Proceedings of the 2019 Winter Simulation Conference
N. Mustafee, K.-H.G. Bae, S. Lazarova-Molnar, M. Rabe, C. Szabo, P. Haas, and Y.-J. Son, eds.

A POST-BREXIT TRANSPORTATION SCENARIO ANALYSIS FOR AN AGRI-FRESH PRODUCE SUPPLY CHAIN

Amr Mahfouz
Declan Allen
Amr Arisha

3S Group, College of Business
Technological University Dublin
Aungier St.
Dublin 2, IRELAND

Ralf Elbert
Michael Gleser

Chair for Management and Logistics
Technische Universitt Darmstadt
Hochschulstrae 1
64289 Darmstadt, GERMANY

ABSTRACT

The ever-increasing demand for fresh and healthy products initiated an urgency for effective planning for Agri-Fresh Produce Supply Chains (AFPSC). However, AFPSC faces many challenges, including product vulnerability to market disruption and limited shelf-life. In case of a no-deal Brexit (i.e., the UK leaving the EU without an agreement), trade between Ireland and the UK will most probably be subjected to customs control. In effect, transportation delays and products deterioration rates will increase. Based on interviews with an Irish AFPSC forwarder, a simulation model was developed to investigate different systems' dynamics and operating rules under different delay patterns on the (yet non-existent) inner-Irish border. A cost analysis of varying border regimes favours a more thorough change in operations, e.g., route adjustments. This paper gives a first indication on how AFPSC forwarders in Ireland can deal with a no-deal Brexit situation.

1 INTRODUCTION

Trade policy exerts a powerful influence on the transportation and logistics activities in today's global food supply chain. One pre-eminent risk is the harmful effect of the changes in trade agreements, customs declarations, rules of origin regulations, and food-specific tests on products' availability and perishability (Bakker and Nikhil 2018). Evidence suggests that any trade regime that introduces friction trade is likely to cause a leap in customer demand, increase food prices (particularly of fresh-produce products), and create an uncertain business environment for the sector's decision makers (Seferidi et al. 2019).

Brexit is expected to have profound implications on food movement between the Republic of Ireland (RoI) and the United Kingdom (UK), including Northern Ireland (NI) (McFarlane et al. 2018). At the moment, food movements between RoI and NI are relatively straightforward since supply chains are highly integrated and operate on a whole island basis. The UK landbridge (the UK road network) provides Irish business with a significant competitive advantage in terms of frequency and transit time with a high degree of transportation reliability (Vega and Evers 2016). Applying custom checks along RoI/NI borders will significantly increase the transportation cost and deterioration rates of the products. Maintaining a low deterioration rate is critical for the product market value, customer acceptability, and food safety (Nakandala et al. 2016). The Organisation of Economic Corporation and Development (OECD) advised that increasing transportation delays and costs will cause a boost in trade transaction costs by up to 24% of the value of products (OECD, 2013). This figure is likely to increase in the case of fresh-produce supply chains where limited shelf life is a substantial characteristic of all products. Hence, food supply chain professionals in Ireland have to find answers to critical questions regarding the future of their business

978-1-7281-3283-9/19/$31.00 ©2019 IEEE

practices, core operating models, supplier relationships, transportation and logistics strategies, and supply chain design after Brexit to mitigate the Brexit impact. It is vital that evidence-based scenario planning is quickly initiated so that new transportation and logistics strategies are evaluated to cope with post-Brexit disruptions. To date, most publications address Brexit from an economic and financial perspective and investigate its impact on the trade flow between Ireland and the UK at a macroeconomic level (Vega et al. 2018). Few studies explored the operational effects of re-introducing border controls between RoI and the UK and the potential delays in product delivery and the increase in shipping costs. Moreover, simulation technology is rarely used in the Brexit context although it offers a powerful tool to develop and manage various operational alternatives and strategic policies to realise desired levels of cost, quality of service, and environmental impact.

Hence, this paper aims to fill this research gap by introducing a hybrid-simulation model that integrates Discrete Event Simulation (DES) and Agent-Based Modelling (ABM) to model different transportation decisions of AFPSC between RoI and NI under different Brexit scenarios. The model will mimic the dynamics and complexity of the transportation system to investigate the impact of truck delays on the borders on product shipping, operating and waste costs.

2 LITERATURE REVIEW

Previous research efforts addressed different Brexit risk factors associated with the trade flow between RoI and the UK, political implications, financial systems, energy and climate policies (Bergin et al. 2017; Lawless and Morgenroth 2019; Pollitt and Chyong 2017; Samitas et al. 2018). It was noted that a number of UK and global agencies including UK Treasury, European Commission (EC), OECD, and International Monetary Fund (IMF) employed macroeconomic models to understand the economic consequences of Brexit including Computable General Equilibrium model (CGE) (Siles-Brgge 2019), Dynamic Stochastic General Equilibrium model (DSGE) (Driffield and Karoglou 2019), and Econometric Trade Models (Bruno et al. 2016). These models simulated the medium- and long-run impacts of Brexit on trade flow, foreign direct investment (FDI), migration and exchange rate fluctuation. On the other hand, supply chain modelling is rarely used in the Brexit context despite business vulnerability to the expected changes in trade agreements, product flow, transportation routes, and jurisdiction's laws and regulations post-Brexit. For instance, an efficient stated preference experience model was conducted to choose between two maritime routes from RoI to Europe; one with products shipped through the UK landbridge and the other with a direct route to Europe (Vega et al. 2018). In another study, Brexit has shown a negative impact on the performance of the logistics in the UK compared to their counterparts in the EU (Tielmann and Schiereck 2017). The authors used event study methodology and regression analysis and concluded that air transportation companies are affected by being not a part of several flight agreements. The impact of Brexit was also extended to Asian manufacturers and supply chain design. Nakamura et al. developed a supply chain modelling using mixed integer programming illustrating that Asian manufacturers have to think in restructuring their supply chain configurations after Brexit if custom duty rates are increased (Nakamura et al. 2019).

