Institution: Cardiff University

Unit of Assessment: Business and Management (17)

Title of case study: Developing financially sustainable national and international supply chains

Period when the underpinning research was undertaken: 2000 – 2020

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:
Aris Syntetos	Professor	01/09/2012 – present
Stephen Disney	Professor	20/11/1995 – 31/08/2019
Daniel Eyers	Senior Lecturer	01/08/2011 – present
Athanasios Gkoltsos	Lecturer	24/11/2014 – present
Mohamed Naim	Professor	01/10/1987 – present
Andrew Potter	Professor	01/08/2001 – present
Xun Wang	Senior Lecturer	01/03/2014 – present

Period when the claimed impact occurred: 01/08/2013 – 31/12/2020

Is this case study continued from a case study submitted in 2014? No

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

Due to demand uncertainty and the difficulties of modelling complex production and inventory systems, many companies suffer from excessive inventory levels, which results in financially unsustainable supply chains. Cardiff Business School researchers developed new forecasting, inventory control and production planning policies that helped companies reduce their immense investments in inventories. Cardiff's work with partner companies (DSV/Panalpina, Qioptiq, Lexmark, Accolade Wines and Yeo Valley) created multi-million-pound financial benefits through efficiencies, income growth, new contracts, and safeguarding and creating jobs. For example, DSV/Panalpina reported £50M in direct benefits, Yeo Valley reported £3M in cash and trading benefits, and Qioptiq secured an £82M contract, leading to job retention and creation.

2. Underpinning research (indicative maximum 500 words)

Accurately forecasting demand is vital for production and inventory decision-making and, subsequently, supply chain cost-effectiveness. These cause-and-effect connections seem straightforward to address, yet the total value of inventory in the US alone is equivalent to about 15% of its gross domestic product. This excess inventory results from companies keeping too much stock of some items, whilst simultaneously struggling to service customer needs due to insufficient stock of other items.

Excess inventory ties up working capital and raises the risk of obsolescence; insufficient inventory leads to stock-outs and missed sales. Eliminating inventories is not possible but setting minimum reasonable inventory levels is feasible and desirable. Solving this problem requires a systems approach; considering the combined, as well as individual, effects of forecasting, production, and inventory policies.

2.1 A generalisable policy for production planning

Cardiff research established the initial principles of a generic forecasting, production planning and inventory control approach. This was designed to support setting the 'right' inventory levels for companies facing uncertain demand, even when dealing with hundreds or even thousands of different products. The approach was developed through a sustained Cardiff-led research programme into a generalisable policy (and its variants), which underpins the operation of commercial Materials Requirements Planning (MRP) / Enterprise Resource Planning (ERP) systems **[3.1]**.

As part of the aforementioned research, an ESPRC-funded project (2001-2005) **[G3.1]** integrated, for the first time, lean thinking (the banishment of waste material and information)

with analysis of the systemic (dynamic) behaviour of supply chains. It highlighted the importance of the bullwhip effect (amplification of demand uncertainty as we move upstream in a supply chain, from a retailer to a distributor to a manufacturer through to original suppliers). The bullwhip effect creates uncertainty for decision makers and increases production and inventory holding costs **[3.2]**.

The researchers also investigated the dynamic implications of modern, e-commerce enabled, supply chain structures, such as vendor managed inventory (VMI), collaborative planning, forecasting and replenishment (CPFR) and efficient consumer response (ECR). In doing so, they identified the relative benefit of implementing lean manufacturing versus these other supply chain improvement strategies (VMI, CPFR and ECR) in certain contexts. This enables managers to select the most appropriate one depending on the circumstances **[3.3]**.

2.2 Deriving 'reasonable' solutions for inventory holding

Cardiff's research led to further new insights on the impact of ordering policies on supply chain behaviour, including that order-up-to (OUT, a commonly used inventory replenishment policy) will always generate bullwhip for all possible demand patterns, forecasting methods and lead-times **[3.2]**. The research team developed a generalised-OUT rule (proportional order-up-to, POUT) to generate smooth ordering patterns and eliminate the bullwhip effect. This work was further expanded by another EPSRC project **[G3.2]** which investigated collaborative strategies for managing the total pipeline from raw materials to the end customer. It also led to the consideration of human judgement into otherwise algorithmically derived OUT solutions **[3.4]**. Collectively, the researchers found that:

- Forecasting has to be properly integrated into the inventory and ordering policy.
- Cognitive issues and judgmental biases impact not only forecasting accuracy but also inventory performance.

