

Institution: Brunel University London		
Unit of Assessment: 12 Engineering		
Title of case study: Optimising Global Transportation Networks Using Meta-Heuristic Approaches		
Period when the underpinning research was undertaken: 2010-2015		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Dr Tatiana Kalganova	Reader	08/2000-present
Period when the claimed impact occurred: November 2016-December 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact (indicative maximum 100 words)

Dr Kalganova's research on Ant Colony Optimisation (ACO) has had significant impacts on the business performance, profitability and strategic planning of Caterpillar Inc., an American Fortune 100 corporation. Her work has been fully embedded in their network modelling and optimisation solutions, GEMSTONE, in November 2016 and has been used to design the logistics to manage supply chains for every Caterpillar product and component globally since then. This involves over 3,000,000 individual products and approximately 700,000 service parts globally. In the UK alone, GEMSTONE supports more than 7,000 employees and 30 production facilities that distribute products worldwide. Dr Kalganova's research has enabled GEMSTONE to constantly optimise their entire supply chain as well as their operations in near real-time (every 32 minutes). As it dramatically improves the supply network performance, GEMSTONE has delivered a significant reduction in transportation costs and transport time, contributing to the reduction of the company's overall environmental footprint since 2016.

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GEMSTONE is also used to deal with orchestrating their responses to emergencies (whether due to natural disasters or disruptions like fire) and to develop scenario-planning and analyse the impact of plausible futures (e.g. Brexit), reducing its modelling and reconfiguring total time of global supply chains to 24 hours from 2.5 weeks. This means Caterpillar has complete control over any situations and responds in a way that would ensure timely and profitable logistic solutions.

2. Underpinning research (indicative maximum 500 words)

Dr Kalganova specialises in optimisation of supply chains through the development of agile algorithms which gradually increase its capability of handling and optimising the complexity of BIG Data in the shortest possible computational time without compromising the quality of solutions. Since 2010, Dr Kalganova (then Lecturer) and Caterpillar's Global Technology team have been working to find a software solution that could scale up to the size of Caterpillar's network and deliver the most efficient supply network system. Unlike commercial software which typically is limited to about 1,000 connections between nodes represented by fixed transportation rates and transport times, a typical Caterpillar model has over 400,000,000,000,000,000 (400 quadrillion) connections that must be represented stochastically for each product.

Impact case study (REF3)

Dr Kalganova and her team demonstrated the superior behaviour of evolutionary strategy and Cartesian genetic programming, while being selected as a Finalist of demand strategy competition organised by Research and Innovation, Caterpillar Inc. in 2011-2012.

Subsequently, they have worked in collaboration to investigate the dynamics of more than 20 algorithms in order to sustain the quality of the solution while gradually increasing the dimensions of the optimisation. This resulted in the development of the hybrid supply chain modelling and optimisation.

In 2013-2014, through research funded by Caterpillar Inc, Dr Kalganova's team, in collaboration with research teams from Caterpillar and Bradley University, demonstrated that the evolutionary strategy applied to supply chain modelling is capable of discovering the solutions from the wide search space. The academic team demonstrated that the existing algorithms developed within the scope of transportation network optimisation are applied to significantly lower complexity problems in terms of number of nodes and edges used in comparison with the existing size of Caterpillar's supply chain network [Ref 1]. The systemic investigation into multi-objective algorithms demonstrated that the proposed superposition method significantly outperformed goal syntheses [Ref 2]. The results of the research led to the development of supply network optimisation method and system for multiple objectives, improving profit, service level and network resilience. In order to decrease the computational algorithmic effort, prediction of best termination condition has been developed and integrated into ant colony optimisation [Ref 3]. The method and system for managing supply chain networks with multiple supply layers included the development of the algorithmic foundation supporting multilayers. The strategies for mapping algorithmic structure into the hardware architecture has been proposed and investigated in depth [Ref 4].

3. References to the research (indicative maximum of six references)

- [Ref 1] Ogunbanwo A., A. Williamson, M. Veluscek, R. Izsak, T. Kalganova and P. Broomhead (2014) Transportation Network Optimization. Encyclopaedia of Business Analytics and Optimization, February 2014, Ed. John Wang. pp. 2570-2583. <http://doi.org/10.4018/978-1-4666-5202-6.ch229>
- [Ref 2] Veluscek M, Kalganova T, Broomhead P, Grichnik A (2015) Composite Goal Methods for Transportation Network Optimization Expert Systems With Applications, *Expert Systems with Applications*, 42 (8), 3852-3867 <https://doi.org/10.1016/j.eswa.2014.12.017>
- [Ref 3] Veluscek M, Kalganova T, Broomhead P (2015) Improving Ant Colony Optimization Performance through Prediction of Best Termination Condition, *2015 IEEE International Conference on Industrial Technology (ICIT 2015)*. <https://doi.org/10.1109/ICIT.2015.7125451>
- [Ref 4] Dzalbs I. and T. Kalganova (2020) Accelerating supply chains with Ant Colony Optimization across range of hardware solutions, *Computers & Industrial Engineering*, 147 (100610) <https://doi.org/10.1016/j.cie.2020.106610>

4. Details of the impact (indicative maximum 750 words)

Dr Kalganova's research on Ant Colony Optimisation (ACO) has led to significant economic impact. Her work has been fully embedded in the network modelling and optimisation solutions of Caterpillar Inc by November 2016 under the new name GEMSTONE (Generation and Evaluation of Manufacturing, Supply and Transportation Optimisation for Networks technology). GEMSTONE has been used globally to produce and deliver every Caterpillar product and

Impact case study (REF3)

component through constantly optimising and reconfiguring its entire global and local networks, maximising Caterpillar's profitability and network resilience without compromising service-level.