In the AFPSC context, modelling logistics and transportation systems has received increasing attention in the literature to optimise cost, time and product flow (Seuring 2013; Zhang et al. 2012). Unlike other industries' supply chains, AFPSC concerns specifically with the transportation performance and food quality measures (Akkerman et al. 2010). Diverse Management Science techniques were used for modelling fresh-food transportation cost and food deterioration rate. For instance, a taboo search algorithm was used to investigate the influence of the change in food quality on the cost function of a cold chain food distribution system (Zhang et al. 2003). The travel time between clients' locations was also addressed in solving a vehicle routing problem (VRP) for a fresh product distribution network (Osvald and Stirn 2008). Other techniques that were also used to model AFPSC include Genetic Algorithm (GA) (Altiparmak et al. 2006), Fuzzy Logic Guided GA (Lau et al. 2010), Linear Programming (Nadal-Roig and Pla-Aragones 2015), Non-Linear Programming (Amorim et al. 2012), and Hybrid Optimisation models (Blackburn and Scudder 2009).

Many authors utilised simulation to effectively model the behaviour of agri-food supply chains and to predict their responses to the trade and environmental policy changes (Crainic et al. 2018). For instance, a Dynamic Simulation model was utilised to evaluate different alternatives of management strategies, maximising the net present value of orchard (Hester and Cacho 2003). Morande and Maturana introduced a simulation-based decision support system that allowed winemakers to make decisions regarding the pick grapes, allocate wine presses and manage warehouse operations (Morande and Maturana 2010). Ampatzidis et al. optimised resource allocation (e.g., machinery and labours) in the harvesting process of fresh fruits using simulation and queuing theory (Ampatzidis et al. 2014). However, few studies were found applying simulation to model the distribution and transportation systems of AFPSC in the Brexit context (de Keizer et al. 2015; Soysal et al. 2015). In the Brexit context, a case study was published based on a simulation model to investigate the economic impact of applying hard borders between RoI and NI on a fresh produce supply chain on the financial and operational levels (Mahfouz and Allen 2018).

3 HARD BORDERS IMPLICATIONS ON FRESH-PRODUCE SUPPLY CHAIN

3.1 Case Study

ABC Transport was founded in 1996 with one refrigerated vehicle operating from Galway. Now, the company has become the first logistics company in Ireland to be awarded the prestigious BRC accreditation for the cross-docking and distribution of chilled and frozen food. With a modern fleet containing more than 75 trucks and 100 trailers, ABC entered the European market offering a wide variety of logistics services including supermarket distribution, warehousing, seafood logistics, container and road tanker transportation. The company reinforced its position in the UK through full Fast Moving Consumers Goods (FMCG) temperature controlled delivery networks that distribute chilled, frozen and ambient products from the 32 Irish counties to all UK supermarket distribution centres. The company collects fresh-products and shellfish from all Irish counties (e.g., North Donegal, South Kerry) and brings them along into a hub in Dublin Port for cross-docking and moving to the UK and European market through the UK landbridge.

3.2 Problem Definition

In the event of no agreement between the UK and EU, trade between Ireland and the UK will, most probably, be subject to custom controls. An increase in logistics cost and transportation lead time would be inevitable. Company managers stated that having hard borders between the RoI and NI is a real risk for business since there is currently much traffic across the borders and any transportation delay will bring harmful impacts on the deterioration rate of the products and customer satisfaction. Therefore the company's managers found themselves facing increasing pressure to adopt new strategies and contingency plans to the critical transportation route between RoI and NI for distributing fresh salads and vegetables. The product pallets are loaded in Dublin Port and transported to Belfast in NI. The trucks are then moved from Belfast to Killyleagh, which is about an hour and a quarter from Belfast, for reloading with fresh products that are brought down to Dublin Port for Cross Docking. After that, trucks are headed down to a customer's central distribution hub in Mitchelstown (Cork, RoI). Figure 1 visualises the route studied.

Company's clients in Belfast and Mitchelstown apply firm picking cut-off times that if the transport team could not satisfy, the orders are struck off causing a considerable knock-on effect in terms of products waste and shipping cost. Moreover, EU law regulates the driving time of professional drivers using goods vehicles over 3.5 ton (including trailers) by 9 hours daily with 45 minutes mandatory break after 4.5 hours driving. With the existence of customs checks and the potential delay on the borders, the company faces significant challenges to meet the tight cut-off time with only one driver. By participating in this research, the company is seeking to understand better the implications of the hard border on this transportation route and what impact that would have on products delivery, shelf-life and any additional cost to the business.

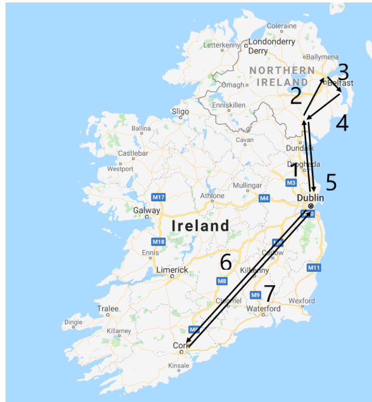


Figure 1: Investigated standard route.

4 HYBRID SIMULATION MODEL

4.1 Conceptual Modelling

Integrated Definition Language (IDEF) is used to model the logic of the studied transportation route conceptually. It provides an intuitive but structured set of modelling capabilities to facilitate the communication between the modellers and business partners (Menzel and Mayer 1998). The existence of a unified syntax and semantic of modelling helps to avoid a misunderstanding in developing system logic and to integrate different modelling perspectives, including process modelling, agent-based structure, and information flow.