2.3 The impact of contemporary issues on supply chains

Two further streams of research explored: i) the dynamics of additive manufacturing (3D printing) enabled supply chains **[3.5]**, and ii) how forecasting policy influences inventory performance both in linear and closed loop supply chains **[3.6, G3.3]**.

- In the former case, it was found that effective multi-directional collaboration and outsourcing is feasible in 3D printing contexts.
- In the latter, forecasting is found to benefit from sensor data that helps accurately calculate the time between sales and returns in circular economic contexts.

The Cardiff team translated their research on forecasting, inventory control, production planning, and supply chain cost-effectiveness into commercially viable solutions, supporting enhanced inventory management for companies.

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

[3.1] Syntetos, A.A., Boylan, J.E. and **Disney, S.M.** (2009) Forecasting for inventory planning: a 50-year review, *Journal of the Operational Research Society*, 60 (SI), 149-160. https://doi.org/10.1057/jors.2008.173

[3.2] Dejonckheere, J., **Disney, S.M**., Lambrecht, M.R. and Towill, D.R. (2003) Measuring and avoiding the bullwhip effect: a control theoretic approach, *European Journal of Operational Research*, 147 (3), 567-590. https://doi.org/10.1016/S0377-2217(02)00369-7

[3.3] Disney, S.M., Naim, M.M., and **Potter, A.** (2004) Assessing the impact of e-business on supply chain dynamics, *International Journal of Production Economics*, 89 (2), 109-118. https://doi.org/10.1016/S0925-5273(02)00464-4

[3.4] Syntetos, A.A., Kholidasari, I. and **Naim, M.M.** (2016), The effects of integrating management judgment into OUT levels: in or out of context? *European Journal of Operational Research*, 249 (3), 853-863. https://doi.org/10.1016/j.ejor.2015.07.021

[3.5] Hedenstierna, C.P., **Disney, S.M., Eyers, D.,** Holmstrom, J., **Syntetos, A.A**. and **Wang, X.** (2019) Economies of collaboration in build-to-model operations, *Journal of Operations Management*, 65 (8), 753-773. https://doi.org/10.1002/joom.1014

[3.6] Gkoltsos, T., Syntetos, A.A. and van der Laan, E. (2019) Forecasting for Remanufacturing: the Effects of Serialisation, *Journal of Operations Management*, 65 (5), 447-467. https://doi.org/10.1002/joom.1031

Selected grants:

[G3.1] Cardiff University, *Integrating Transport and E-Commerce in Logistics Supply Chains*, Department for Transport / ESPRC, LINK Future Integrated Transport (FIT) programme (STP 14/6/17) (2001-2005), £262,712.
[G3.2] Naim, M. *The Cardiff Innovative Manufacturing Centre*, EPSRC (GR/S75505/01, EP/C515404/1) (2004-2007), £3.6M
[G3.3] Syntetos, A. *Resilient Remanufacturing Networks: Forecasting, Informatics and Holons* EPSRC (EP/P008925/1) (2017-2019), £711,899

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

The researchers bridged the gap between theory and practice through industry collaborations, translating their inventory management research into bespoke systems to help major companies reduce inventory and develop leaner supply chains. This was facilitated by:

- a strategic partnership with DSV/Panalpina: The company provided £700K to establish the PARC Institute for Manufacturing, Logistics, and Inventory at Cardiff;
- a £6.2M investment for the Cardiff element of the Advanced Sustainable Manufacturing Technologies (ASTUTE) programme, a £27M, interdisciplinary, pan-Wales European Regional Development Fund project.

Through the above mechanisms, and a series of knowledge transfer partnerships (KTPs), the team's research was implemented into practice delivering measurable benefits for five large organisations: DSV/Panalpina, Qioptiq, Lexmark, Accolade Wines, and Yeo Valley.