Impact on Business Performance and Profitability

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This involves more than 3,000,000 individual products and approximately 700,000 service parts. Approximately over 3,000 suppliers, 600 carriers, 100 facilities in over 20 countries, 4,500 transportation lanes and 3,000 dealer-owned facilities operate within the global supply chain of Caterpillar. In the UK alone, GEMSTONE supports more than 7,000 employees and 30 production facilities that make products that are distributed worldwide.

Dr Kalganova's research contribution to GEMSTONE has been '*fundamental*' to Caterpillar's profitability: it provides Caterpillar with an almost real-time optimisation, by helping how to optimise its supply chain from materials to a global network of suppliers, assembly locations, dealers and customers to maximise their profits. This proactive response gives a strategic advantage which has led to 'substantial improvements in both profitability and network resilience' [E1].

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Reducing Environmental Footprints

Carrying more than 90% of the world's trade, ships are responsible for 3% of greenhouse-gas emissions (equivalent to 1,000,000,000t). By burning heavy fuel oil, just 15 of the largest ships emit more of the noxious NOx than all the world's cars put together, making it a major source of air pollution. (Economist, 11 Mar 2017)

Given the size of Caterpillar, which relies heavily on maritime transports, its significant reduction in transport time within the global supply chain, achieved by GEMSTONE, means that it was able to reduce its CO₂e emissions as it is directly correlated to the transportation time/distance and the mode of transportation has not been changed. [E3] Although it is difficult to calculate the direct contributions to reducing its environmental footprint from GEMSTONE, Caterpillar was able to reduce its greenhouse gas emissions intensity since 2016: from 54.2 in 2016 to 46.4 in 2017, 40.4 in 2018 and 33 in 2019 (in metric tonnes of CO₂e per million dollars of revenue). (E6)

Impact on Business Strategy

The scale of profitability is possible because GEMSTONE can orchestrate its response to emergency and scenarios by reconfiguring networks in 24 hours. This means Caterpillar has complete control over any situations and responds in a way that would ensure timely and profitable logistic solutions.

Compared to 2011 when it took Caterpillar 2.5 weeks to assess the impact of Tsunami, in 2018 when Brexit was voted for, Caterpillar managed to model, optimise and reconfigure the overall global supply chain in 24 hours. [E4]

GEMSTONE has been used to estimate costs for various scenario modelling for Caterpillar Inc., and was immediately employed after the referendum in the UK in 2016 to assess the impact of Brexit, directly influencing their strategic management decisions. In 2018, a representative from Caterpillar acknowledged that "*The supply chain modelling technology integrated into Caterpillar business process developed by Brunel, ...helped to analyse, model, optimise and implement the global supply chain within 24 hours from the Brexit vote happening.*" [E5]

Impact case study (REF3)

This successful university-industry partnership was globally acknowledged by achieving Global Excellence in Analytics Award from the International Institute of Analytics in 2016 as well as being named one of the Top 3 2017 Global Innovative Applications in Analytics by INFORMS (The Institute for Operations Research and the Management Sciences). Both awards recognise organisations' dedication to using analytics to improve business results.

5. Sources to corroborate the impact (indicative maximum of 10 references)

All sources have been provided in PDFs except E5.

E1) Corroborating Letter 1 from Global Technology Leader, Global Supply Network, Caterpillar Inc.

E2) Corroborating Letter 2 from Global Technology Leader, Global Supply Network, Caterpillar Inc.

E3) Caterpillar Wins 2016 ANNY Excellence in Analytics Award, International Institute for Analytics honors Caterpillar for supply network optimization:
<https://www.prweb.com/releases/2016/09/prweb13725080.htm>

E4) Caterpillar became 2017 IAAA Finalist: Assurance of Supply Centre – Excellence through Supply Network Optimization: [2017 IAAA Finalist: Assurance of Supply Center – Excellence through Supply Network Optimization - INFORMS](#) and <https://www.youtube.com/watch?v=b0aWIFmSP88&feature=youtu.be>

E5) Caterpillar presentation on GEMSTONE Technology: <https://youtu.be/SLNUrGFkibg>

E6) Statista, Caterpillar's GHG emissions intensity worldwide 2006-2019 (4 May 2020) <https://www.statista.com/statistics/619610/ghg-emissions-intensity-of-caterpillar/>