The activities' Input, Output, Controls, and Mechanisms are presented by vertical and horizontal arrows, as shown in Figure 2. Activities' control can be documentation, regulations and process parameters, whereas Mechanisms represent the agents and resources that facilitate the execution of the operations. The

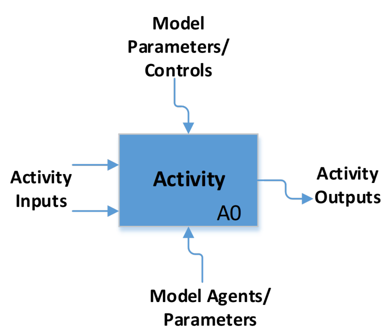


Figure 2: IDEF concept.

process starts with receiving job orders from the company's clients to transport fresh and seafood products to different destinations in NI. For simplification, a new order is triggered every day containing the required products quantities, customers' locations, and the agreed cut-off delivery time. The planning team then plans for delivery by assigning the trailer types that suit the nature of products (e.g., Multi-Temp Controlled Trailer, Skeletal Trailer, Drawbars), and determining the start time of the truck's loading based on products quantities, delivery locations and the defined cut-off time. Subsequently, checking documentation is taking place before the start of the journey where shipping bills, invoices, contracts, export documentation and driver's tachograph (i.e., instruments that measure the amount of time a driver is on the road) are tested.

The journey is then started according to the transportation route in Figure 1. Trucks are loaded at Dublin port with destination to Belfast, NI - crossing the (yet non-existent) inner Irish border at Newry. After arriving at Belfast, the load is cleared, and the empty truck continues to Killyleagh where it is loaded again. After finishing truck loading, it heads back to Dublin port crossing the border once more at Newry. At Dublin Port, the load needs to be cross-docked to a larger truck with several other fresh produce. The loaded truck then heads for a round trip to Mitchelstown (near Cork) to supply a supermarket with the delivered products. The tour finishes at the starting point of Dublin port. The sequence of activities along with the involved inputs, outputs, resources, and controls is modelled in an IDEF0 map shown in Figure 3.

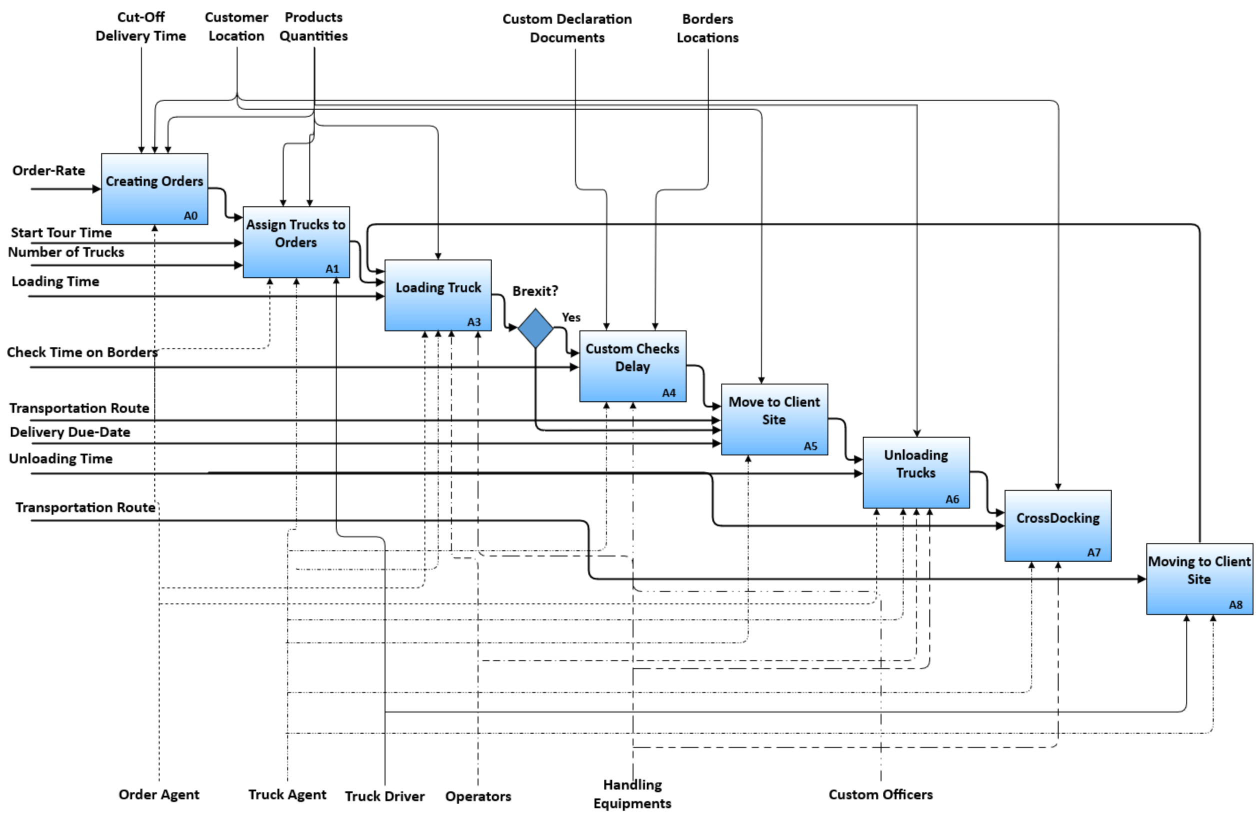


Figure 3: IDEF model.

