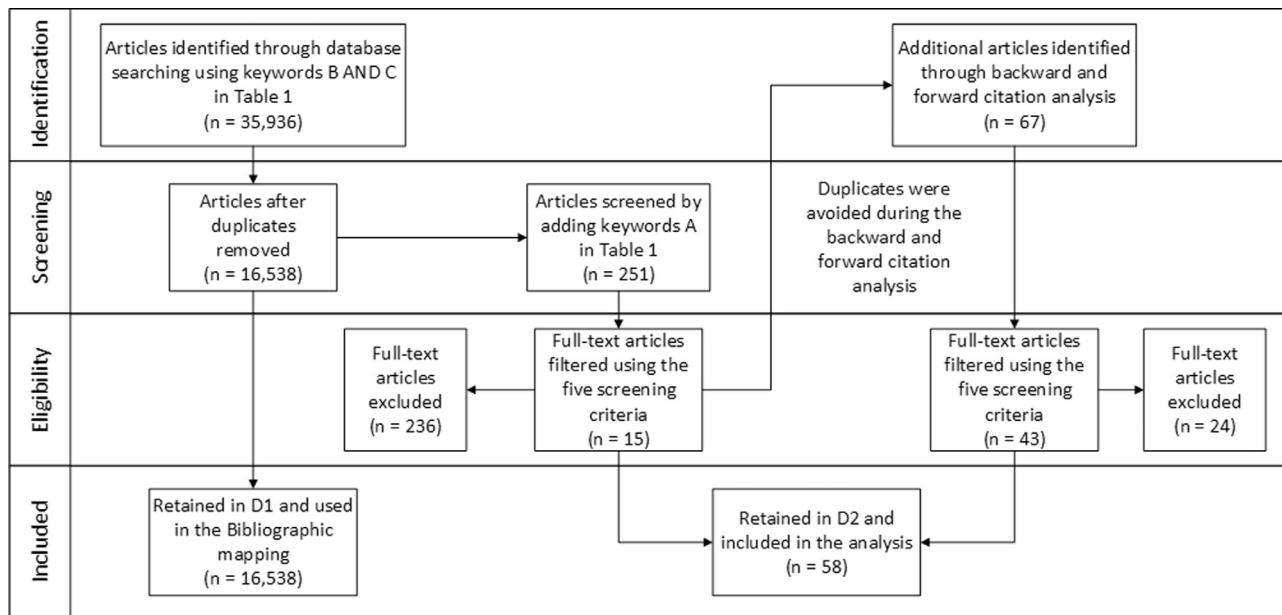
In common with other OR/MS techniques, ABS is being continually developed and enhanced. Our paper provides a review of the ABS methods used in ASC in order to identify topics in ASC that

\* Corresponding author.

E-mail address: [stephan.onggo@tcd.ie](mailto:stephan.onggo@tcd.ie) (B.S. Onggo).

**Table 1**  
Keywords used in database searching and the number of returned articles.

Code	Keywords	ABI/INFORM	Academic search complete	Business source complete	Science direct	Web of science	Total
A	("Agent based" OR "multi agent") AND ("simulation" OR "modelling" OR "modelling")	6360	5029	2014	27,148	11,885	41,736
B	"Supply chain" OR "supply chains"	44,606	9774	23,230	43,972	23,100	144,682
C	"Agriculture" OR "agricultural" OR "food" OR "agri-food" OR "livestock" OR "fisheries"	276,808	1139,158	116,263	1877,194	716,254	4125,677
D	B AND C	13,608	2000	1849	16,035	2444	35,936



**Fig. 1.** PRISMA flow diagram of the data collection process.

merit further research using ABS. Our review is complementary to earlier reviews of the application of ABS in related agriculture fields. These include the environment (Kelly et al., 2013), climate adaptation (Berger & Troost, 2014) and land use (Matthews, Gilbert, Roach, Polhill, & Gotts, 2007; Robinson et al., 2007). Furthermore, we demonstrate how bibliographic mapping can supplement a conventional literature review to identify research opportunities for the application OR/MS techniques.

Initially, we describe our literature search methodology (in Section 2). We then present an overview of the application of ABS in ASC based on our literature review and discuss the models and modelling approaches reported. In particular, the modelling objectives, application context, models (inputs, outputs, actors, rules and interactions), output analysis, experimentation, validation and model representation are discussed (in Section 3). Subsequently, we present a bibliographic mapping analysis and discuss the ASC topics that are yet to be addressed by ABS researchers (Section 4). Finally, we present the conclusions of this literature review in Section 5.

## 2. Method

The literature search employed the following databases: ABI/INFORM, Academic Search Complete, Business Source Complete, Science Direct and Web of Science. We restricted the search to articles published in international peer-reviewed journals that were written in English and published before February 2016. The keywords used in literature search and the results returned from

the search are presented in Table 1. The keyword search was applied to the content of the articles (i.e., not limited to title and abstract only).

The approach taken for the literature review is illustrated in Fig. 1 using a PRISMA four-phase flow-diagram (Moher, Liberati, Tetzlaff, Altman, & PRISMA Group, 2009; Vrubel, 2015). It begins with Dataset D from Table 1. Dataset D contains articles relating to ASC. Duplicate articles along with editorials, news, announcements, proceedings and dissertations were removed to create dataset D1 comprising 16,538 articles. Dataset D1 would be used for the bibliographic mapping analysis and did not require further filtering.

From dataset D1, we searched for articles on ABS applications in ASC (i.e., using keyword "A and D"). The number of articles retained was 251. These articles were then screened individually to ensure relevance using the following criteria. Firstly, the article must be accessible to the wider academic community. Secondly, the article must feature a complete ABS model rather than simply an unimplemented conceptual ABS model. Thirdly, we excluded literature review papers. Fourthly, we excluded articles that focus only on nonhuman actors and articles in which the keywords only appear in the reference section. Finally, the article must address research questions related to supply chain topics (e.g., processes and production systems, inventory management, demand management and improving the performance in the supply chain (Oliveira, Lima, & Montevechi, 2016) and include one or more ASC actors (e.g., producers, harvesting and transport, food processor and storage, packaging and handling, distributors, retailers, consumers, and waste management). Similar to

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