4.1 The impact of contemporary issues on supply chains

a. DSV/Panalpina

Panalpina World Transport Ltd was recently acquired by DSV, forming the fourth largest third-party logistics provider in the world (60,000 employees worldwide). It partnered with Cardiff on two KTP projects in 2014 **[5.1]** and 2015 **[5.2]** applying Cardiff research on inventory management **[3.1]** to help Panalpina's customers reduce their investments in inventory.

The Cardiff team developed a demand-driven inventory algorithm which allowed Panalpina to forecast the demand of a client company's products and plan inventories accordingly. Implementation of this enabled Panalpina to analyse its clients' supply chains and identify opportunities to reduce inventories, free up cash and improve service levels. Andrew Lahy, DSV's Solutions Design Director, confirmed that the Cardiff projects were "*essential in implementing a vast number of changes within our organisation from a strategic level all the way down to the tactical level"* **[5.3]**. Lahy confirmed that these included **[5.3]**:

- changing organisational thinking about the importance of forecasting and inventory optimisation, which are now *"standard offerings"* and *"a big focus"* for the organisation;
- integrating the concept of distributed manufacturing **[3.5]**, which had *"a huge impact"* by cutting lead times down for clients – *"one particular customer cut lead times down from 120 days to 20 days. This has had a hugely positive impact on their sales…customers now make more products locally and do not hold as much inventory due to the reduced lead times which has reduced waste"*;
- introducing 3D printing as a service "*as a result of [Cardiff] research on this topic*" **[3.5, 5.2]**. A subsequent award of £500,000 (Welsh Government) for a 3D printing centre "*would not have been possible without Cardiff's research",* a development which helped DSV to *"gain new business and form new networks"* as *"customers want to learn more about 3D printing and are enticed by the fact that we are ahead of our competitors."* The company was also able to *"[draw] on the printing expertise we had*

acquired through the KTP" to set up manufacturing within weeks to support provision of 3D printed visors for the NHS during COVID19.

Lahy confirmed that these changes *"improved efficiencies, led to financial benefits, jobs creation and increased training"* **[5.3]**. He further stated that: *"The above changes have no doubt had a vast impact on the overall profit of the organisation. Prior to beginning our KTP projects with Cardiff University, Panalpina was losing 40 million euro per year. At the time of DSV buying Panalpina, and after implementing the changes above, we were making 10 million euro per year which is an overall annual profit benefit of £50M"* **[5.3]**.

b. Qioptiq

Cardiff's work on circular supply chains (by which returned items are remanufactured and circulated again into the market) **[3.6]** underpinned a KTP with Qioptiq, a Welsh photonics company. Prior to the KTP, Qioptiq was unable to predict how many items would be ordered and how many returned; this had a knock-on effect on its ability to set prices, meet demand, and plan operations. The Cardiff team, drawing on their forecasting research, developed and implemented an inventory control decision support system to facilitate leaner supply chains and reduce costs through enhanced inventory management **[5.4a]**.

As a result, Qioptiq reduced its inventory by 25%, leading to major cost savings. Qioptiq's Managing Director said *"The KTP led us to simplify our supply chain and utilise a new toolset to support our logistics supply operations, allowing us to effectively pinpoint demand, forecast returns and plan inventory orders"* **[5.4a]**. As a brand-new offering for Qioptiq, this Cardiff-developed system provided the company with a competitive edge to win new business. The company *"secured a contract with the UK Ministry of Defence worth £82 million – its largest ever – thanks to an Innovate UK KTP giving them access to research expertise at Cardiff Business School"* **[5.4b]**.

As a result of this new contract, Qioptiq further benefitted from the opening of a new £3.7M warehouse facility, and increased employment (10 workers retained, an additional seven recruited) in the relatively deprived region of North West Wales **[5.4b, 5.5]**. Welsh Government Economy Secretary Ken Skates MS praised the partnership's 'outstanding results', stating: *"Qioptiq is one of our most innovative High Value Manufacturing companies operating in a priority sector and I have no doubt that the partnership has helped secure the long-term future of the plant in St Asaph. This in turn has had a significant impact on the local economy, providing high quality local employment and benefitting the wider supply chain"* **[5.4c]**.