4.2 Data Collection and Analysis

The model's input variables were grouped into four main categories; (1) Order/Shipping, (2) Routing/Transportation, (3) Products Delivery, and (4) Cost elements. The model investigated the system performance in terms of Customer Service Level, Products Quality, and Operating Cost. Figure 4 gives an overview of the input parameters. The primary data was collected based on several interviews with the company's operations manager and on-site observations. Within the parameter variation experiment, the waiting time at the border (**timeOnBorder**) was adjusted in 0.1 steps ranging from 0 to 5 hours waiting time at the border. A uniform distribution was selected to model the stochastic nature of the loading/unloading and cross-docking operation times with 1.5 2.5 hours and 2 4 hours respectively. The use of the uniform distribution is supported by the operations manager and own rough measurement observations on site. According to the operations manager, the studied transportation route experiences less variation compared to the other routes run by the company due to the straightforward supply chain design between RoI and NI under the current border's arrangement. This design explains the constant rates identified for the rest of the input variables, as shown in Figure 4.

	Category	Variable	Model Identification	Initial Values
Input Parameters	*Orders/Shipping*	Order Rate (Order/Day)	***orderRate***	1 Order/Day
		Number of Pallets Per Truck	***numberPallet***	33 Pallet/Truck
		Trucks Loading/Unloading Times	***loadingTime/ unloading Time***	Uniform (1.5 – 2.5 h)
		Cross-Docking Time	***crossDockingTime***	Uniform (2 - 4 h)
	Routing/Transportation	Delays on Border between ROI & NI	***timeOnBorder***	0-5h (.1 Step)
		Trucks Speed	***maxSpeed***	80 km/h
		Time of Driving for One Driver	***routeDrivingTime***	9 h
	Products Delivery	Delivery Cut-off Time at Client Site (Belfast, Killyleagh, Dublin Port, Mitchelstown)	***clientDueDate***	BEL: 02:00 am KIL: 08:00 am DUB: 12:00 pm MIT: 4:00 pm
	Cost Elements	Truck and Overhead Cost	***costPerShipping***	700€/Truck
		Extra Driver Cost	***costExtraDriver***	300€/Truck
		Waste Cost per Pallet	***costPerPallet***	19€/Pallet
Outcomes	*Customer Service*	**Tardiness Products**: Amount of Time Exceeding Cut-off Time		***overDueTimeCity***
	Product Quality	**Waste Cost**: Cost of Products Waste at all Cities		***lostCCity***
	Operating Cost	**Shipping Cost**: Cost of Hiring Extra Driver + using Extra Truck		***costExtraDriver costPerShipping***

Figure 4: Input parameters for model.

4.3 Model Scenarios

Based on the interviews conducted, different strategies were identified to deal with a hard inner-Irish border. These strategies were then incorporated into three distinct scenarios used for analysis. The first scenario is keeping up the operation as is with one truck driving the round-trip Dublin-Belfast-Killyleagh- Dublin and the route Dublin-Cork-Dublin. The second investigated scenario is adding an extra driver to the truck for the standard route. The rationale behind this is to avoid the mandatory 45min driving break after 4.5h driving (border waiting time included) and the daily driving limit of 9h. After cross-docking, we assume the use of another fresh driver. The third scenario uses two trucks, whereas one truck starts in Dublin for Belfast, the other truck starts to get loaded in Killyleagh from 2 am and starts its tour to Dublin after loading. This way the first cyclical tour can be avoided at the cost of paying for two trucks. The adjusted route is visualized in Figure 5.

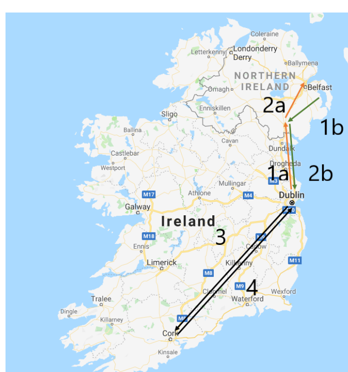


Figure 5: Investigated two truck route.

4.4 Mathematical Formulation

The primary goals of the forwarder are improving the quality of delivery (as measured in arrival on time) and minimising the total transportation cost. In total, four destinations need to be reached on time in the order Belfast, Killyleagh, Dublin Port and Cork. Transportation cost is, on the one hand, depending on the fixed costs due to the chosen operational mode and on the other hand due to waste costs at delayed delivery. Waste cost is calculated as the number of pallets loaded times the price for the loaded pallets. We don't discriminate between the locations for the waste cost, so for late arrival waste cost is the same for every site. The cost function, therefore, consists of a fixed operational cost part and the variable waste cost part.

$$Cost_{total} = (1+x)*Cost_{truck} + y*Cost_{extraDriver} + (a+b+c+d)*Cost_{waste}$$

$x = 1$ if using two truck route, 0 if not.
$y = 1$ if having an extra driver, 0 if not.

$a = 1$ if overdue in Belfast, else 0.
$b = 1$ if overdue in Killyleagh, else 0.
$c = 1$ if overdue in Dublin Port, else 0.
$d = 1$ if overdue in Cork, else 0.

4.5 Simulation Experiment

For building and running the simulation model, the software AnyLogic 8 was used. Every day at 9 pm a new order is triggered within the model, and a truck is driven to fulfil it. In the case of the two truck route, another truck appears at 2 am in Killyleagh to start its tour. The data collection is done using a parameter variation experiment, whereas the waiting time at the border was varied in 0.1h steps ranging from 0 to 5 hours. in addition to the border waiting time, different runs were undertaken for the extra driver and two truck route scenario. Each simulation within the parameter variation experiment was run for 100 days.

5 EXPERIMENT OUTCOME ANALYSIS

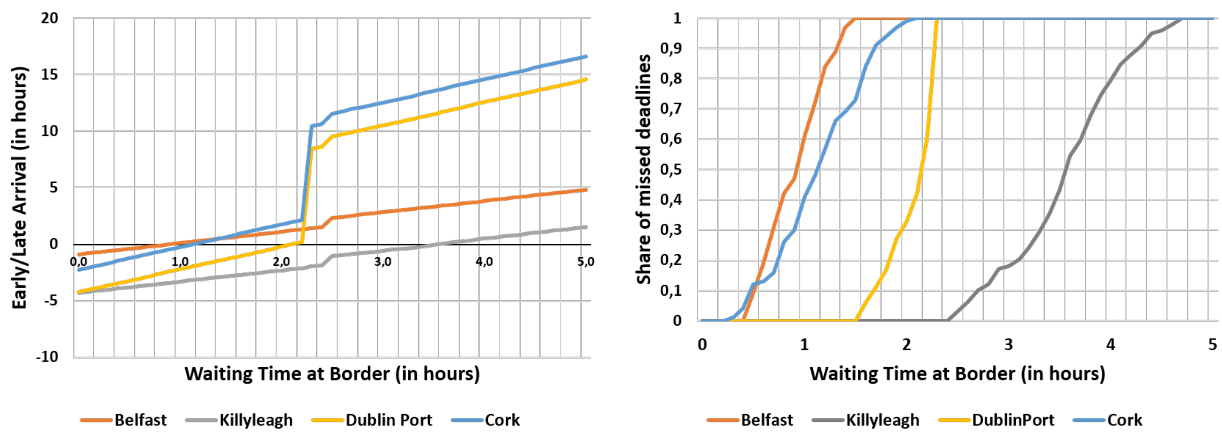
The collected data were analysed for two dimensions. The analysis of the overdue delivery allowed us to get a closer look at different waste cost drivers under different scenarios. The total cost analysis allowed for making strategic decisions regarding possible post-Brexit changes.

5.1 Overdue Analysis

An overdue analysis was conducted for each of the three scenarios. Within the three scenarios, the total truck lateness, early arrival, and the percentage of the deadlines missed were analysed for different border waiting times.

5.1.1 Standard Route

The impact of the variations in the trucks' waiting time for the standard route is displayed in Figure 6. With no modifications in the border waiting time, the delivery deadlines in the four cities are quite tight. This behaviour can be seen in the close arrival time to the due time in Belfast. With a longer waiting time on the borders, the delay in the arrival times increases linearly up to the border waiting time of around 2.2h at which point the daily allowed driving time limit is reached, and an 8 hours break needs to be taken by the driver. This delay doesn't affect the waste costs though as for the first three sites, all due delivery times are already missed. The waste percentage of the different locations start to increase from different border waiting times whereas the waste at Cork and Belfast react fastest with border waiting time.

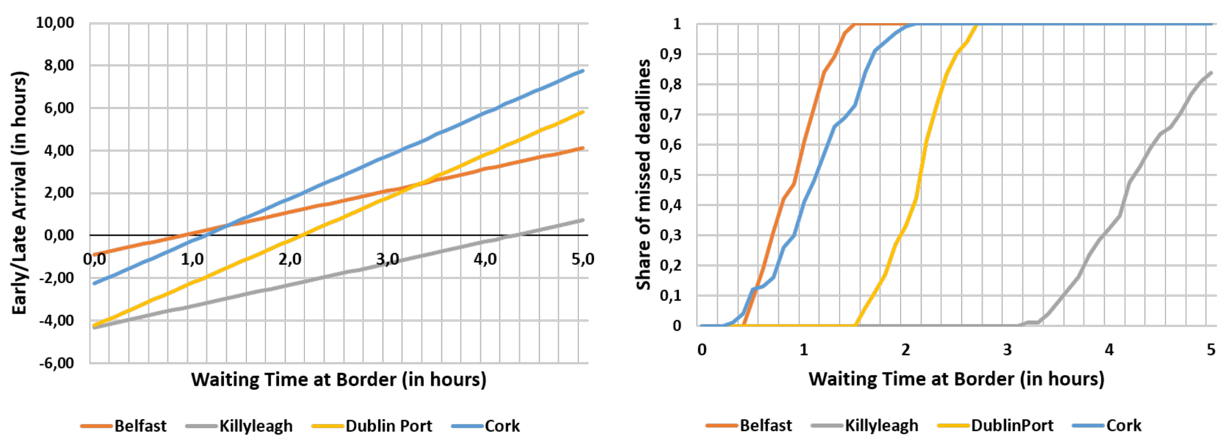


(a) (b)

Figure 6: Standard route scenario: (a) arrival times, (b) waste (%).

5.1.2 Extra Driver

Adding a second driver to avoid driving restrictions leads to a change in arrival times, as shown in Figure 7. An additional driver on the truck smooths out the arrival times to increase linearly with the increase of waiting times on the borders. The arrival times for Dublin Port and Cork increase with double the gradient as the truck has to cross the border twice. The waste percentage at the different locations looks similar to the one driver scenarios in case of the low waiting times (below 2.2h) but increases slower after that. This behaviour can be explained due to the avoidance of reaching the 9h driving limit per day.