4.2 Deriving 'reasonable' solutions for inventory holding

Lexmark invited the Cardiff team to help it reduce bullwhip in its operations. Throughout 2014-2015 the Cardiff team worked with Lexmark to design a new OUT planning system and implement Cardiff's knowledge and algorithms **[3.1, 3.2]** into its Enterprise Resource Planning system, SAP. This resulted in significant bullwhip reduction, the success of which was recognised with the Frost and Sullivan's 2014 Manufacturing Leadership Award in the supply chain management section **[5.6]**. These Awards are judged by expert manufacturing leaders and honour companies shaping the future of global manufacturing.

4.3 A generalisable policy for production planning

a. Accolade Wines

Accolade Wines, a major global wine business, runs the largest wine warehouse and distribution centre in Europe. In 2018, Richard Lloyd, the company's General Manager (European Operations & Supply Chain) asked the Cardiff team to improve the company's production and inventory forecasting capabilities *"after it became apparent that Aris and his team's latest thinking and expertise in inventory, production and optimisation could assist us with our envisioned strategy and process improvements"* **[5.7]**. Drawing on Cardiff's research findings **[3.1]**, the two-year project (2018-2020) helped the company streamline operations and achieve significant reductions in its inventory levels **[5.7]**. Examples of improvements include **[5.7]**:

- A new production schedule was put in place after the Cardiff team identified a better way of scheduling the production unit. Lloyd noted *"This is directly linked to what we learnt from CBS [Cardiff Business School]"* and "*has led to a more efficient use of cash whilst maintaining service levels"*.
- Responding to algorithmic improvements identified by the Cardiff team, *"Accolade Wines have fundamentally changed the way we calculate our safety stock, and this has allowed us to offer the same service to our customers at less cost"*.

Lloyd confirmed that *"whilst it is not possible to quantify the financial benefits of these changes there is no doubt that they have led to a distinct reduction in the amount of cash Accolade Wines has tied into inventory. The project has most certainly, directly and indirectly, positively impacted approximately 400 employees across the South of England"* **[5.7]**.

b. Yeo Valley

In 2016, Cardiff worked with Yeo Valley (the largest UK organic dairy producer) to streamline the company's forecasting, production planning and replenishment systems, via application of research in **[3.1, 3.2]**. This involved tuning forecasting algorithms, shortening production cycles, setting appropriate safety stocks, and re-designing Yeo Valley's production planning system. The company estimates that *"the stock holding and commercial opportunities this project has directly and indirectly produced,"* have led to *"approximately £3m worth of cash and trading benefits"* **[5.8]**. Managing Director Robert Sexton further confirmed that the researchers helped the company to **[5.8]**:

- produce and sell yoghurts two days younger (equivalent to a reduction in inventory of £1.5M);
- *"grow market share by using the expanded shelf-life to persuade retailers to stock our products in more stores, including those with lower rates of sale. Our distribution points have grown by many thousands";*
- reduce rush production orders by 90% and out-of-date stock disposals by 98%;
- *"provide more competitive prices to national food retailers part funded by the savings that we have made and without reducing the price paid to farmers for the milk."*

Sexton confirmed: *"There have been some really profound shifts in our end to end processes as a result of working with CBS [Cardiff Business School] …Planning sets the rhythm of Yeo Valley's processes and CBS have positively impacted the heartbeat of the business"* **[5.8]**.

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

[5.1] Final report (2015): KTP between Panalpina World Transport Ltd and Cardiff University, KTP 9208
[5.2] Final report (2018): Double KTP between Panalpina World Transport Ltd and Cardiff University, KTP 10165
[5.3] Testimonial: Andrew Lahy, DSV Solutions Design Director
[5.4] a. 'Innovation in Business', Cardiff University news article, 10 July 2019 **b**. 'Qioptiq: £83 million contract win with Ministry of Defence', Case study on GOV.UK website, 3 January 2019 **c. '**University Knowhow helps Qioptiq win £82m contract' *Business News Wales*, 14 May 2018
[5.5] Final report (2018): KTP between Qioptiq Ltd and Cardiff University, KTP 10171
[5.6] Press announcement of Frost and Sullivan's 2014 Manufacturing Leadership Award 2014
[5.7] Testimonial: Richard Lloyd, General Manager European Operations and Supply Chain, Accolade Wines
[5.8] Testimonial: Robert Sexton, Managing Director, Yeo Valley Farms (Production) Ltd