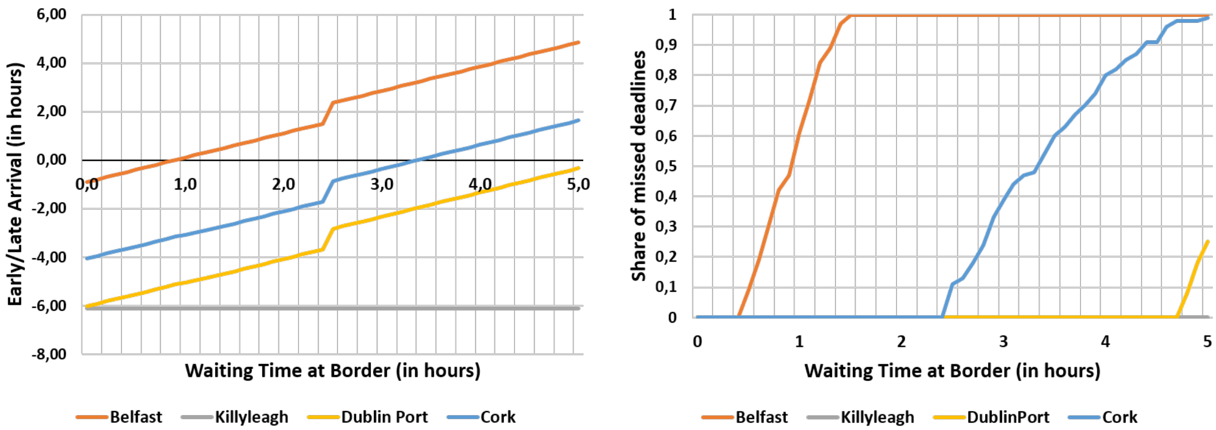


(a) (b)

Figure 7: Extra driver scenario: (a) arrival times, (b) waste (%).

5.1.3 Two Truck Route

Having an additional truck on the road leads to a change in the route driven and the system's performance, see Figure 8. Whereas the single truck scenario operates two round-trips starting from Dublin Port, the two truck scenario splits the tour having a Dublin Port to Belfast and a Killyleagh to Dublin Port tour. Therefore the truck can never arrive late at Killyleagh as this part of the journey is not driven. We assume the second truck to start loading on time at Killyleagh from 2 am. All arrival times increase linearly in this scenario, even with the same gradient up until a 2.4 h waiting time where the driving limit of 4.5h is reached, and the driver needs to rest for 45 min. This scenario caused the small jump in the graph at hand. For the waste percentage, the Belfast case does not change much compared to the single truck scenario, whereas deploying two trucks has definite advantages at the other destinations in Dublin Port and Cork. A two truck scenario, therefore, can tolerate much higher border waiting times.



(a) (b)

Figure 8: Two truck route scenario: (a) arrival times, (b) waste (%).

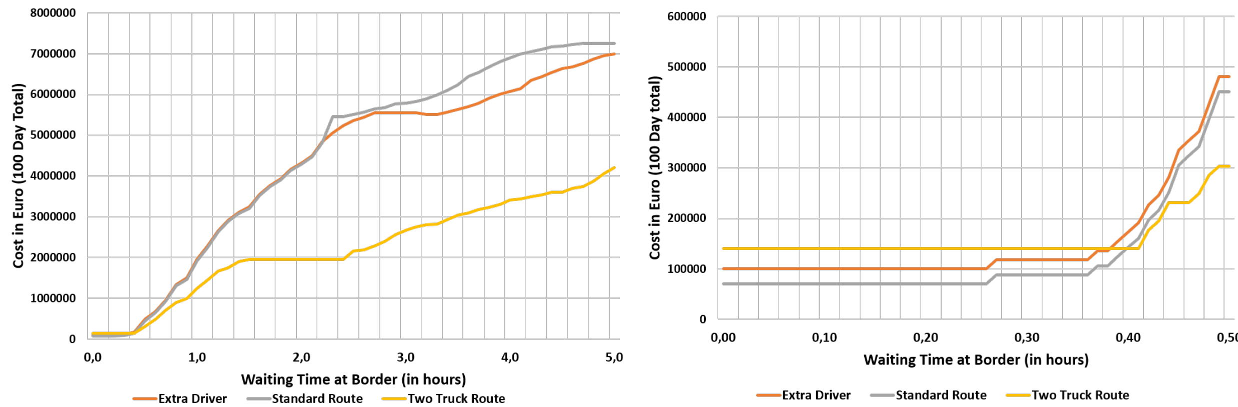
5.2 Total Cost Analysis

Bringing together all three scenarios in Figure 9 the differences in total cost occurred can be analysed. As the graphs for low border waiting times (especially below 0.5h) are running at a similar value, additional analysis for this part of the figure is undertaken. With an increase in border waiting times, the two truck scenario has the advantage of about 0.5h waiting time on borders. The additional fixed cost is compensated by much lower waste cost. The extra driver scenario shows its advantage at about 2.3h border waiting time outperforming the standard scenario as it runs into daily driving time limitations, leading to a jump in missed deadlines and increased total cost.

Taking a closer look at the increases in total cost when assessing the range from 0 to 0.5 h border waiting time in 0.01 h steps the standard scenario is an advantage up until around 0.40 where the two truck route scenario beats it. Even small waiting times add up to the total costs significantly and should be considered when finding possible strategies for dealing with a post-Brexit scenario.

6 IMPLICATIONS, LIMITATIONS AND CONCLUSION

This paper has studied a scenario-mapping simulation based on a case study from an Irish Agri-Fresh Produce Supply Chain forwarder in a post-Brexit case. A hard inner-Irish border has severe consequences for service quality and overall cost of the studied forwarder. Within the reviewed scenarios, different border waiting times were assessed. The standard tour scenario (i.e. single-truck scenario) is hereby superior only up to 24min (0.4h) waiting time at the border. From that point on using two trucks becomes beneficial regarding cost. Having an additional driver on board (to avoid driving time restrictions, ironically by EU regulation) does not seem feasible for the studied case. For the forwarder at hand, simple changes to the operations, therefore, don't seem feasible regarding total cost occurring. Rather a change in transportation routes, different truck deployment and negotiations with customers should be assessed.



(a) (b)

Figure 9: Total cost for all scenarios: (a) total cost (overall), (b) total cost (focused).

The simulation model has several limitations to be noted when assessing its practical implications. The loading and unloading times at the different locations follow a uniform distribution, having minimum and maximum values set prior to the simulation run. These factors could be influenced as well with the use of additional staff or optimisation of processes. To incorporate these limitations, it is necessary to collect additional data and theoretical background for different optimisation scenarios. Using a different distribution (e.g., normal distribution) might lead to a more realistic case as well but needs to rely on more fundamental statistical data than provided in the interviews that lead to the model at hand.

With the postponement of the definite Brexit date and the sword of Damocles of a no-deal Brexit hanging over the Irish island, Irish forwarders need to be prepared for potential outcomes of different Brexit scenarios. The work at hand hereby gives a first investigation on how to deal with a hard inner-Irish border and occurring waiting times at the border. With tight deadlines and threatening waste costs in the agri-fresh produce supply chain, a post-Brexit border regime could be threatening to the business operations of cross-border forwarders. As long as no definite post-Brexit agreement has been found between EU and UK, further research should focus on investigating factors that could be influenced by the forwarder at hand (e.g., loading/unloading times), to be prepared for all eventualities.

ACKNOWLEDGEMENTS

We would like to express our gratitude to the Freight and Transportation Association Ireland (FTA), in particular Mr. Aidan Flynn for his support for the research, especially the phases of collecting data, conceptual modeling and system analysis.

REFERENCES

Akkerman, R., P. Farahani, and M. Grunow. 2010. “Quality, Safety and Sustainability in Food Distribution: A Review of Quantitative Operations Management Approaches and Challenges”. *OR Spectrum* 32(4):863–904.

Altiparmak, F., M. Gen, L. Lin, and T. Paksoy. 2006. “A Genetic Algorithm Approach for Multi-objective Optimization of Supply Chain Networks”. *Computers Industrial Engineering* 51(1):196–215.

Amorim, P., H.-O. Gnther, and B. Almada-Lobo. 2012. “Multi-Objective Integrated Production and Distribution Planning of Perishable Products”. *International Journal of Production Economics* 138(1):89–101.

Ampatzidis, Y. G., S. G. Vougioukas, M. D. Whiting, and Q. Zhang. 2014. “Applying the Machine Repair Model to Improve Efficiency of Harvesting Fruit”. *Biosystems Engineering* 120:25–33.

Bakker, J. and D. Nikhil. 2018. “Hard Cheese? Dairy Products will be More Expensive after Brexit.”. https://blogs.lse.ac.uk/brexit/2018/08/06/hard-cheese-dairy-products-will-be-more-expensive-after-brexit/, accessed 30th April.

Bergin, A., A. Garcia-Rodriguez, E. Morgenroth, and D. Smith. 2017. "Modelling the Medium- to Long-Term Potential Macroeconomic Impact of Brexit on Ireland". *The Economic and Social Review* 48(3):305–316.

Blackburn, J. and G. Scudder. 2009. "Supply Chain Strategies for Perishable Products: The Case of Fresh Produce". *Production and Operations Management* 18(2):129–137.

Bruno, R., C. Nauro, E. Saul, and T. Meng. 2016. "Technical Appendix to The Impact of Brexit on Foreign Investment in the UK Gravitating towards Europe: An Econometric Analysis of the FDI Effects of EU Membership.". http://cep.lse.ac.uk/pubs/download/brexit03_technical_paper.pdf, accessed 30th April.

Crainic, T. G., G. Perboli, and M. Rosano. 2018. "Simulation of Intermodal Freight Transportation Systems: A Taxonomy". *European Journal of Operational Research* 270(2):401–418.

de Keizer, M., R. Haijema, J. M. Bloemhof, and J. G. van der Vorst. 2015. "Hybrid Optimization and Simulation to Design a Logistics Network for Distributing Perishable Products". *Computers & Industrial Engineering* 88:26–38.

Driffield, N. and M. Karoglou. 2019. "Brexit and Foreign Investment in the UK". *Journal of the Royal Statistical Society: Series A (Statistics in Society)* 182(2):559–582.

Hester, S. M. and O. Cacho. 2003. "Modelling Apple Orchard Systems". *Agricultural Systems* 77(2):137–154.

Lau, H. C. W., T. M. Chan, W. T. Tsui, and W. K. Pang. 2010, April. "Application of Genetic Algorithms to Solve the Multidepot Vehicle Routing Problem". *IEEE Transactions on Automation Science and Engineering* 7(2):383–392.

Lawless, M. and E. L. W. Morgenroth. 2019. "The Product and Sector Level Impact of a Hard Brexit across the EU". *Contemporary Social Science* 14:1–19.

Mahfouz, A. and D. Allen. 2018. "Brexit: Preparing for the Worst Scenarios". In *Proceedings of the 2018 Winter Simulation Conference*, edited by M. Rabe, A.A. Juan, N. Mustafee, A. Skoogh, S. Jain, and B. Johansson, 4115–4116. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

McFarlane, G., T. Lewis, and T. Lang. 2018. "Food, Brexit and Northern Ireland: Critical Issues". Working paper, London, UK.

Menzel, C. and R. J. Mayer. 1998. *The IDEF Family of Languages*, 209–241. Berlin, Heidelberg: Springer.

Morande, H. and S. Maturana. 2010. "Design and Validation of a Decision Support System for Oenologists". *Revista ICHIO* 1:46–58.

Nadal-Roig, E. and L. M. Pla-Aragones. 2015. *Optimal Transport Planning for the Supply to a Fruit Logistic Centre*, 163–177. New York: Springer.

Nakamura, K., T. Yamada, and K. H. Tan. 2019. "The Impact of Brexit on Designing a Material-Based Global Supply Chain Network for Asian Manufacturers". *Management of Environmental Quality: An International Journal* 5(30):980–1000.

Nakandala, D., H. Lau, and J. Zhang. 2016. "Cost-Optimization Modelling for Fresh Food Quality and Transportation". *Industrial Management & Data Systems* 116(3):564–583.

Osvald, A. and L. Z. Stirn. 2008. "A Vehicle Routing Algorithm for the Distribution of Fresh Vegetables and Similar Perishable Food". *Journal of Food Engineering* 85(2):285–295.

Pollitt, M. G. and K. Chyong. 2017. "Brexit and Its Implications for British and EU Energy and Climate Policy.". https://www.cerre.eu/publications/brexit-and-its-implications-british-and-eu-energy-and-climate-policy, accessed 30th April.

Samitas, A., S. Polyzos, and C. Siriopoulos. 2018. "Brexit and Financial Stability: An Agent-based Simulation". *Economic Modelling* 69:181–192.

Seferidi, P., A. A. Laverty, J. Pearson-Stuttard, P. Bandosz, B. Collins, M. Guzman-Castillo, S. Capewell, M. O'Flaherty, and C. Millett. 2019. "Impacts of Brexit on Fruit and Vegetable Intake and Cardiovascular Disease in England: A Modelling Study". *BMJ Open* 9(1):1–8.

Seuring, S. 2013. "A Review of Modeling Approaches for Sustainable Supply Chain Management". *Decision Support Systems* 54(4):1513–1520. Rapid Modeling for Sustainability.

Siles-Brgge, G. 2019. "Bound by Gravity or Living in a 'Post Geography Trading World'? Expert Knowledge and Affective Spatial Imaginaries in the Construction of the UKs Post-Brexit Trade Policy". *New Political Economy* 24(3):422–439.

Soysal, M., J. M. Bloemhof-Ruwaard, R. Haijema, and J. G. van der Vorst. 2015. "Modeling an Inventory Routing Problem for Perishable Products with Environmental Considerations and Demand Uncertainty". *International Journal of Production Economics* 164:118–133.

Tielmann, A., and D. Schiereck. 2017. "Arising Borders and the Value of Logistic Companies: Evidence from the Brexit Referendum in Great Britain". *Finance Research Letters* 20(C):22–28.

Vega, A., and N. Evers. 2016. "Implications of the UK HGV Road User Charge for Irish Export Freight Transport Stakeholders – A Qualitative Study". *Case Studies on Transport Policy* 4(3):208–217.

Vega, A., M. Feo-Valero, and R. Espino-Espino. 2018. "The Potential Impact of Brexit on Ireland's Demand for Shipping Services to Continental Europe". *Transport Policy* 71:1–13.

Zhang, G., W. Habenicht, and W. E. L. Spie. 2003. "Improving the Structure of Deep Frozen and Chilled Food Chain with Tabu Search Procedure". *Journal of Food Engineering* 60(1):67–79.

Zhang, Q., H. Wang, and H. Liu. 2012. "4stage Distribution Network Optimization of Supply Chain with Grey Demands". *Kybernetes* 41(5/6):633–642.

AUTHOR BIOGRAPHIES

AMR MAHFOUZ is the team leader of supply chain research team at 3S Research Group, College of Business, Technological University Dublin (TU Dublin). Dr Mahfouz has received his PhD in operations and supply chain management from TU Dublin and he is currently a full-time lecturer in School of Management, TU Dublin. Amr has published several articles in prestigious journals and international conferences in the area of supply chain resilience, modelling and simulation, lean supply chain, and disaster management. His research interest includes supply chain resilience, lean distribution/warehousing, leanness assessment, and simulation modelling applications in business process analysis. His email address is amr.mahfouz@dit.ie.

RALF ELBERT is Professor at the Chair of Management and Logistics at the Department of Law and Economics at TU Darmstadt since 2011. Before he held the DB Schenker foundation chair for Logistics Services and Transportation at Technische Universitt Berlin from 2009-2011. His recent research interests include, among others, intermodal freight transportation, urban transportation, and intralogistics. His email address is elbert@log.tu-darmstadt.de. His website is https://www.log.tu-darmstadt.de.

MICHAEL GLESER is a research assistant at the Chair of Management and Logistics at the Department of Law and Economics at TU Darmstadt. He obtained his Master Degree at Technische Universitt Darmstadt in Business Information Systems. Among his research interests are the digitization of logistics services. His email address is gleser@log.tu-darmstadt.de.

DECLAN ALLEN received his MBS in Business Logistics and Manufacturing Strategy from The Michael Smurfit Graduate Business School UCD in 1996. He is the former Head of Department of Transport Engineering, Dublin Institute of Technology. Declan is currently the Assistant Head of School in the School of Management, College of Business, Technological University Dublin where he is Programme Director of the School of Management's BSc in Logistics and Supply Chain Management degree programmes, the MSc in Technology and Innovation Management and the newly established Logistics Associate Apprenticeship. He is a Fellow of the Chartered Institute of Logistics and Transport (UK) having served as Chair of the CILT Irelands Education Committee and as Council Member from 2004-2006. Declan has published numerous papers in journals and international conferences on automotive industry, logistics, and supply chain management. He is currently a registered DBA student with the Grenoble Ecole de Management, France. His email address is declan.allen@dit.ie.

AMR ARISHA is the Director of the 3S Group and the Head of International Business Department at College of Business, Technological University Dublin (TU Dublin). He received his PhD in Industrial Engineering from Dublin City University (DCU). Intel-Ireland has sponsored his research from 2000 - 2005. His research path is focused on the ultimate goal of developing an integrated solution framework leveraging existing mathematical and systems tools from a number of fundamental approaches including system analysis, value stream mapping, stochastic modelling, game theory, simulation, and optimization. His work places the quest for operations excellence at the heart of many contemporary challenges in applications such as healthcare, supply-chain management, production scheduling, and teaching/training. He is a member in IIE, IMECH, IEI, ESE, ORS, IEEE and ASME and Chief Examiner at MII. His email address is amr.arisha@dit.ie.